sustainability

Special Issue Reprint

Exploring the Relationship between Urban Form, Mobility and Social Well-Being

Towards an Interdisciplinary Field of Sustainable Urban Planning and Transport Development

Edited by
Mengqiu Cao, Claire Papaix, Tianren Yang and Benjamin Büttner

mdpi.com/journal/sustainability

MDPI

Exploring the Relationship between Urban Form, Mobility and Social Well-Being: Towards an Interdisciplinary Field of Sustainable Urban Planning and Transport Development

Exploring the Relationship between Urban Form, Mobility and Social Well-Being: Towards an Interdisciplinary Field of Sustainable Urban Planning and Transport Development

Editors

Mengqiu Cao
Claire Papaix
Tianren Yang
Benjamin Büttner

MDPI

Basel • Beijing • Wuhan • Barcelona • Belgrade • Novi Sad • Cluj • Manchester

Editors
Mengqiu Cao
University of Westminster
London, UK

Claire Papaix
Montpellier Business School
Montpellier, France

Tianren Yang
The University of Hong Kong
Hong Kong, China

Benjamin Büttner
Technical University of Munich
Munich, Germany

Editorial Office
MDPI
St. Alban-Anlage 66
4052 Basel, Switzerland

This is a reprint of articles from the Special Issue published online in the open access journal *Sustainability* (ISSN 2071-1050) (available at: https://www.mdpi.com/journal/sustainability/special_issues/urban_form_mobility).

For citation purposes, cite each article independently as indicated on the article page online and as indicated below:

Lastname, A.A.; Lastname, B.B. Article Title. *Journal Name* **Year**, *Volume Number*, Page Range.

ISBN 978-3-0365-8942-8 (Hbk)
ISBN 978-3-0365-8943-5 (PDF)
doi.org/10.3390/books978-3-0365-8943-5

Cover image courtesy of Mengqiu Cao.

Contents

About the Editors

Mengqiu Cao

Mengqiu Cao is a Senior Lecturer in Transport, Logistics, and Urban Planning at the School of Architecture and Cities, University of Westminster. He was awarded his Ph.D. at University College London (UCL). He works in both academia and industry, specializing in an interdisciplinary research field, which is primarily a mixture of transport analysis and urban studies. In addition, he has also worked with public authorities and international funding organizations. He has served as the UK Ambassador for the Association of European Transport.

Claire Papaix

Claire Papaix is an economist specializing in urban mobility and well-being appraisal. She joined Montpellier Business School in 2020, within the Entrepreneurship, Strategy, Technology, Innovation, and Management Department, whereby she leads and teaches CSR and sustainability management, societal marketing, and research methods modules for bachelor and masters students. Working at the University of Greenwich in London for the previous 5 years, she was a program leader and Senior Lecturer in Transport and Business Logistics and went on a research sabbatical in between jobs to acquire new knowledge in geo-spatial analysis and deepen her expertise in well-being appraisal in urban mobility, in collaboration with English and French Universities.

Tianren Yang

Tianren Yang serves as an Assistant Professor and the Assistant Head of the Department of Urban Planning and Design at the University of Hong Kong. His interest lies in the development and application of urban analytics and predictive modeling techniques. He aims to provide a comprehensive understanding of how cities evolve, with a particular emphasis on the dynamic influences of urban technology, planning policy, and human behavior. His efforts in predictive modeling and knowledge transfer were acknowledged by the Forbes 30 Under 30 China list for Science and Healthcare and Geo-spatial World 50 Rising Stars.

Benjamin Büttner

Benjamin Büttner is the deputy chair of Urban Structure and Transport Planning and is the head of the Research Group on Accessibility Planning at TUM. He received his Ph.D. in transport engineering after having completed a German Diploma in geography. Currently works in the fields of accessibility planning and decision and policy making. Urban transitions, tactical urbanism, and street experiments are the foci of his professional skills. He serves on the editorial board of the Journal of Transport Geography and the Journal of Sustainable Futures. Since 2019, he has been the head of the EIT Urban Mobility "Doctoral Training Network", which includes 90 interdisciplinary Ph.D. students from all over Europe. Since 2020, he has been the founding Co-Editor-in-Chief of the Journal of Urban Mobility.

sustainability

Editorial

Exploring the Relationship between Urban Form, Mobility and Social Well-Being: Towards an Interdisciplinary Field of Sustainable Urban Planning and Transport Development

Mengqiu Cao [1,*], Claire Papaix [2], Tianren Yang [3] and Benjamin Büttner [4]

1 School of Architecture and Cities, University of Westminster, London NW1 5LS, UK
2 Department of Management of Economy, Human Resources, Information Systems and Diversity, Montpellier Business School, 34080 Montpellier, France; c.papaix@montpellier-bs.com
3 Department of Urban Planning and Design, The University of Hong Kong, Pok Fu Lam, Hong Kong 999077, China; tianren@hku.hk
4 Department of Civil Geo and Environmental Engineering, Technical University of Munich, 80333 Munich, Germany; benjamin.buettner@tum.de
* Correspondence: m.cao@westminster.ac.uk

Citation: Cao, M.; Papaix, C.; Yang, T.; Büttner, B. Exploring the Relationship between Urban Form, Mobility and Social Well-Being: Towards an Interdisciplinary Field of Sustainable Urban Planning and Transport Development. *Sustainability* **2023**, *15*, 8498. https://doi.org/10.3390/su15118498

Received: 5 May 2023
Accepted: 15 May 2023
Published: 24 May 2023

1. Introduction

This Special Issue focuses on exploring the relationship between urban form, mobility, and social well-being across neighbourhoods, cities, and regions. Understanding more about these relationships is helpful in shaping integrated sustainable urban planning and transport development strategies.

There is a growing body of research examining changes in well-being in response to social and spatial interventions (e.g., inequality, social exclusion, the built environment, land use, and transport development) and behavioural changes (e.g., travel preferences). However, there is a lack of understanding of the different types of well-being (e.g., social, hedonic, eudaimonic, short-term/long-term, or individual/collective well-being, as well as the spatial nature of well-being) and the variations in their impact. Furthermore, limited attention has been paid to the standardised measurement of well-being in both quantitative and qualitative terms in the field of social sciences, particularly regarding social and eudaimonic well-being, since they are abstract concepts and thus difficult to assess accurately. Therefore, there is an urgent need to further explore the relationship between urban form, mobility, and social well-being, as well as to examine the ways in which different types of well-being can be measured by applying various advanced models and research approaches within the broad field of urban planning and transport.

2. Discussion of the Papers

The first paper, entitled 'The impacts of transportation sustainability on higher education in China', written by Daqing Zu, Kang Cao, and Jian Xu [Contribution 1], uses a panel analysis to examine how the impacts of transport sustainability can contribute to the existing literature on the development of higher education in China. Four dimensions, namely the political, environmental, social, and economic, are explored to assess the complex effects of transport sustainability. The authors argue that there is a significant spatial dependence and spatial clustering effect on county-level higher education attainment across different provinces, and demonstrate how sustainable transportation can be used to improve this.

The second paper, 'Deciphering property development around high-speed railway stations through land value capture: Case studies of Shenzhen and Hong Kong', by Weihang Gong, Victor Li, and Mee Kam Ng [Contribution 2], applies a holistic power approach (the rail-plus-property model) to analyse the railway financing strategies used in Shenzhen and Hong Kong, focusing on the relationship between railway transport investment and the value capture of proximate land. They show that there is a significant difference between the pivotal stakeholder role played by the Shenzhen transit company and that of the Hong Kong government regarding how railways are financed and how land values are captured in these two cities. The findings of this study primarily contribute to the existing literature on sustainable railway financing.

The third paper, by Xuesong Gao, Hui Wang, and Lun Liu [Contribution 3], entitled 'Profiling residents' mobility with grid-aggregated mobile phone data using Chengdu as a case study', takes Chengdu, the capital of China's southwest Sichuan Province, as a case study, and uses mobile phone data to investigate the transformation of individual data-based mobility metrics to fit with grid-aggregate data in order to contribute to the existing knowledge on human mobility, as well as developing algorithms to measure mobility metrics more accurately. They also argue that even without relying on privacy-sensitive individual-level data, grid-aggregate mobility data could be used to help profile people's mobility patterns.

The fourth paper, 'Engaging smallholders in the flower agribusiness for inclusive rural development: The case of Yunnan, China', written by Jieming Zhu, Chen Chen, and Lie You [Contribution 4], discusses the issues of equitable and inclusive rural development in relation to flower growing among smallholders, social well-being, and the scarcity of farmland. They find that smallholders play a significant role in proactively contributing to flower agriculture, which in turn facilitates rural economic development. It is argued that endogenous non-agricultural job opportunities can support rural development, increase farm size, and improve social well-being.

The fifth paper, written by Cong Liao and Teqi Dai [Contribution 5], is entitled 'Is attending a nearby school actually near? An analysis of travel-to-school distances of primary students in Beijing using smart card data' and examines the crucial issue of children's mobility and educational equity. They use smart card data collected from students to explore the relationship between the spatial characteristics of school children's commuting distances by public transport and the residence–school spatial patterns. It is found that the policy of assigning children of primary school age to schools near their place of residence does not in fact ensure that they have a shorter commuting distance to school. The findings could contribute to the existing literature on children commuting by public transport and on housing studies/house prices and their implications for the distance children must travel from home to school (geography of education and geo big data analytics). They also point out that travel distance and housing and school locations should be taken into account in educational policymaking from a social equity perspective.

The sixth paper, by He Zhu, Qianyun Ji, Ying Lin, Ting Wang, and Jingqing Lu [Contribution 6], is entitled 'Street usage characteristics, subjective perceptions and urban form in relation to the aging population group: A case study of Shanghai, China'. The authors highlight the trajectory of an aging society in China and examine the key determinants of older adults' needs, as well as exploring the relationship between urban street form and spatial perceptions, using Shanghai as a case study. They find that improving urban form can facilitate the renovation of street spaces in a way that meets the needs of the older population, contributing to the existing literature on the significance of a need hierarchy for aging people and the understanding of different street forms and spatial perceptions among older people.

The seventh paper, entitled 'An empirical analysis of the benefits of opening a highway in terms of changes in housing prices', written by Wonchul Kim and Sung Hyo Hong [Contribution 7], investigates the social benefits of opening a new highway (the Pyeongtaek-Jecheon highway route in Korea) on changes in housing prices in the surrounding areas, using a treatment group living in close proximity to the new highway and a control group with no new highway development nearby. A difference-in-difference framework is applied to examine the effects of the newly built highway. The average price is found to be between USD 586 and 3075 per flat (i.e., between USD 10 and 53 per square metre). The main contributions of this study involve complementing the existing literature on cost benefit analysis (CBA).

The eighth paper, 'Does high spatial density imply high population density? Spatial mechanism of population density distribution based on population-space imbalance', written by Dian Shao and Weiting Xiong [Contribution 8], analyses how population density is influenced by different urban spatial characteristics and the distribution characteristics of city blocks, using Changzhou as a case study. The authors formulate a population–space correlation algorithm and compare the association between vector spatial data and mobile phone data. The study shows that an unbalanced density distribution depends on the spatial characteristics of an area and the critical value of spatial density. This research contributes to the development of the existing algorithm employed to quantitatively measure population density using big data, and its findings could also be used to suggest policy interventions designed to balance population density and urban public resources.

The ninth paper, by Dongho Han and Ji Hyun Kim [Contribution 9], entitled 'Multiple smart cities: The case of the Eco Delta City in South Korea', investigates the notion of smart cities and sustainable urban planning with specific reference to a new waterfront development in South Korea, using diverse archival sources and interviews. They find that, rather than the traditional government top-down policy, smart city mobilisation has in fact emerged from complex bottom-up local relationships between actors. In addition, the study finds that policy mobilisation can be managed and evaluated via the assemblage approach. It contributes to the existing research on smart cities and sustainable urban regeneration.

The tenth paper, 'The effect of hukou accessibility on migrants' long term settlement intentions in regard to destination', written by Peilin Li, Yufeng Wu, and Hui Ouyang [Contribution 10], uses a nation-wide large-scale survey carried out in 46 Chinese cities to analyse social equity issues relating to 'hukou' and migrants' long-term settlement patterns. This study contributes to Lee's 1966 theory of migration. It shows that hukou is still a barrier to people's mobility and movement across different cities in China, although there is also a non-linear trajectory regarding its adverse impacts on migrant workers' intentions to live in particular areas. In addition, it suggests that urban planners and policymakers should pay more attention to migrant cohorts when it comes to future strategic urban development, particularly in terms of welfare, medical, and educational distribution.

The eleventh paper, by Jiankun Yang, Min He, and Mingwei He [Contribution 11], entitled 'Exploring group differences in the nonlinear relationship between commuting satisfaction and commuting time', takes Kunming as a case study and analyses the non-linear association between commuting time and commuting satisfaction by applying a random forest approach. Using a k-means clustering algorithm, the authors identify three different commuting group: short-, medium-, and long-duration-tolerant groups. In addition, factors such as educational attainment, income, job–housing distance, and commuting modes are all shown to have significant impacts on the aforementioned cluster groups. Consequently, they argue in favour of using different planning strategies to address different commuting groups' needs to improve their commuting satisfaction and subjective well-being.

The twelfth paper, by Gang Li, Ruining Zhang, Shujuan Guo, and Junyi Zhang [Contribution 12], entitled 'Analysis of ride-hailing passenger satisfaction and life satisfaction based on a MIMIC model', uses a multiple-indicators multiple-causes (MIMIC) model to explore the impact of various factors on passenger satisfaction with ride hailing in Dalian, China. Some positive impacts are identified, notably relating to service operation and perceptions of safety and service quality. The findings also show that passenger satisfaction has different effects on people's overall level of well-being due to the heterogeneity in individual socio-economic characteristics. The study also contributes to research on the interactive relationship between passenger and life satisfaction in relation to ride hailing for a daily trip.

The thirteenth paper, by Maciej Kruszyna [Contribution 13], entitled 'NOAH as an innovative tool for modelling the use of suburban railways', uses a novel approach, the Nest of Apes Heuristic (NOAH), to model a suburban railway system by combining the technical aspects of transport systems with human decision making using Wroclaw, Poland, as a case study. It is argued that the proposed NOAH method can be used to observe different sets of data and the interactions between them without requiring precise knowledge on the influence of a specific factor on the outcomes. This method is also able to take dynamic changes of leadership into account and can thus be used to measure the effects of human decision making in a transport context.

The final paper, 'Users' preferences in selecting transportation modes for leisure trips in the digital era: Evidence from Bandung, Indonesia', written by Tri Basuki Joewono, Mohamed Yusuf Faridian Wirayat, Prawira Fajarindra Belgiawan, I Gusti Ayu Andani, and Clint Gunawijaya [Contribution 14], focuses on the key determinants of leisure trips among people who live in cities in the Bandung area. Applying a multinomial logit model, the authors find that residents are more likely to choose buses and trains for leisure travel rather than private vehicles. Furthermore, the findings show that travel cost and time are the most significant factors influencing people's choice of travel mode. They also demonstrate how online mobile apps could be used as a payment method for leisure travel in the current digital era.

3. Conclusions

Overall, this Special Issue contributes to the existing literature on the interdisciplinary field of the impact of urban planning and transport on social well-being, and facilitates novel ways of measuring the abstract concept of well-being, particularly in Asian and European countries. Further research could explore these themes in greater depth by means of both theoretical frameworks and methodological developments in this integrated field.

List of Contributions

1. Zu, D.; Cao, K.; Xu, J. The Impacts of Transportation Sustainability on Higher Education in China.
2. Gong, W.; Li, J.; Ng, M.K. Deciphering Property Development around High-Speed Railway Stations through Land Value Capture: Case Studies in Shenzhen and Hong Kong.
3. Gao, X.; Wang, H., Liu, L. Profiling Residents' Mobility with Grid-Aggregated Mobile Phone Trace Data Using Chengdu as the Case.
4. Zhu, J.; Chen, C.; You, L. Engaging Smallholders in Flower Agribusiness for Inclusive Rural Development: The Case of Yunnan, China.
5. Liao, C.; Dai, T. Is "Attending Nearby School" Near? An Analysis of Travel-to-School Distances of Primary Students in Beijing Using Smart Card Data.
6. Zhu, H.; Ji, Q.; Lin, Y.; Wang, T.; Lu, J. Street Usage Characteristics, Subjective Perception and Urban Form of Aging Group: A Case Study of Shanghai, China.
7. Kim, W.; Hong, S.H. An Empirical Analysis of the Benefits of Opening a Highway in Terms of Changes in Housing Prices.
8. Shao, D.; Xiong, W. Does High Spatial Density Imply High Population Density? Spatial Mechanism of Population Density Distribution Based on Population–Space Imbalance.
9. Han, D.; Kim, J.H. Multiple Smart Cities: The Case of the Eco Delta City in South Korea.
10. Li, P.; Wu, Y.; Ouyang, H. Effect of *hukou* Accessibility on Migrants' Long Term Settlement Intention in Destination.
11. Yang, J.; He, M.; He, M. Exploring the Group Difference in the Nonlinear Relationship between Commuting Satisfaction and Commuting Time.
12. Li, G.; Zhang, R.; Guo, S.; Zhang, J. Analysis of Ride-Hailing Passenger Satisfaction and Life Satisfaction Based on a MIMIC Model.

13. Kruszyna, M. NOAH as an Innovative Tool for Modeling the Use of Suburban Railways.
14. Joewono, T.B.; Wirayat, M.Y.F.; Belgiawan, P.F.; Andani, I.G.A.; Gunawijaya, C. Users' Preferences in Selecting Transportation Modes for Leisure Trips in the Digital Era: Evidence from Bandung, Indonesia.

Conflicts of Interest: The authors declare no conflict of interest.

sustainability

MDPI

Article

The Impacts of Transportation Sustainability on Higher Education in China

Daqing Zu [1], Kang Cao [2] and Jian Xu [1,*]

[1] School of Foreign Studies, China University of Mining and Technology (Xuzhou), Xuzhou 221116, China; dqzu@cumt.edu.cn
[2] Department of Regional and Urban Planning, Zhejiang University, Hangzhou 310058, China; k_cao@126.com
* Correspondence: jansenxu@hotmail.com

Abstract: Improving transportation sustainability serves as a means of reducing the perceived and real distance, thereby contributing to the city and higher education development. In this paper, the complexity of transport sustainability is measured via four different dimensions: economy, society, environment and politics. The variables are designed by the four dimensions. The higher education development is measured via the ratio of higher education degree holders, reflecting the skilled work mobility. Over the last 30 years, university students moving to cities for study and work purposes have become an important part of rural–urban transition mobility. However, few studies have explored the impacts of transportation sustainability on higher education development in China. The economic, environmental, social and political dimensions in transportation sustainability can boost China's higher education attainment in different ways. Against this background, this study, drawing on the panel data and employing the spatial multilevel model, investigated the impacts of transportation sustainability on higher education in China, adding new empirical evidence for China's higher education development. A panel analysis revealed that the increase in transportation sustainability induces the growth of higher education. Moreover, higher education attainment showed significant spatial dependence at the county level and had significant spatial clustering of county-level higher education attainment across provinces. Furthermore, modeled test results showed that the spatial multilevel model was more suitable for our study than traditional regression models. By identifying transport sustainability variables that have an effect on higher education, this study is the first to uncover the complexity of transportation sustainability and contributes to the latest policy implications for promoting higher education attainment through sustainable transportation.

Keywords: transportation sustainability; higher education; university students; skilled work; spatial multilevel analysis

Citation: Zu, D.; Cao, K.; Xu, J. The Impacts of Transportation Sustainability on Higher Education in China. *Sustainability* **2021**, *13*, 12579. https://doi.org/10.3390/su132212579

Academic Editors: Mengqiu Cao, Elżbieta Macioszek, Claire Papaix, Tianren Yang and Benjamin Büttner

Received: 15 September 2021
Accepted: 12 November 2021
Published: 15 November 2021

1. Introduction

Modern transportation mode choices such as air transportation and high-speed railways have connected distant regions, thereby contributing to accessibility through boosting opportunities for individuals to study, work, and even migrate to distant areas [1]. Although there is emerging research that focuses on the positive role of transport in an area's development [2–6], it has not yet been addressed that transportation sustainability affects interregional long-distance mobility, migration of high-end, and high-skilled human capital [6,7]. Therefore, this study contributes to understanding the associations between sustainable transportation and higher education development through choosing key variables that reflect the effects of transportation sustainability on higher education attainment and then providing empirical evidence and implications for the growth dynamics and competitiveness of regions.

Growing transportation demand has led to a series of problems such as traffic congestion and pollution, consequently creating barriers to regional development. Under this circumstance, sustainability is introduced to transportation studies, encompassing a holistic consideration of environmental, social, and economic progress [8]. In this study, we follow the definition of transportation sustainability provided by the Centre for Sustainable Transportation (CST). The CST built on the debates proposed by the Organization for Economic Co-operation and Development (OECD) and then established the definition of sustainable transportation: "it ensures the basic needs of individuals and societies to be met safely and in a manner consistent with human and ecosystem health, with equity both within and between generations; It is affordable, operates efficiently, offers choice of transport mode, and supports a vibrant economy; and it limits emissions and waste to those within the planet's ability to absorb them, minimizes consumption of nonrenewable resources, limits consumption of renewable resources to the sustainable yield level, reuses and recycles components, and minimizes the use of land and the production of noise". In order to achieve transportation sustainability, policymakers need to monitor and evaluate the sustainability of transportation systems [9]. Thus, in the evaluation process, transportation sustainability is evaluated using a series of indicators and criteria [8]. Mahdinia et al. [10] studied 89 sustainable transportation indicators and used them to develop a measuring framework algorithm that considers the variables' inter-correlations and ensures that several numbers of indicators are proposed. In the study by Mahdinia et al. [10], three dimensions (environmental, social, and economical) were identified and divided and then included in the algorithm, and their subcategories were also defined. In the present study, we also followed the existing research and evaluated transportation sustainability from economic, social, and environmental dimensions.

There is emerging research examining the impacts of transport development on work [11], but minimal studies have investigated the impacts on higher education development. We measured higher education development according to the share of adults with at least a bachelor's degree to the working population since it can reflect the impacts of skilled workers on the population and growth within a region [12]. It is expected that the elasticity of transportation sustainability on higher education attainment would be larger compared to previous studies, due to the imbalanced transportation development and distorted labour markets in China. Considering the achievement of sustainable and balanced development, higher education resources should be better allocated between developed and less-developed regions.

Across the background in which China visualizes innovation and sustainability as important tasks [13], this study focuses on the unbalanced development of transportation and higher education attainment in China. Additionally, because China is facing significant inequality in higher education development and transportation sustainability, it is necessary to explore the impacts of transportation sustainability on higher education in the Chinese context. In order to investigate the development of the skilled work, economic upgrade, and higher education [14], drawing on data from the official provincial statistical yearbooks and China City Statistical Yearbooks from 2010–2020, this study answers the following research question: What are the associations between transportation sustainability and China's higher education based on the measure of sustainable transport development? With the help of a spatial multilevel analysis, we provide an empirical analysis for understanding the various dimensions of transportation sustainability and its impacts on higher education. Through answering the above research question, this study contributes to the extant body of literature by focusing on the case of China's sub-national policies and provides policy implications for transportation and higher education development planning.

2. Literature Review

Emerging research is developing reliable and meaningful indicators of transportation sustainability. The OECD defines sustainable transportation indicators as statistical measures that provide an indication of social, environmental, and economical sustainability [15]. Mahdinia et al. [10] measured transportation sustainability based on an indicator-based algorithm, with a focus on U.S. states, encompassing environmental, social, and economical dimensions, helping to build and analyze a comprehensive indicator system consisting of 89 sustainable transportation indicators. It is worth noting that different indicators could be adopted based on data availability [10]. Existing studies provide rich systems of indicators in terms of transportation studies, allowing the recognition of the indicator selection. The process of indicator selection should be driven by research questions and practical needs [16,17]. In line with recognizing specific questions, indicators should be designed as understandable, reasonable, measurable, quantifiable, accessible, and changeable [16,18]. Due to the growing research interests in indicator design (the selection of particular indicators within a study) for sustainable transportation, there are a large number of systematic literature reviews providing a comprehensive overview of sustainable transportation indicators [19,20]. Through these systematic reviews, this complexity—in an integrated and holistic manner of sustainable transportation—can be understood and addressed. Building on a systematic review of Lopez-Arboleda, Sarmiento, and Cardenas [19], it was found that many existing studies investigate transportation sustainability from the economic and environmental dimensions. However, scarce research has focused on social development. The holistic and systematic integration of the social dimension could provide a better understanding of the transportation sectors [19]. These systematic reviews offer a bigger picture for the study and selection of sustainable transportation indicators.

A small body of research has directly investigated the effects of transportation sustainability on higher education attainment or skilled work/migration [21,22]. The current literature is focused mainly on the impacts of transportation development on various types of human resources in the job market. Most studies have found that advanced transportation can significantly improve employment rates [23,24]. In addition, political recognition of transportation or the improvement of the government's transportation management ability is considerably important for work mobility and employment [25,26]. However, the relationship between transportation sustainability and work attraction or higher education attainment is unclear. On one hand, regions with better transportation development have higher rates of employment or higher education [21]. In contrast, only minor research shows that regions with advanced transportation development have good sustainability, let alone the relationship between this sustainability and higher education or the job market.

In addition, some previous studies underline the importance of transportation flexibility to the extent of job–education mismatch [27,28]. The extent of higher education attainment may be a reflection of transportation-constrained job hunting, which in turn relies on the spatial distribution of job markets and the individual's spatial flexibility [29]. For example, in Germany, public transportation availability is significantly related to a lower probability of education, while the results are different from an increase in travel time to the nearest agglomeration [29]. Moreover, advanced public transportation can decrease the effects of higher commuting distance on a lower probability of over-education [30]. Thus, advanced public transportation development can reduce the risk of job–higher education mismatch. Based on the mobility distance between higher education cities and working cities, Hensen et al. [31] concluded that graduates who enjoy better public transportation have reasonably higher education levels. However, talents experiencing long-distance mobility may have a lower possibility of reasonably higher education attainment [32]. On the other hand, transportation sustainability—shown by the regional quality of road infrastructures—is negative to higher education and the job market [33]. To conclude, transportation development is associated with the match quality between occupation and higher education [34,35].

Moreover, the relationships between public transportation development or policies and higher education are indicated by the inequalities in education and transport infrastructure. Transportation distance to education is important for promoting a more equitable supply of jobs to diverse groups [36]. Thus, job market accessibility, based on particular transport modes, has received increased attention in previous studies [37], and these studies based on education accessibility have considered the socioeconomic indicators as well as school outcomes [38,39]. In addition, as a dynamic and highly political production, public transportation is significant for explaining the associations between transportation progress and education inequalities and the extent to which they are mutually strengthened [36].

Specifically, Harland and Stillwell [40] studied transport for school planning by exploring the movement between schools and residences. In order to establish a sound model, variables including school rolls, commuting distances, pupil mobility, residential migration, pupil gender, and ethnicity were selected. The established model provided analytical results showing the key effects of transportation on school planning. Contrasting from the study by Harland and Stillwell, Wang et al. [41] investigated freight from the perspective of China's national economic development. Their analytical results revealed that freight transport plays an important role in economic growth. In detail, the contribution of high freight-demand sectors to economic development has decreased, indicating China's economic transition [41], thus resulting in different industrial structures and geographical characteristics of each region in China. Consequently, talent mobility also indicates diversity. Although scarce research has explored the relationship between freight and education, some studies have recognized the effects of freight on talent mobility and schooling.

Considering the fact that the higher education population has a higher demand for obtaining driver's licenses and accessing different transportation modes, transportation sustainability may be of importance to the improvement or growth of regional higher education [42]. Due to high housing prices in the urban center, new urban migrants tend to live in the suburbs or far away from the city center [42]. Meanwhile, the expansion of the spatial distance of the labour force entering the job market also promotes the continuous improvement of transportation technology resulting in sustainability [43]. Therefore, the sustainability of transportation is of great significance to the healthy development of cities and the improvement of the quality of life of higher education workers.

3. Methods

3.1. Data and Variables

We obtained data from second-hand sources and also from China's Statistical Yearbooks of Provinces, China's Statistical Yearbooks of Transportation, China Industrial Statistics Yearbooks, China City Statistical Yearbooks, and China Social and Economic Statistical Yearbook in counties/county-level cities, and Statistics of China's Ministry of Education. The range of the data was from 2015–2019.

The complex and dynamic process of transportation sustainability involves the interaction between economic, social, environmental, and political factors. Thus, in order to explore the reason for transportation sustainability affecting higher education, the study examines the potential determinants from four aspects of the economy, society, environment, and politics (Table 1). A large number of existing studies have examined the influence of transport development on work [11,44]; however, scant literature has directly focused on transportation sustainability and higher education or skilled work. Moreover, the study focuses on the different levels, and thus, we expect that the determinants might produce different impacts due to spatial disparities.

The indicator choice in the economic aspect mainly considers transportation investment, transportation employment, and transportation freight. Therefore, the study selects transportation expenditures in infrastructures per GDP per capita (EI) to test the economic effects of transportation infrastructures. Existing studies have indicated the spatial inequalities in transportation infrastructures and strong relations between transportation infrastructures and economic activities [45,46]. Due to different spatial levels, the economic role of transportation infrastructures depends on the different economic development levels and governmental supports. In order to clarify the expenditure benefit of transportation systems users, this study uses public transportation expenditures per capita (PE). By choosing this indicator, we expect to improve the higher education level by increasing the benefit and decreasing the expenditure of transportation systems users [10]. In terms of transportation employment, the number of public transportation employment per capita (NE) is selected to reflect the expenditure and revenue of transportation systems operators. Existing studies have also suggested that high transportation employments can attract greater migration due to the propensity to earn higher wages and coordinated employment transportation plans [47,48]. We selected freight shipment by rail per capita (FR) to show transportation benefits. Based on the existing research, freight has effects on school planning and work/talent mobility [40,41], so in this study, we also considered relevant variables including freight shipment by rail per capita. Previous studies also show that sustainable transportation development can benefit transportation revenue however, the results rely on local tax policies [49].

Table 1. Variables to measure transportation sustainability.

Variables		Definition
Economy	EI	Transportation expenditures in infrastructures per GDP per capita
	PE	Public transportation expenditures per capita
	NE	Number of public transportation employments per capita
	FR	Freight shipment by rail per capita
Society	TA	Transportation accidents per capita
	TD	Transportation accident deaths per capita
	NV	Total number of vehicles per capita
	VR	Total length of motor vehicle routes per capita
	TM	Number of available transportation modes
Environment	GE	Greenhouse gas emissions by transportation per capita
	TN	Transport noise per capita
	RE	Renewable energy consumption per total transportation energy consumption
	RL	Total urban roads length per capita
Politics	PT	Proportion of the number of public policies in transportation to the total number of public policies
	TL	Closure rate of transportation law cases

Regarding the social dimension, this study focuses on the perspectives of safety, accessibility, and transportation diversity. For the safe aspect, we select two indicators: transportation accidents per capita (TA) and transportation accident deaths per capita (TD). Transportation safety is viewed as a strong predictor for traffic crashes and social welfare in the existing literature, and it is suggested that transportation safety can provide a powerful policy incentive for social and economic growth [50,51]. In order to test the sustainability in accessibility, the total number of vehicles per capita (NV) and total length of motor vehicle routes per area (VR) are selected. Using these two indicators, the study sets out to enhance the accessibility of transportation systems, so as to promote regional higher education attainment. In the literature, accessibility to transportation infrastructure could attract more skilled workers by promoting industrial clusters [52]. Moreover, improved transportation accessibility can help bring job opportunities closer to workforces [53]. In addition, within the social dimension, we hope to improve transportation sustainability by increasing the diversity of transportation modes. Thus, the study selects a number of available transportation modes (TM). Due to rapid urban development, the number of transportation modes is constantly increasing. Therefore, we examine whether the increase in transportation diversity can help attract more skilled workers with higher education.

In terms of the environmental dimension, the study begins from the perspectives of pollutant emissions, energy utilization, and land efficiency of transportation. Previous studies have shown that the two most important aspects of traffic pollution are greenhouse gas emissions and noise pollution [53,54]. Consequently, greenhouse gases emissions by transportation per capita (GE) and transport noise per capita (TN) are selected. Existing studies have indicated that traffic pollution emissions have led to increasing gaps both within and between cities [55]. These gaps impact the urban attraction to skilled workers with higher education, which further exacerbates regional and urban inequalities. In order to arrive at sustainable transportation, the aim of energy utilization is to reduce petroleum dependence and use renewable energy [10]; thus, renewable energy consumption per total transportation energy consumption (RE) is chosen to test the effects. The positive role of renewable energy in regional and urban growth and work has been clarified in the literature [56,57]; in particular, renewable electricity support policies can raise the equilibrium unemployment rate by 0.1–0.3% [58]. Thus, high renewable energy consumption in a region can bring more workers with higher education. In terms of land efficiency of transportation, this study uses total urban roads length per capita (RL) because the improvement in interregional transportation could benefit land-use efficiency and work mobility [59].

Although some studies have indicated the relationships between governance and public factors and transportation or higher education [60,61], little effort has been made to clarify the effects of political factors in transportation sustainability on higher education. In the field of transportation sustainability, the politics dimension is used to capture the transportation governance theme. Connecting to our case, we select a proportion of transportation public policies to the total number of public policies (PT), and the closure rate of transportation law cases (TL). The existing literature argues that politics can help to decrease inequalities by transportation development, and the improvement of institutional quality—led by transportation development—can promote the mobility of skilled workers [62–64]. Thus, the study argues that high institutional quality in transportation is a reflection of sustainability and can increase higher education attainment. The data in the study are from province statistical yearbooks and China City Statistical Yearbooks from 2010–2020. The indicators on policies are from pkulaw.com. In addition, this study also includes some control variables—socio-demographic index (SDI). The SDI was constructed by Kassebaum et al. and measures, by income per capita, the average years of schooling and total fertility rate [63]. Urbanization and GDP are chosen to measure county-level socioeconomic development. Urbanization is measured by the ratio of the urban population [62,65]. In our study, we followed the existing research, measuring urbanization by the ratio of the urban population. Based on the human development index (HDI) method [66], the SDI values are from 0 to 1, and the Jenks method is employed to generate five classes of SDIs—SDI 1 indicates the lowest level and SDI 5 indicates the highest.

3.2. Method

This study employs a spatial multilevel analysis to explore the effects of transportation sustainability on higher education attainment. Due to the significantly high spatial auto-correlation coefficients and significant differences across different regions in China, we decided to use spatial multilevel analysis. Compared with traditional multilevel analysis, a spatial multilevel analysis adds spatial auto-correlated residuals to a standard multilevel model with random intercept [67]. We first calculate Moran's index and Local Moran's index to show spatial autocorrelation. The Moran index refers to a kind of spatial autocorrelation coefficient, which is used to judge whether there is autocorrelation in space [67]. Local Moran's index examines the individual locations, ensuing hotspots to be identified, building on a comparison with the neighboring samples [67]. Weights in this study are produced by rook contiguity relations between pairwise units. Then, the variance components model is used to test the significance of provincial heterogeneity in county-level higher education attainment. The function of this model follows:

$$HEA_{ij} = \beta_0 + \varepsilon_{ij} + \mu_j \left[\mu_j \sim N\left(0, \sigma_\mu^2\right); \varepsilon_{ij} \sim \left(0, \sigma_\varepsilon^2\right) \right] \quad (1)$$

where HEA_{ij} is the higher education attainment for *i* county in *j* province. β_0 is the overall mean of HEA across all groups. ε_{ij} indicates the residuals at the county level, and μ_j shows the residuals at the provincial level. ε_{ij} and μ_j follow a normal distribution. If the residual is normally distributed, we take it as random. If it is random, it fits better to the random error.

In order to avoid the biased estimation in standard errors resulting from a standard regression model [68], the study employs spatial multilevel models with spatial errors. This model allows us to add spatial autocorrelation residuals to standard multilevel models with random intercepts. Thus, the specification of the spatial multilevel analysis in the study is:

$$HEA_{ij} = \beta_0 + \sum_{n=1}^{m} \beta_n TS_{nij} + \sum_{t=1}^{r} \beta_t TS_{tj} + \varepsilon_{ij} + \mu_j \tag{2}$$

$$\varepsilon_{ij} = \lambda \sum_{j=1}^{k} w_{ij}\varepsilon_{ij} + \zeta_{ij} \tag{3}$$

$$\mu_j \sim N\left(0, \sigma_\mu^2\right);\ \zeta_j \sim N\left(0, \sigma_\zeta^2\right) \tag{4}$$

where β_n and β_t (in Equation (2)) are the coefficients at county and provincial levels, respectively; *m* and *r* are the number of variables at county and provincial levels, respectively; λ indicates the degree of spatial dependence; k shows the number of neighbors in ε_{ij}; w_{ij} is the spatial contiguity weight matrix, and $w_{ij}\varepsilon_{ij}$ presents the spatial errors; ζ_{ij} is random error, and together with μ_j, they both follow a normal distribution.

Our study highlights the importance of contextual effects and spatial dependence, the associations between transportation sustainability and higher education attainment, and the intersections of transportation sustainability and economic growth impacting higher education attainment. Referencing the study of Gu et al. [67], our study implements 18 sub-models. The aim of Model 1 is to examine the significance of group effects (higher education attainment at the provincial level) in comparison to a one-level model. Model 1 belongs to the variance components model, which contains only one constant. In order to explore the determinants and to compare their importance, the spatial errors of higher education attainment, economy, society, environment, and politics are added from Models 2–6, respectively. Model 7 examines the joint effects of spatial error and transportation sustainability. Based on Model 7, Model 8 adds socioeconomic indicators at the country level. Model 9 includes all the variables. Models 10–18 test the interactions between transportation sustainability and the urban socio-demographic index, which helps to further understand the potentially different influences of transportation sustainability on higher education attainment under different contextual backgrounds. In the study, the socio-demographic index includes a common logarithmic transformation of the gross domestic product (GDP) and the proportion of the population living in the urban district.

In order to avoid the multicollinearity between independent variables, the study conducts the Pearson correlation coefficients test between pairwise variables. In addition, we use the Akaike Information Criterion (AIC) to indicate the fitness of models since it combines fit goodness with variables' complexity [69]. Moreover, the robustness associations between transportation sustainability and higher education attainment are examined through exploring the potentially lagged effects of previous transportation sustainability.

4. Results and Analysis

The potential roles of China's transportation sustainability on higher education attainment at the county level have not been given much attention previously. Our study explores the associations between transportation sustainability, including economy, society, environment and politics, and higher education attainment. We consider the spatial autocorrelation of higher education attainment across the country and the potential spatial clustering of higher education attainment across provinces. Table 2 depicts the results of the Pearson correlation analysis. According to Table 2, except for TM, other determinants are positively related to HEA. In these variables, TA, VR, PT, and log(GDP) have higher coefficients. In addition, NE, TM, and RE are statistically insignificant. Moreover, the results of the Pearson correlation coefficients also indicate that collinearity does not significantly influence the analysis. Collinearity is always an issue in statistical analysis, in which its existence must be acknowledged and dealt with accordingly. However, after the models were tested by Pearson correlation, it was confirmed that the existence of collinearity did not significantly affect the models' results.

Table 3 shows the results of transportation sustainability affecting higher education attainment within the framework of spatial multilevel models. Determinants with significant coefficients in Models 2–6 are presented. The changes in AIC values indicate that the spatial dependence (6352.4) of higher education attainment contributes most in understanding the variation in higher education attainment, followed by the politics factor (PT) (6428.3). In comparison, determinants at the provincial level have the least exploratory power. According to Models 7 and 8, after incorporating county-level socioeconomic indicators, the variables PE, TM, and RL are no longer significant. For most of China's counties, public transportation is unsound, and people prefer private vehicles (i.e., private electric bicycles), therefore, PE is statistically insignificant. The limited transportation choice across counties means that the variables PE, TM, and RL have different results among Models 7 and 8. After considering the provincial-level SDIs, Model 9 suggests that when we control other factors, the higher education attainment in less-developed provinces (SDI 1) is generally lower than those in medium-level development (SDI 3). Meanwhile, the smaller AIC values also indicate that the predictors at the country level have better explanatory powers than those at the provincial level.

Regional effects and spatial autocorrelation should be explored to consider the associations between transportation sustainability and higher education attainment at different spatial scales. Spatial multilevel models have better suitability than regular regression models in examining the association between transportation sustainability and higher education attainment. This can be supported by the significant effects at the province level on county-level higher education attainment and the spatial autocorrelation of county-level higher education attainment and residuals. Meanwhile, in order to avoid the estimation bias of standard errors resulting from spatial homogeneity or spatial heterogeneity, we further emphasize the importance of considering both spatial homogeneity and spatial heterogeneity in studying transportation and education data with spatial structure [70]. The results of spatial multilevel models suggest that transportation sustainability plays a significant role in higher education attainment. In particular, PT consistently maintained a significant and strong impact in Models 2–9. This result shows that the sustainability of transportation is not only reflected in the traditional three dimensions: politics, economy, and society. The political dimension is an important institutional guarantee for the in-depth development of traffic sustainability as local political preferences are able to affect the modal, costs, ridership, and route analyses of transportation [71]. Moreover, the transportation sustainability of the political dimension can help to attract workers with higher education by the political incorporation of immigrants [72].

In addition, the log(GDP) coefficients also indicate that politics may be a potential mediator in the association between the socioeconomic indicator and higher education attainment. The coefficients of log(GDP) increase and change from insignificant to significant. China's economic growth and planning are administrative driven [73,74]. Thus, transportation planning is closely related to regional politics and economic development, and better transportation planning is accompanied by reasonable politics and growth in developed provinces [75,76]. Thus, although numerous mediators on socioeconomic growth indirectly affect the regional attraction on higher education immigration, the politics factor also has strong potential. Moreover, when we consider the indicator from the politics dimension in Model 8, the significant coefficients of economic, social, and environmental dimensions increase. Consequently, politics quality is a potential confounder in the association between transportation sustainability and higher education attainment. This finding shows that the institutional environment has an extremely significant impact on higher education attainment.

Table 2. Pearson correlation coefficients between variables (two-tailed test).

Variables	HEA	EI	PE	NE	FR	TA	TD	NV	VR	TM	GE	TN	RE	RL	PT	TL	log(GDP)
EI	0.21 **																
PE	0.32 *	0.16 *															
NE	0.14	0.15 *	0.29 *														
FR	0.27 *	0.20 *	0.34 *	0.46 *													
TA	0.97 *	0.17 **	0.88 *	0.13 *	0.41 *												
TD	0.23 **	−0.05	0.11 *	0.48 *	0.29 *	0.28 *											
NV	0.55 *	0.40 *	0.78 *	0.15 *	0.23 *	0.31 *	0.15										
VR	0.85 **	0.18 *	0.05	0.12	0.72 *	0.13	0.06 *	0.06 *									
TM	−0.03	0.11	0.26 *	0.33 *	0.67 *	0.72 *	0.22 *	0.16	0.17 *								
GE	0.22 **	0.07	0.28 *	0.49 *	0.25 *	0.36 *	0.73 *	0.27 *	−0.1	0.14 *							
TN	0.64 *	0.22 *	0.70 *	0.09	0.40 *	0.55 *	0.14 *	0.32 *	0.13 *	0.09 *	0.16 *						
RE	0.07	0.64 *	0.66 *	0.27 *	0.33	0.1	0.22 *	0.13 *	0.73	0.28 **	0.24 *	0.26 *					
RL	0.11 *	0.21 *	0.15 **	0.40 *	0.46 *	0.12	0.09	0.21 *	0.28 *	0.03	0.1	0.62 *	0				
PT	0.89 *	0.15	0.19 *	0.43 *	0.17 *	0.47 *	0.33 *	0.37 *	0.24 *	0.81 *	0.17 *	0.41 *	0.24 *	0.41 *			
TL	0.38 *	0.13	0.81 **	0.24 *	0.60 *	0.20 **	0.15 *	0.25 **	0.51 *	0.23 *	0.28 *	0.64 *	0.13	0.34 *	0.42 *		
log(GDP)	0.70 *	0.25 *	0.69 *	0.27 **	0.25 **	0.23 *	0.66 *	0.45 *	0.11	0.17 *	0.16 *	0.17	0.12 *	0.13 **	0.25 *	0.37 *	
Urbanization	0.36 *	0.09	0.21 **	0.34 *	0.27 *	0.14	0.18 *	0.12	0.3	0.49 **	0.04 **	0.19 **	0.02	0.17 *	0.31 *	0.31 *	0.54 **

Note: ** $p < 0.01$; * $p < 0.05$.

Table 3. Results from spatial multilevel models.

Variables	Models 2–6	Model 7	Model 8	Model 9
		Spatial error (AIC = 6352.4)		
λ	0.512 **	0.194 **	1.323 **	0.648 *
		Economy (AIC = 6517.3)		
PE	0.225 **	0.151 **	0.031	0.181 *
FR	−0.104	0.332 **	0.511 *	0.657 **
		Society (AIC = 6652.1)		
TA	−0.166 *	−0.743 *	−0.227 *	−0.513 **
NV	0.087 **	0.124 **	0.131 **	0.073 **
TM	0.748 **	0.076 *	0.095	0.161 *
		Environment (AIC = 6719.9)		
GE	−0.115 *	−0.227 **	−0.345 **	−0.357 **
RE	0.113 *	0.156 **	0.654 **	0.247 **
RL	0.436 **	0.162 *	0.265	0.208 **
		Politics (AIC = 6428.3)		
PT	0.315 **		0.393 **	0.327 **
		Socioeconomic indicators (AIC = 6557.6)		
log(GDP)	0.283		0.145 **	0.362 **
		Provincial level (AIC = 6798.8)		
SDI 1	−0.804 **			−0.568 **
SDI 2	−1.001 **			−0.174
SDI 4	0.191			0.146 **
SDI 5	0.804 **			0.173 *
AIC		5231.4	5587.1	5726.3

Note: ** $p < 0.01$; * $p < 0.05$. Variables that were insignificant in the models were excluded.

Table 4 shows the results from the spatial multilevel analyses of higher education attainment on interactions of transportation sustainability and SDIs. In Model 10, the association between PE and higher education attainment at the county level is significant, and the interaction of PE and SDI 1 is significantly higher than that of PE and SDI 3. The FR holds similar results to PE. Moreover, in Model 11, both the interactions of FR and SDI 1 and SDI 2 are significantly higher than that of PE and SDI 3. In Model 12, although the coefficient of TA is insignificant in the main part, a higher number of transportation accidents can significantly reduce the higher education attainment in SDI 1. Model 13 shows that the increasing number of vehicles (NV) per capita is significantly linked to higher education attainment. Moreover, the interactions between NV and SDI 1 and SDI 4 are significantly positive, meaning that NV can help less-developed and developed provinces attract more skilled workers. On the contrary, Model 14 shows that a higher number of available transportation modes (TMs) can promote the attraction of higher education in less-developed provinces, whereas the interaction of TM and developed provinces is not significant. The greenhouse gas emissions indicator, by transportation per capita (GE), is significantly negative to higher education attainment in the main part of model. However, the interactions of GE and SDIs indicate that the negative effects are significant in less-developed provinces; however, developed provinces retain their attraction to talent due to the increase in greenhouse gas emissions. Model 16 gives us the results of renewable energy consumption (RE). Overall, RE is significantly positive to higher education attainment. In particular, according to the interaction of RE and SDI 4 and SDI 5, the increased consumption of renewable energy can help developed provinces obtain higher education attainment. Regarding the result of total urban roads length per capita (RL), it has, overall, significant positive impacts on higher education attainment. However, when we observe the interactions, increasing urban roads length per capita could decrease the higher education attainment in less-developed provinces (−0.121), whereas it has strong positive effects in developed provinces (1.304). In Model 18, the result of the politics dimension (PT) suggests that the policy bias in the field of transportation is significantly linked to higher education attainment in the main part (0.166). Moreover, after the interaction items are included, the transportation political preference in less-developed provinces has great attraction for higher education talents.

Table 4 indicates that the intensity of potential influences of transportation sustainability on higher education attainment varies within the different levels of contextual backgrounds. Overall, less-developed provinces are affected more significantly, while developed provinces still maintain a strong attraction. Especially, regarding the interaction with less-developed provinces (SDI 1 and SDI 2), PE, FR, NV, TM, and PT have significant and positive effects. Increasing public transportation expenditures can promote more work with higher education by inducing private mobility systems to afford larger expenditures in transportation, so as to augment their relative convenience in less-developed regions [77]. Freight transport can contribute to economic growth in lower-middle-income regions because it improves the logistics efficiency of products and promotes market transactions between regions [78]. Thus, with the introduction of regional talent policy, developing freight transport is an important indicator of sustainability and can attract more talents. NV and TM are reflections of transportation accessibility. Previous studies have indicated that improved transportation accessibility has a strong positive impact on different job markets in low-wage job regions, and discussions on transportation accessibility can induce significant differences in regional equalities [79,80] The positive impact of policy preferences on less-developed regions is obvious, and they are viewed as an effective tool with which to promote regional equalities. On the contrary, TA, GE, and RL are negative within the context of less-developed regions. Increasing transportation accidents not only means chaotic urban transportation planning but also reflects the lack of transportation governance. Moreover, it can also lead to low-quality citizens and stigmatize the city. Coupled with backward economic conditions, increasing transportation accidents will naturally reduce the attraction of talents in less-developed regions. As the indicators of the environmental dimension, the negative effects of GE and RL in less-developed provinces mean that health and life quality are important factors in selecting work locations [81,82].

In terms of developed provinces (SDI 4 and SDI 5), NV, RE, and RL show significant and positive interaction effects. Although some studies indicate that increasing vehicle ownership will increase energy use and CO_2 emissions [83], improved social welfare and career prospects in developed regions still have a strong attraction to work with higher education [84,85]. The development of sustainable energy is mostly concentrated in technology-intensive industries. At the same time, due to rapid economic development, developed regions have a high demand for sustainable energy. Therefore, these regions require highly skilled migrants. Moreover, the development of sustainable energy technology has also greatly reduced residents' transportation and living costs in developed regions. Therefore, the interaction between the index and developed regions shows a positive effect. The increase in per capita roads in developed regions not only means reasonable transportation planning and transportation management but also indicates the further development of urbanization in a region. Moreover, the increase in roads per capita also leads to high spatial accessibility, which means that the distance from work to the market is shortened and efficiency is improved [76]. Therefore, according to the above results and analysis, Figure 1 demonstrates how transportation sustainability impacts higher education.

Table 4. Spatial multilevel analyses of higher education attainment on interactions of transportation sustainability and SDIs.

Variables	Model 10	Model 11	Model 12	Model 13	Model 14	Model 15	Model 16	Model 17	Model 18
λ	0.551 ***	0.361 ***	0.354 ***	0.565 ***	0.237 *	0.451 ***	0.256 **	0.397 ***	0.429 **
PE	0.447 ***	0.142 **	0.118	1.14 *	0.579 **	0.495 **	0.616 ***	1.203 ***	0.554 ***
FR	0.051	0.231 ***	0.501 ***	0.79 **	0.510 ***	0.325 ***	0.132 ***	0.259 **	0.451 ***
TA	−0.331 ***	0.000	−0.268	−0.721 **	−0.107 **	−0.121	−1.432	−0.156 *	−0.123 **
NV	0.159 *	0.161 *	0.419 **	0.461 **	0.151 ***	0.203 **	0.101 ***	0.045 **	0.074 **
TM	0.457 ***	0.082 **	0.249 **	0.303 *	0.021 ***	0.023 *	0.091 **	0.019 ***	0.261 ***
GE	−0.742 ***	−0.018 *	−0.546 *	−0.167 **	−0.457 *	−0.106 **	−0.194 *	−0.189 **	−0.114
RE	0.059 **	0.036 *	0.319 **	0.088	0.108 ***	0.214 ***	0.141 ***	0.161 ***	0.451 **
RL	0.092 *	0.193 **	0.029 **	0.103 **	0.100 **	0.181 ***	0.061 ***	0.069 ***	0.079 ***
PT	0.444 ***	0.499 ***	0.402 *	0.563 **	0.293 ***	0.575 ***	0.169 ***	0.114 ***	0.166 **
log(GDP)	0.119 *	0.665 **	0.261 **	0.171 ***	0.081 ***	0.035 ***	0.262 ***	0.231 ***	0.203 ***
SDI 1	−1.792 *	−0.021 *	−0.385 **	−0.165 *	−0.093 **	−1.065	−0.097	−0.284 **	−0.140 *
SDI 2	−0.011 *	−0.222 **	−0.588 *	−0.071 ***	−0.121 **	−0.106	−0.072 ***	−0.231	−0.144 **
SDI 4	0.001 ***	0.591	0.002 *	0.110 **	0.145 ***	0.058 **	0.228 ***	0.170 ***	0.129 **
SDI 5	0.039 **	1.003 *	0.038	0.022 **	0.043 *	0.071	0.037 **	0.030 ***	0.084 ***
PE*SDI 1	0.149 **								
PE*SDI 2	0.874								
PE*SDI 4	0.361								
PE*SDI 5	−0.027								
FR*SDI 1		0.196 **							
FR*SDI 2		0.532 *							
FR*SDI 4		−1.591							
FR*SDI 5		0.532							
TA*SDI 1			−0.389 **						
TA*SDI 2			−0.001						
TA*SDI 4			1.902						
TA*SDI 5			0.185						
NV*SDI 1				0.104 ***					
NV*SDI 2				0.562					
NV*SDI 4				0.146 **					
NV*SDI 5				−0.167					
TM*SDI 1					1.008 ***				
TM*SDI 2					0.081 *				
TM*SDI 4					0.537				
TM*SDI 5					0.535				
GE*SDI 1						−0.305 ***			
GE*SDI 2						0.093			
GE*SDI 4						0.832			
GE*SDI 5						0.344			
RE*SDI 1							0.239		
RE*SDI 2							−0.052		
RE*SDI 4							0.050 *		
RE*SDI 5							0.021 ***		
RL*SDI 1								−0.121 *	
RL*SDI 2								0.146	
RL*SDI 4								0.082	
RL*SDI 5								1.304 **	
PT*SDI 1									0.254 ***
PT*SDI 2									0.182
PT*SDI 4									1.074
PT*SDI 5									−0.061
AIC	7423.8	7489.4	7653.2	7238.9	7781.5	7543.3	7886.4	7795.3	7854.7

Note: *** $p < 0.001$; ** $p < 0.01$; * $p < 0.05$. Insignificant variables in the models were excluded.

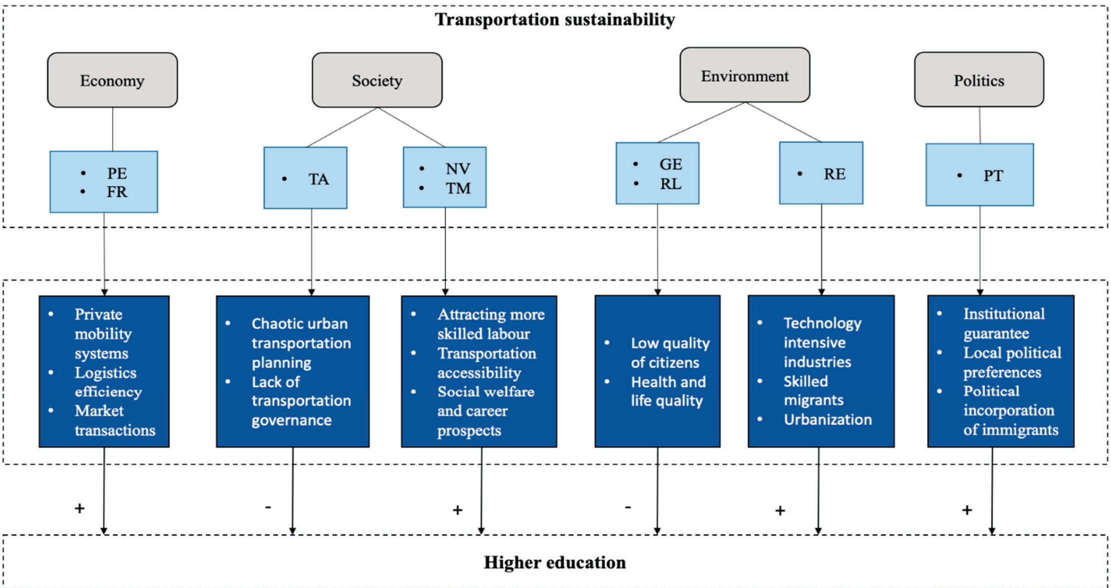


Figure 1. The mechanism of transportation sustainability affecting higher education.

5. Conclusions

This study examined whether the presence of transportation sustainability was currently relevant as a factor encouraging higher education attainment in China from a geographical perspective. Our empirical analysis indicates that higher education attainment had significant spatial dependence at the county level and had significant spatial clustering of county-level higher education attainment across provinces. Moreover, model test results show that the spatial multilevel model was more suitable for our study than traditional regression models. Overall, transportation sustainability was significantly related to higher education attainment at the county level based on economy, society, environment, and politics, and dependent on socioeconomic backgrounds. This study is the first to understand the complexity of transportation sustainability by identifying variables that contribute to transport sustainability influencing higher education attainment and socioeconomic development based on impacting aggregate higher education attainment indicators. In particular, we take the politics dimension into consideration for transportation sustainability. Moreover, spatial lag and spatial clustering are included in the mechanisms. In addition, the intersection within transportation sustainability and between transportation sustainability and socioeconomic development affect higher education attainment by dividing China's provinces into five regions.

Our analysis offers complete evidence for the confounding role of the politics dimension in affecting the associations between transportation sustainability and higher education attainment, as well as the potential mediating role of the politics dimension in linking economic growth to higher education attainment. The results indicate that after considering the politics indicator, the coefficients of economy, society, and environment increase and are more significant. Moreover, the politics indicator is one of the potential mediators to indirectly influence higher education attainment. In addition, there is a strong correlation between the four dimensions of transportation sustainability and higher education attainment. In theory, this study has laid the groundwork for understanding the complex causal channels linking transportation sustainability to regional development. Furthermore, the results also suggest that transportation sustainability has robust influences on higher education attainment. Based on the associations between transportation sustainability and regional development, we have extended the research field of transportation sustainability and regional development by underlining the politics dimension and higher education attainment. In terms of policy implications, this study further promotes the roles of transportation sustainability and higher education in regional equalities. Attracting more skilled talent through the sustainable development of transportation is a powerful tool to reduce the regional gap.

Author Contributions: Conceptualization, K.C., J.X. and D.Z.; methodology, K.C. and D.Z.; software, D.Z.; formal analysis, K.C. and J.X.; investigation, D.Z.; resources, D.Z.; data curation, D.Z.; writing—original draft preparation, K.C. and D.Z.; writing—review and editing, J.X., K.C. and D.Z. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Román, C.; Martin, J.C. Integration of HSR and air transport: Understanding passengers' preferences. *Transp. Res. Part E Logist. Transp. Rev.* **2014**, *71*, 129–141. [CrossRef]
2. Dargay, J.M.; Clark, S. The determinants of long distance travel in Great Britain. *Transp. Res. Part A Policy Pract.* **2012**, *46*, 576–587. [CrossRef]
3. Mabit, S.L.; Rich, J.; Burge, P.; Potoglou, D. Valuation of travel time for international long-distance travel—Results from the Fehmarn Belt stated choice experiment. *J. Transp. Geogr.* **2013**, *33*, 153–161. [CrossRef]
4. Ortega, E.; Lopez, E.; Monzón, A. Territorial cohesion impacts of high-speed rail under different zoning systems. *J. Transp. Geogr.* **2014**, *34*, 16–24. [CrossRef]
5. Arbués, P.; Baños, J.F.; Mayor, M.; Suárez, P. Determinants of ground transport modal choice in long-distance trips in Spain. *Transp. Res. Part A Policy Pract.* **2016**, *84*, 131–143. [CrossRef]
6. Cattaneo, M.; Malighetti, P.; Paleari, P.; Redondi, R. The role of the air transport service in interregional long-distance students' mobility in Italy. *Transp. Res. Part A Policy Pract.* **2016**, *93*, 66–82. [CrossRef]
7. Haapanen, M.; Tervo, H. Migration of the highly educated: Evidence from residence spells of university graduates. *J. Reg. Sci.* **2012**, *52*, 587–605. [CrossRef]
8. Ramani, T.; Potter, J.; Deflorio, J.; Zietsman, J.; Reeder, V.; Transportation Research Board; National Cooperative Highway Research Program. *A Guidebook for Sustainability Performance Measurement for Transportation Agencies*; National Academies Press: Washingotn, DC, USA, 2011.
9. Herb, C.; Pitfield, D.E. ELASTIC—A methodological framework for identifying and selecting sustainable transport indicators. *Transp. Res. Part D Transp. Environ.* **2010**, *15*, 179–188. [CrossRef]
10. Mahdinia, I.; Habibian, M.; Hatamzadeh, Y.; Gudmundsson, H. An indicator-based algorithm to measure transportation sustainability: A case study of the U.S. states. *Ecol. Indic.* **2018**, *89*, 738–754. [CrossRef]
11. Zhang, M.; Duan, F.; Mao, Z. Empirical Study on the Sustainability of China's Grain Quality Improvement: The Role of Transportation, Labour, and Agricultural Machinery. *Int. J. Environ. Res. Public Health* **2018**, *15*, 271. [CrossRef]
12. Choy, L.H.T.; Li, V.J. The role of higher education in China's inclusive urbanization. *Cities* **2017**, *60*, 504–510. [CrossRef]
13. Shen, Y.; Shen, M.; Chen, Q. Measurement of the new economy in China: Big data approach. *China Econ. J.* **2016**, *9*, 304–316. [CrossRef]
14. Radinger-Peer, V.; Pflitsch, G. The role of higher education institutions in regional transition paths towards sustainability. *Rev. Reg. Res.* **2017**, *37*, 161–187. [CrossRef]
15. Joumard, R.; Gudmundsson, H. (Eds.) *Indicators of Environmental Sustainability in Transport*; Les Collections de l'INRETS; European Commission: Brussels, Belgium, 2010.
16. Zhang, Y.; Guindon, B. Using satellite remote sensing to survey transport-related urban sustainability Part 1: Methodologies for indicator quantification. *Int. J. Appl. Earth Obs. Geoinf.* **2006**, *8*, 149–164. [CrossRef]
17. Li, F.; Liu, X.; Hu, D.; Wang, R.; Yang, W.; Li, D.; Zhao, D. Measurement indicators and an evaluation approach for assessing urban sustainable development: A case study for China's Jining City. *Landsc. Urban Plan.* **2009**, *90*, 134–142. [CrossRef]
18. Nourry, M. Measuring sustainable development: Some empirical evidence for France from eight alternative indicators. *Ecol. Econ.* **2008**, *67*, 441–456. [CrossRef]
19. Esteban, L.; Alfonso, T.S.; Cardenas, M.L. Systematic Review of Integrated Sustainable Transportation Models for Electric Passenger Vehicle Diffusion. *Sustainability* **2019**, *11*, 2513. [CrossRef]
20. Kraus, L.; Proff, H. Sustainable Urban Transportation Criteria and Measurement—A Systematic Literature Review. *Sustainability* **2021**, *13*, 7113. [CrossRef]
21. Kawabata, M. Job Access and Work among Autoless Adults in Welfare in Los Angeles. *Ann. Assoc. Am. Geogr.* **2002**, *104*, 1156–1182.

22. Gurley, T.; Bruce, D. The effects of car access on employment outcomes for welfare recipients. *J. Urban Econ.* **2005**, *58*, 250–272. [CrossRef]
23. Cervero, R.; Sandoval, O.; Landis, J. Transportation as a Stimulus of Welfare-to-Work: Private Versus Public Mobility. *J. Plan. Educ. Res.* **2002**, *22*, 50–63. [CrossRef]
24. Li, T.; Burke, M.; Dodson, J. Transport impacts of government employment decentralization in an Australian city—Testing scenarios using transport simulation. *Socio-Econ. Plan. Sci.* **2017**, *58*, 63–71. [CrossRef]
25. Jonas, A.E.G.; Goetz, A.R.; Bhattacharjee, S. City-regionalism as a Politics of Collective Provision: Regional Transport Infrastructure in Denver, USA. *Urban Stud.* **2014**, *51*, 2444–2465. [CrossRef]
26. Bretos, I.; Errasti, A.; Marcuello, C. Multinational Expansion of Worker Cooperatives and Their Employment Practices: Markets, Institutions, and Politics in Mondragon. *Ind. Labour Relat. Rev.* **2019**, *72*, 580–605. [CrossRef]
27. McGuinness, S. Overeducation in the Labour Market. *J. Econ. Surv.* **2006**, *20*, 387–418. [CrossRef]
28. Leuven, E.; Oosterbeek, H. Overeducation and Mismatch in the Labour Market. In *Handbook of the Economics of Education*; Hanushek, E., Welch, F., Eds.; Elsevier: Amsterdam, The Netherlands, 2011. [CrossRef]
29. Di Paolo, A.; Matas, A.; Raymond, J.L. Job accessibility and job-education mismatch in the metropolitan area of Barcelona. *Pap. Reg. Sci.* **2017**, *96*, S91–S112. [CrossRef]
30. Büchel, F.; Van Ham, M. Overeducation, regional labour markets and spatial flexibility. *J. Urban Econ.* **2003**, *53*, 482–493. [CrossRef]
31. Hensen, M.M.; De Vries, M.R.; Cörvers, F. The role of geographic mobility in reducing education-job mismatches in the Netherlands. *Pap. Reg. Sci.* **2009**, *88*, 667–682. [CrossRef]
32. Jauhiainen, S. Overeducation in the Finnish regional labour markets. *Pap. Reg. Sci.* **2011**, *90*, 573–588. [CrossRef]
33. Ramos, R.; Sanromá, E. Overeducation and Local Labour Markets in Spain. *Tijdschr. Econ. Soc. Geogr.* **2013**, *104*, 278–291. [CrossRef]
34. Croce, G.; Ghignoni, E. Educational mismatch and spatial flexibility in Italian local labour markets. *Educ. Econ.* **2015**, *23*, 25–46. [CrossRef]
35. Devillanova, C. Over-education and spatial flexibility: New evidence from Italian survey data. *Pap. Reg. Sci.* **2013**, *92*, 445–464. [CrossRef]
36. Moreno-Monroy, A.I.; Lovelace, R.; Ramos, F.R. Public transport and school location impacts on educational inequalities: Insights from São Paulo. *J. Transp. Geogr.* **2018**, *67*, 110–118. [CrossRef]
37. Geurs, K.T.; Van Wee, B. Accessibility evaluation of land-use and transport strategies: Review and research directions. *J. Transp. Geogr.* **2004**, *12*, 127–140. [CrossRef]
38. Asahi, K. *The Impact of Better School Accessibility on Student Outcomes*; Political Science, SERC Discussion Paper; The London School of Economics: London, UK, 2014.
39. Falch, T.; Lujala, P.; Strøm, B. Geographical constraints and educational attainment. *Reg. Sci. Urban Econ.* **2013**, *43*, 164–176. [CrossRef]
40. Harland, K.; Stillwell, J. *Using PLASC Data to Identify Patterns of Commuting to School, Residential Migration and Movement between Schools in Leeds*; Working Paper No. 07/03; University of Leeds: Leeds, UK, 2007.
41. Wang, H.; Han, J.; Su, M.; Wan, S.; Zhang, Z. The relationship between freight transport and economic development: A case study of China. *Res. Transp. Econ.* **2021**, *85*, 100885. [CrossRef]
42. Zhu, J.; Li, B.; He, B.-J. Is linked migration overlooked in peri-urban Shanghai? Uncovering the domino effect of driving away interregional migrants. *Habitat Int.* **2019**, *94*, 102046. [CrossRef]
43. Lane, B.W. Revisiting 'An unpopular essay on transportation:' The outcomes of old myths and the implications of new technologies for the sustainability of transport. *J. Transp. Geogr.* **2019**, *81*, 102535. [CrossRef]
44. Klarl, T. Urban growth, transportation and the spatial dimension of the work market: A note: Urban growth, transportation and the work market. *Pap. Reg. Sci.* **2015**, *94*, 597–605. [CrossRef]
45. Fasihi, H.; Parizadi, T.; Agah, F. Analyzing Spatial Structure of Residence and Economic Activity in Relation with Transportation Infrastructures in Iran. *Transp. Dev. Econ.* **2021**, *7*, 1–7. [CrossRef]
46. Nezu, Y.; Fujii, S. Construction of simulation model masrac for impact analysis of the macro economy by transportation infrastructure investment. *Stud. Sci. Technol.* **2016**, *5*, 185–195. [CrossRef]
47. Thakuriah, P. Variations in employment transportation outcomes: Role of site-level factors. *Pap. Reg. Sci.* **2011**, *90*, 755–772. [CrossRef]
48. Kasu, B.B.; Chi, G. The Evolving and Complementary Impacts of Transportation Infrastructures on Population and Employment Change in the United States, 1970–2010. *Popul. Res. Policy Rev.* **2018**, *37*, 1003–1029. [CrossRef]
49. Pulipati, S.B.; Mattingly, S.P.; Casey, C. Evaluating state level transportation revenue alternatives. *Case Stud. Transp. Policy* **2017**, *5*, 467–482. [CrossRef]
50. Cai, Q.; Abdel-Aty, M.; Sun, Y.; Lee, J.; Yuan, J. Applying a deep learning approach for transportation safety planning by using high-resolution transportation and land use data. *Transp. Res. Part A Policy Pract.* **2019**, *127*, 71–85. [CrossRef]
51. Stanton, N.A.; Salmon, P.M. Planes, trains and automobiles: Contemporary ergonomics research in transportation safety. *Appl. Ergon.* **2011**, *42*, 529–532. [CrossRef] [PubMed]
52. Cervero, R.; Rood, T.; Appleyard, B. Tracking Accessibility: Employment and Housing Opportunities in the San Francisco Bay Area. *Environ. Plan. A* **1999**, *31*, 1259–1278. [CrossRef]

53. Waqas, M.; Dong, Q.; Ahmad, N.; Zhu, Y.; Nadeem, M. Understanding Acceptability towards Sustainable Transportation Behavior: A Case Study of China. *Sustainability* **2018**, *10*, 3686. [CrossRef]
54. Ensslen, A.; Gnann, T.; Jochem, P.; Plötz, P.; Dütschke, E.; Fichtner, W. Can product service systems support electric vehicle adoption? *Transp. Res. Part A Policy Pract.* **2020**, *137*, 343–359. [CrossRef]
55. Glaeser, E.L.; Kahn, M.E. The greenness of cities: Carbon dioxide emissions and urban development. *J. Urban Econ.* **2010**, *67*, 404–418. [CrossRef]
56. Bergmann, A.; Colombo, S.; Hanley, N. Rural versus urban preferences for renewable energy developments. *Ecol. Econ.* **2008**, *65*, 616–625. [CrossRef]
57. Lehr, U.; Lutz, C.; Edler, D. Green jobs? Economic impacts of renewable energy in Germany. *Energy Policy* **2012**, *47*, 358–364. [CrossRef]
58. Rivers, N. Renewable energy and unemployment: A general equilibrium analysis. *Resour. Energy Econ.* **2013**, *35*, 467–485. [CrossRef]
59. Amirapu, A.; Hasan, R.; Jiang, Y.; Klein, A. Geographic Concentration in Indian Manufacturing and Service Industries: Evidence from 1998 to 2013. *Asian Econ. Policy Rev.* **2019**, *14*, 148–168. [CrossRef]
60. Anderson, C. Transnational Histories of Penal Transportation: Punishment, Labour and Governance in the British Imperial World, 1788–1939. *Aust. Hist. Stud.* **2016**, *47*, 381–397. [CrossRef]
61. Magalhães, A.; Veiga, A.; Ribeiro, F.; Amaral, A. Governance and Institutional Autonomy: Governing and Governance in Portuguese Higher Education. *High. Educ. Policy* **2013**, *26*, 243–262. [CrossRef]
62. Toro López, M.; Scheers, J.; Van den Broeck, P. The Socio-politics of the urbanization—Transportation nexus: Infra-structural projects in the department of Antioquia in Colombia through the lens of technological politics and institutional dynamics. *Int. Plan. Stud.* **2021**, *26*, 321–347. [CrossRef]
63. Gao, X.; Cao, M.; Yang, T.; Basiri, A. Transport development, intellectual property rights protection and innovation: The case of the Yangtze River Delta Region, China. *Res. Transp. Bus. Manag.* **2020**, *37*, 100563. [CrossRef]
64. Zhu, J.; Li, B.; Pawson, H. The end of 'toleration'? Policy ambiguity and converted-housing occupancy in China. *Hous. Stud.* **2020**, *36*, 479–499. [CrossRef]
65. Zhu, J.; Tang, W. Conflict and compromise in planning decision-making: How does a Chinese local government negotiate its construction land quota with higher-level governments? *Environ. Urban.* **2018**, *30*, 155–174. [CrossRef]
66. Collaborators, H. Global, regional, and national disability-adjusted life-years (DALYs) for 315diseases and injuries and healthy life expectancy (HALE), 1990–2015: A systematic analysis for the global burden of disease study 2015. *Lancet* **2016**, *388*, 1603–1658. [CrossRef]
67. Pierewan, A.C.; Tampubolon, G. Spatial dependence multilevel model of well-being across regions in Europe. *Appl. Geogr.* **2014**, *47*, 168–176. [CrossRef]
68. Gu, L.; Rosenberg, M.; Yang, L.; Yu, J.; Wei, B. A spatial multilevel analysis of the impacts of housing conditions on county-level life expectancy at birth in China. *Appl. Geogr.* **2020**, *124*, 102311. [CrossRef]
69. Luke, D. *Multilevel Modeling*; Sage Publications: Thousand Oaks, CA, USA, 2016.
70. Bivand, R.; Sha, Z.; Osland, L.; Thorsen, I.S. A comparison of estimation methods for multilevel models of spatially structured data. *Spat. Stat.* **2017**, *21*, 440–459. [CrossRef]
71. Taylor, B.; Kim, E.; Gahbauer, J. The Thin Red Line: A Case Study of Political Influence on Transportation Planning Practice. *J. Plan. Educ. Res.* **2009**, *29*, 173–193. [CrossRef]
72. Lauby, F. Transportation and immigrant political incorporation. *J. Ethn. Migr. Stud.* **2019**, *206–222*, 1–18. [CrossRef]
73. Cartier, C. What's territorial about China? From geopolitical narratives to the 'administrative area economy'. *Euras. Geogr. Econ.* **2013**, *54*, 57–77. [CrossRef]
74. Ma, L.J. Urban administrative restructuring, changing scale relations and local economic development in China. *Political Geogr.* **2005**, *24*, 477–497. [CrossRef]
75. Lin, X.; MacLachlan, I.; Ren, T.; Sun, F. Quantifying economic effects of transportation investment considering spati-otemporal heterogeneity in China: A spatial panel data model perspective. *Ann. Reg. Sci.* **2019**, *63*, 437–459. [CrossRef]
76. Jiang, X.; Zhang, L.; Xiong, C.; Wang, R. Transportation and Regional Economic Development: Analysis of Spatial Spillovers in China Provincial Regions. *Netw. Spat. Econ.* **2016**, *16*, 769–790. [CrossRef]
77. Bonatti, L.; Campiglio, E. How can transportation policies affect growth? A theoretical analysis of the long-term effects of alternative mobility systems. *Econ. Model.* **2013**, *31*, 528–540. [CrossRef]
78. Nasreen, S.; Saidi, S.; Ozturk, I.; Johansson, N.; Robertson, L.; Weber, R. Assessing links between energy consumption, freight transport, and economic growth: Evidence from dynamic simultaneous equation models. *Environ. Sci. Pollut. Res. Int.* **2018**, *25*, 16825–16841. [CrossRef] [PubMed]
79. Fan, Y.; Guthrie, A.E.; Levinson, D.M. Impact of light rail implementation on labour market accessibility: A transportation equity perspective. *J. Transp. Land Use* **2012**, *5*, 28–39. [CrossRef]
80. López, F.A.; Paez, A. Spatial clustering of high-tech manufacturing and knowledge-intensive service firms in the Greater Toronto Area. *Can. Geogr.* **2017**, *61*, 240–252. [CrossRef]
81. De Vries, S.; Verheij, R.A.; Groenewegen, P.P.; Spreeuwenberg, P. Natural Environments—Healthy Environments? An Exploratory Analysis of the Relationship between Greenspace and Health. *Environ. Plan. A* **2003**, *35*, 1717–1731. [CrossRef]

82. Ewing, R.; Tian, G.; Goates, J.P.; Zhang, M.; Greenwald, M.J.; Joyce, A.; Kircher, J.C.; Greene, W.H. Varying influences of the built environment on household travel in 15 diverse regions of the United States. *Urban Stud.* **2015**, *52*, 2330–2348. [CrossRef]
83. Wu, T.; Zhao, H.; Ou, X. Vehicle Ownership Analysis Based on GDP per Capita in China: 1963–2050. *Sustainability* **2014**, *6*, 4877–4899. [CrossRef]
84. Domonkos, S. Promoting a higher retirement age: A prospect-theoretical approach. *Int. J. Soc. Welf.* **2015**, *24*, 133–144. [CrossRef]
85. Zhai, K.; Gao, X. Higher education institutions and urban attraction: An empirical study based on 13 cities in Jiangsu Province. *J. Xuzhou Inst. Technol. (Soc. Sci. Ed.)* **2020**, *35*, 86–93. (In Chinese)

sustainability

MDPI

Article

Deciphering Property Development around High-Speed Railway Stations through Land Value Capture: Case Studies in Shenzhen and Hong Kong

Weihang Gong [1], Jing (Victor) Li [1,2,*] and Mee Kam Ng [1,2]

1 Department of Geography and Resource Management, The Chinese University of Hong Kong, Hong Kong, China; gwh.craig@link.cuhk.edu.hk (W.G.); meekng@cuhk.edu.hk (M.K.N.)
2 Institute of Future Cities, The Chinese University of Hong Kong, Hong Kong, China
* Correspondence: victorli@cuhk.edu.hk

Abstract: Property development around transit stations has been viewed by many governments as a considerable way of financing public transportation. However, despite mounting evidence of the positive relationship between transport investment and proximate land value, the stakeholder relationship in enabling complex property–transit development has received relatively scarce attention. In this study, we analyze the railway financing strategies in two cities (Shenzhen and Hong Kong) connected by the first cross-border high-speed rail (HSR) network in China. Using a holistic power approach, this study presents power direction, power strength, and power mechanism as the critical factors for each case. The results reveal that different stakeholder relations arising from different social and institutional contexts have led to varying land value capture practices. The findings of this study contribute to sustainable railway financing in three phases: First, it unravels the relationship between railway financing and property development under the context of an intercity railway program, with the intervention of state power. Second, it sorts out critical elements in the implementation of the land value capture mechanism, especially institutional factors such as the role of the transit agency. Third, it directs a flexible development of the land value capture theory to cope with foreseeable problems such as land resource scarcity, institutional complexity, and interest divergence.

Keywords: land value capture; high-speed rail (HSR); transport; railway financing; rail plus property (R + P) model

Citation: Gong, W.; Li, J.; Ng, M.K. Deciphering Property Development around High-Speed Railway Stations through Land Value Capture: Case Studies in Shenzhen and Hong Kong. *Sustainability* **2021**, *13*, 12605. https://doi.org/10.3390/su132212605

Academic Editors: Mengqiu Cao, Claire Papaix, Tianren Yang and Benjamin Büttner

Received: 18 October 2021
Accepted: 11 November 2021
Published: 15 November 2021

1. Introduction

Improving the provision of public infrastructure is key to achieving sustainable development goals (SDGs) within the global context of increasing inequity and ecological deterioration [1]. For the next decades, it is predicted that the proportion of public infrastructure expenditures in the aggregate economy will continue to rise, accounting for 3.5% of annual GDP worldwide [2]. However, conventional revenue sources such as user charges and general taxes seem inadequate to cover the increasingly burdensome costs [3], generating a fiscal gap between enlarging costs and stagnant benefits. To remedy this imbalance, a variety of financing mechanisms have been invented to facilitate higher levels of private capital engagement. Existing financing modes have covered the wide span between full public financing, semi-public financing (such as public-private partnerships), up to full private financial mechanisms [4].

When it comes to the financing of public transport investment infrastructures such as rail transits, buses, and highways, an indispensable fact to be noted is that they have embraced many merits that have contributed to citizens' higher willingness to pay (WTP) in exchange for improved accessibility [5,6]. However, very limited academic efforts have been devoted to studying how the land-related revenues could affect the financing and planning of public transport projects. One heated topic within this domain could be found in "land value capture" (LVC) studies. LVC has been viewed as an important, feasible, and justifiable transit funding vehicle for public transportation systems by linking land value increment with initial investments [4,7,8]. Aiming at sustainable urban development, city authorities have regarded capturing land value as critical approach for obtaining capital gains from investment, and are thus exploring different policy tools to be able to apply LVC worldwide [9,10].

However, more difficulties arise when we move on to an emerging type of mega public transit—the high-speed rail system. The problems in considering HSR in the context of LVC are attributed to the relatively short history of HSR development, the blurred understanding of its urban impacts, and its complex financing regime [11]. For example, one complexity in analyzing the intercity railway projects is the fact that multiple administrative regions engage in a cross-municipal railway. Drawing on the example of China, the state and provincial sectors provide considerable capital to large-scale intercity rail projects, while the other part is sourced from bank loans. The state railway company is entrusted with the tasks of determining and supervising all detailed issues of railway construction and operation due to its rich experience in delivering national railway projects, which also shares operational profits or deficits with its provincial subsidiaries [12]. Unlike intra-city rail projects, the municipal government is shifting from being a major investor to an ancillary investor, detached from raising capital funding and shouldering operational deficits; it is only requested to prepare land parcels for transit corridors and rail stations, is responsible for resettlement, and is engaged in line alignment and station site selection due to their strong control over local land and affairs [12,13]. Nevertheless, it remains a question whether intercity railway projects can stimulate new town development and create property value premiums which provide the pre-conditions for LVC.

Recognizing all these knowledge deficiencies, this study thus developed the following research questions: (1) Can LVC strategies be used to fund HSR projects? If yes, what are the operational models? (2) What factors have led to divergent practices of LVC? To address these questions, we visited two cases in Shenzhen and Hong Kong after scrutinizing the notion of LVC. Under distinct social and institutional contexts, they both decided to finance their first HSR along the XRL. We utilized a power relation framework developed by Wang et al. [14] to analyze how stakeholder relationships affected the realistic uses of LVC.

The rest of this paper is organized into five sections. In Section 2, we present the conceptual linkage between LVC and stakeholder engagement, and then explain how power framework works under our research context. In Section 3, we introduce the empirical strategy, including the analytical framework and research method. In Sections 4 and 5, we present the two cases as our empirical analysis. Finally, we summarize the findings with policy implications in Section 6.

2. Literature Review

2.1. Land Value Capture

LVC characterizes a certain aggregation of alternative financing methods by capturing a portion of land value increment that is attributed to the benefits of public interventions [8,10,15]. There are two prerequisites for the use of LVC: (1) there is an uplift in land value from public investment; (2) there are favorable public policies facilitating the capturing of increased land value [9]. It is notable that capturing methods have been diversified to account for all sorts of social, economic, and political circumstances all over the world [16]. According to Mathur [10], existing LVC tools are categorized into two broad categories. One consists of direct value capture mechanisms, such as property and land tax, betterment charges and special assessments, tax increment financing (TIF), and so on. The other comprises indirect value capture mechanisms, which include land lease/land sale, joint development, air rights sale, land readjustments, etc. Direct value capture methods are considered as wealth redistribution instruments that capture "unearned income" from private landowners and require a well-established taxation system. This group of instruments is characterized as being "more sustainable" in circumventing the loss of arable construction land by implementing a recurring benefit-capturing mechanism, although facing public charges of regressive effects or arbitrary taxation rates [16]. In contrast, indirect capture methods prevail in a wider geographical scope because they hold a more pragmatic attitude towards value capture: that of generating revenues without encountering the risk of distorting the existing fiscal regime [4,16,17]. Furthermore, multiple LVC instruments can be used simultaneously to fund public transport projects. For example, property management and sale of land development rights are adopted by the Hong Kong rail operator, the Mass Transit Railway Corporation Limited (the MTRC), to fund the construction of its own metro system [10].

Overall, LVC has spread from well-established markets, where tax-based mechanisms are used, to some flourishing markets, where land-centered financing practices are popular for mobilizing different resources to fund large-scale public infrastructure [1,16]. As Mathur [10] points out, to enhance the cooperation among stakeholders in LVC, inclusive value creation should be enabled to properly share the increased land value among public agencies, transit agencies, private real estate developers, and residential communities [18]. This inclusive strategy calls for a transparent and efficient policy that targets all involved stakeholders, but also a diversified way of generating land revenues, i.e., existing property appreciation, new transit-oriented developments, and so on [10]. Correspondingly, scholars should take a more comprehensive viewpoint in defining, observing, and analyzing LVC.

2.2. Analyzing Stakeholder Engagement in LVC: A Holistic Power Framework

Stakeholder engagement has long been identified as a critical prerequisite for successful transport planning that should be considered in the decision-making as well as the project workflow establishment stage [19,20]. On the one hand, engagement of stakeholders from diverse backgrounds helps to enrich project objectives and interests; on the other hand, engagement is also essential at the implementation stage in order to ensure the support from stakeholders [20]. For example, "inclusive value creation" calls for creating and sharing land value increment among all stakeholders—from public agencies and transit agencies to real estate developers, business holders, and surrounding neighborhoods, among others [16,21]. That being said, the specific role of transit agencies in LVC has rarely been reported in value capture studies. In most markets, transport agencies only participate in some phases within the LVC process (i.e., in transport construction and operation). For example, the transit agency in Washington DC is perceived as a "pure transit provider" despite its diversified utilization of LVC instruments, including the one-time lump sale/lease of property/development rights, connection fee charges from retailers, and the sharing of operational costs with developers [22]. In Hong Kong and Tokyo, the partial or complete privatization of transit agencies have given rise to entrepreneurial transit agencies that are willing to take up diversified business strategies towards land development around transit stations [9,23,24]. In a nutshell, the significant disparity of business focuses of transit agencies is believed to produce quite different approaches towards station-adjacent property development opportunities, and thus, their LVC preferences.

Recognizing that power relations among critical stakeholders could affect LVC outcomes, Wang et al. [14] developed a theoretical framework to unravel the complex power relations between LVC stakeholders. Borrowing the knowledge from the studies on Mechanics by Wilcox [25], the power relation framework features various perspectives of power, i.e., direction, strength, and mechanism: (1) Direction of power refers to the business relations among stakeholders in the acquisition of land values, which may either be competition, cooperation, or complementary. (2) Power strength indicates the scale of power, including four forms of power: coercive power—how an authority can coerce others to act; legitimate power—how a legitimate authority can prescribe the actions of others; induced power—using material awards to derive a power advantage; and competent power—using specialties and expertise to obtain power [26,27]. (3) Mechanism of power represents how stakeholders benefit from land, including market mechanisms—using price, supply and demand, and competition as instruments; or administrative mechanisms—using the law, rules, and guidelines as instruments [14]. The power relation framework unravels the disparity in power relations between LVC stakeholders, whether triggered by temporal evolution or from geographical distinction, and will eventually lead to LVC practices. For example, in the dominant private land market in the US, local governments do not have power over land sellers, which exhibits a huge difference as compared to local governments in China that operate based on public land schemes [14].

2.3. The Rail plus Property Model: How A Holistic Power Framework Works

This section introduces a specific practice of LVC in transport planning, the rail plus property (R + P) model, which serves as a benchmark model in our empirical studies analyzing the LVC practices of the HSR projects. This model originated in Hong Kong, where the prosperous real estate market and high public transit usage justify the transit-oriented property development strategy to fuel urban transit system expansion [28]. In the R + P model, land parcels around newly built railway stations are exclusively granted by the Hong Kong government to the transit agency, the MTRC, at a "before rail" price, and then sold to private developers at an "after rail" price. In other words, the Hong Kong government sells the land premia to the MTRC in exchange for the construction and management of rail infrastructure. Property development above the railway station is perceived as the core business. Hong Kong's success in the R + P practice has been reflected in its high-quality train services at relatively low fare prices, its highly compact urban form along corridors and stations, as well as the stable business revenues of the MTRC company over decades [23]. Portrayed with similar public land ownership and debt pressure from large infrastructure investment, many Chinese cities "duplicate" this model, some even inviting the MTRC to participate in their transport development programs [29]. For example, Shenzhen is the first mainland city to successfully implement the R + P project (known as the "Tiara" project). To address legislative barriers from the existing land transfer system, the Shenzhen municipal government managed to make use of conditional bidding (prior to 2012) and the land equity investment approach (after 2012) to grant land development rights above railway stations to the local transit company, the Shenzhen Metro Company (SZMC), instead of conventional cash contributions.

The supremacy of the Hong Kong R + P model is believed to be attributed to the appropriate engagement of the transit agency, which can be further elaborated following the previous holistic power framework of Wang et al. [14]:

(1) In terms of power direction, cooperation overtakes competition, with the transit agency taking up a leading role. This can create an integrated transport–land use pattern and coordinate divergent interests between public and private interests [30]. Aveline-Dubach and Blandeau [31] described the reciprocal relationship between these participants as an "urban growth coalition": the government benefits from obtaining high-quality transport infrastructure and a compact, transit-oriented urban environment without directly devoting fiscal investment; the transit company gains access to property development and maximizes its profitability through a diversified portfolio, such as property development and management, advertising, telecommunications, and so on; the big, local property groups also benefit from expanding their control over the territory, because R + P stipulates that MTRC's land tenders should be awarded to bidders on the basis of financial health status.

(2) In terms of power strength, the MTRC enjoys high levels of competent and legitimate power. Competent power refers to the abundance of specialists and requisite knowledge to solve difficult problems or collaboratively accommodate stakeholder needs. The railway station and above-station properties are linked in terms of site footage, civil works, and ancillary services. Only a single transit agency with a rich experience and professional skills in planning and developing railway property, such as the MTRC, has the power to plan and manage such an integrated project [32]. In fact, the MTRC acts as a "master planner and designer" that not only prepares a de-

velopment layout plan and resolves all interfaces with rail stations, but also takes care of tendering land parcels, acts as a liaison between the government and developers, and monitors development quality as well as the sale and management of completed properties [23]. An agent owns legitimate power when it has the legitimate authority to prescribe the actions of other stakeholders [27]. In this regard, MTRC exploits "Development Agreements" to ensure the compliance of developers in obeying the master plan for station development [30]. MTRC is in a strong position among the contracting parties, i.e., to benefit from the land and hence maximize the synergistic effects of railway property.

(3) In terms of power mechanism, the Hong Kong R + P model mostly uses a market mechanism, where the government, as the landowner, shares land development profits with the transit agency so that all the resources (land, rail, capital, professional skills) can be efficiently disposed by a single company. Compared with an alternative public-led model (where the government directly disposes land development rights to the developers through public auction), this arrangement is argued to decrease the transaction costs and improve overall efficiency [30]. In addition, administrative mechanisms also exist, such as the exclusive land grant from the Hong Kong government to the transit agency.

3. Empirical Strategies

3.1. Selection of Cases and Sources of Data

This study selects Shenzhen and Hong Kong as research sites due to their explicit differences in terms of institutional and social contexts despite their close geographical association along the Guangzhou–Shenzhen–Hong Kong Express Rail Link (the XRL). Both cities are characterized by high population density (over 6700 people per square kilometer), with housing problems. To achieve sustainable growth, both cities have actively embraced a TOD development ideology in urban planning [23,29]. (See Figure 1)

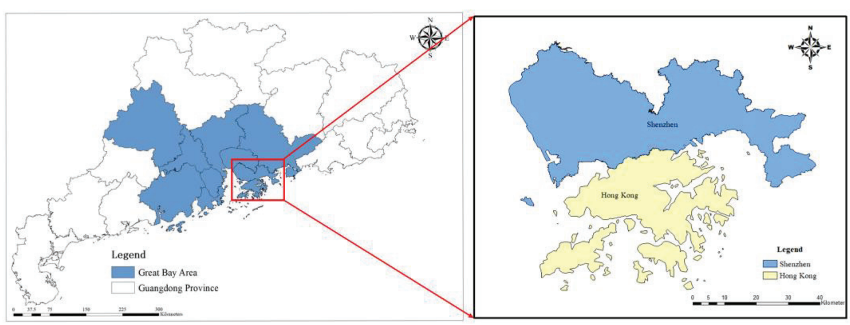


Figure 1. Location of Hong Kong and Shenzhen (Source: authors).

This study mainly uses the mixed-method approach, which includes a policy review and a stakeholder interview. Policy documents are drawn from a wide range of sources, including: (1) literature regarding the rail plus property model, high-speed rail financing, and land value capture; (2) governmental policy documents relevant to LVC practices, including TOD planning and transport financing; (3) project enterprise reports such as annual reports of railway companies; (4) third-party reports. The detailed and reviewed policy documents are presented in the Table 1.

Table 1. Data sources of the policy review.

Category	Institution	Description
Government documents	Hong Kong Legislative Council Committee, subcommittee on Matters Relating to Railways	Papers, reports, and ordinances before and during HSR development, including feasibility assessment; station location selection and supporting facilities; operation matters.
	Town Planning Board, HKSAR	Town Planning Ordinance. Section 3 Functions of the Board, Section 4 Contents of Lay-out Plans and Powers of the Board.
	Transport and Housing Bureau, HKSAR	Report of the Hong Kong Section of the Guangzhou–Shenzhen–Hong Kong Express Rail Link, in 2014, by an independent expert panel.
	Shenzhen Housing and Construction Bureau	Official website; notice on the announcement of the results of the preliminary review of the public rental housing application at Langlu Home.
	People's Government of Guangdong Province	Shenzhen Affordable Housing Regulations. Minutes of the Meeting of the Ministry of Railways and Guangdong Province on Promoting the Construction of the Guangdong Railway in a Sound and Fast Way, 2010.
	National Railway Administration of the People's Republic of China	Official website—introduction of the Shenzhen North Railway Station Comprehensive Transportation Hub Project: Winner of the 2012 Zhan Tianyou Award.
Enterprise reports	SZMC	Official Website; Annual report, 2019.
	SZMC	Corporate Bond Credit Rating Report, 2020.
	SZMC	Public issuance of green corporate bonds, 2021.
	MTRC	Hong Kong SAR Government MTR Privatization Share Offer Prospectus, 2000.
	MTRC	Official Website; Annual report, 2019.
	China Railway Group Limited	Annual report, 2020.
	Guangdong Railway Construction Investment Group Co., Ltd.	Official Website; Tracking rating report, 2017, 2020.

The research also utilizes unstructured expert and stakeholder interviews to obtain actual market information that would help to certify our arguments. Interviewees include: one project manager from the Vanke Property in the HBC Huilong Center project (on-site interview, last over an hour), two real estate agents in the Longhua district, Shenzhen (one online interview, one phone interview, last over half an hour), two property investors in the Huide Tower project (on-site interview, one is a local chain hotel operator). These interviewees all know quite a lot about the local real estate market and government policies.

The interview with the project manager contributes to our understanding of the localized development process. The interview data were analyzed via thematic analysis, which helped the investigators to identify and extract certain themes from a particular data set.

3.2. Analytical Framework

To solve the research questions in Section 1, we built an analytical framework, as shown in Figure 2. Realizing the importance of diverse stakeholder engagement, this paper argues that the power relations are subject to a series of socio-economic and institutional factors (such as railway finance politics, land administrative system, local real estate market, planning system, social attitudes). Furthermore, various power relations can lead to preferences towards varying LVC strategies: cooperative relationship is important for sophisticated LVC policymaking, while power imbalance and public sector dominance may repel the engagement of the private sector such as the transit agency or property developer.

In addition, this study firstly scrutinizes the role of the transit agency in the LVC, which is seldom investigated as previous LVC literature focused more on the land administration and marketization processes [14,18,19,22]. Given the specialized focus on the transit agency, the coercive power is left out in the power relation discussion. The participation of state and municipal governments is also looked upon, as state power is evident in an intercity railway financing regime [12]. In the case of Hong Kong, we applied a city-state concept as it is empowered with an autonomous transport financing regime and land administration [23,33]. We centered on three key stakeholders: the government, the transit agency, and the real estate developer, each with diverse interests and obligations. By employing a holistic power approach, their power relations are examined through three perspectives—direction, strength, and mechanism.

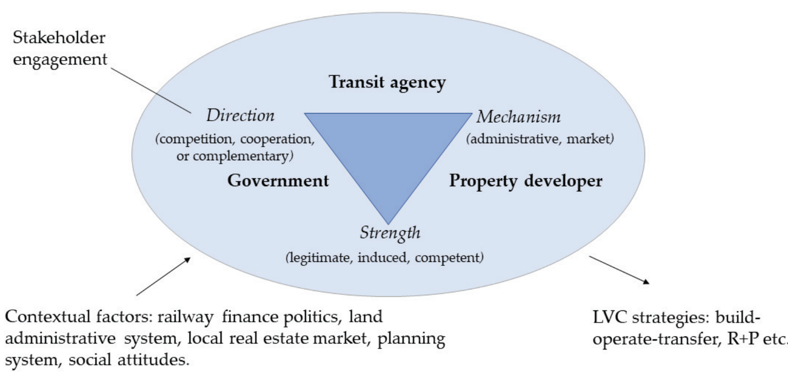


Figure 2. Analytical framework: stakeholder relationship affecting the outcomes of LVC application (the triangle indicates three power perspectives: direction, strength, and mechanism). Source: adapted from Wang et al. [14].

4. The Shenzhen Case

4.1. SZMC as Leading Stakeholder in LVC

The Shenzhen North Railway station (SZNRS) is the principal intercity railway hub for Shenzhen city, covering 2,400,000 m^2 (240 ha) of land, with 11 platforms and 20 railway tracks. The station was the terminal station of the first phase of the XRL—Guangzhou South to Shenzhen North. By year 2015, this station was connected to several national and regional HSR corridors, including the Beijing–Guangzhou line, the Hangzhou–Fuzhou–Shenzhen line, and the Nanning–Guangzhou line. This station was designated to fulfill two targets—to satisfy the long-distance travel demand from Shenzhen (and Hong Kong) residents to other major cities in China, and to effectively reduce the travel time between Guangdong and Hong Kong.

The financing arrangement for the mainland section of the XRL signifies the commencement of a new era of railway financing in mainland China, in which the state and provincial sector each injected 50% of the capital into the newly established railway project company—in this case, the Guangzhou–Shenzhen–Hong Kong Passenger Dedicated Line Co., Ltd. In addition, the local transit agency, the Shenzhen Metro Company (SZMC), acted as a pivotal stakeholder: on the one hand, the SZMC represented the Shenzhen municipality, contributing to 27.43% of the total investment (the shares held by the provincial sector); on the other hand, the SZMC also engaged in the two above-station property development programs in collaboration with the government and private developers—the HBC Huilong center and the Huide Tower [34]. With this factual evidence, an "R + P" model was then regarded as the logical solution to fund the rail development.

4.2. Cooperative Power Direction in Land Value Capture

Due to the involvement of the state and provincial sectors in HSR financing, the value capture mechanism should be modified to allow for inclusive value creation and value sharing among all stakeholders, especially from a single municipality to cross-government level [10,13,23]. In this regard, the SZMC attempted to ally with diverse stakeholders. In the HBC Huilong center project, the SZMC collaborated with a leading domestic property developer, the Vanke Enterprise, to co-develop real estate in synchronization with the railway project. This arrangement is analogous to Japan's joint development model to improve the integration between rail stations and real estate projects (Sina News 2016, interview with Tan Huajie, Senior Vice President of Vanke Enterprise. In the joint venture, the MTRC holds 51% of the total capital. (http://finance.sina.com.cn/roll/2016-07-04/) (accessed on 7 March 2021)). Within this collaboration, the Vanke provided a whole package of professional services after obtaining the land parcel, including design, construction, and property management, offering essential help to shorten the property development process (interviewee 1, project manager). In the Huide Tower project, a joint venture with a state company—the China Railway Group limited (CRG)—was established to capture value for state-owned enterprises (interviewee 1 and 2: project manager, senior real estate agent), in which the shares held by the SZMC also reached 51% [35].

The SZMC retains a flexible and negotiable relationship in sharing land profits with the Shenzhen municipal government. As a subsidiary under the Shenzhen State-owned Assets Supervision and Administration Commission (SASAC), the SZMC can smoothly acquire the land parcels through equity investment from the SASAC [18]. One feature in the R + P practice in Shenzhen is that the SZMC shoulders government obligations in providing public housing as it is able to assume higher financial risks with government backup [34]. In comparison to the practice in Hong Kong, real estate development in Shenzhen is very much a cross subsidy from the government for railway and public housing construction—when property development fails to fill the financial gap for railway construction and operation, the SZMC receives government subsidies to mitigate operation deficits; otherwise, when the government considers that the profit margin of the SZMC is too high during a real estate surge, the SZMC is asked to spare a portion of building units as public housing [29]. The houses would be allocated by Shenzhen government and be rented at a subsidized price to certain groups who are eligible for certain "affordable housing" programs [36]. For instance, Yang et al. [29] reviewed thirteen R + P projects in Shenzhen, finding that six of them were involved in public housing provision.

4.3. Acquisition of Power through Market and Administrative Mechanism

The next question is how the SZMC managed to obtain power in its R + P model. As mentioned earlier, four forms of power exist in stakeholder relations. For competent power, SZMC has accumulated experience in R + P programs as one of the first transit agencies in China to trial the value capture mechanism. Prior to the introduction of the R + P model, transit funds were mainly paid by cash, which could partially come from the public land sale around stations [29]. However, land lease revenues were not dedicated to recoup the construction and operational costs. There was also a significant time gap between expenditures for transit construction and the collection of land lease revenues [29]. Inspired by the success of Hong Kong, in 2013, the SZMC established the department of property development (known as SZMC Property, or "Shentie Zhiye" in Chinese) to manage the property business, especially for R + P projects [18]. A series of subsidiary project companies were set up to be responsible for the development, construction, operation, and management of different R + P projects, all of which were ultimately managed by the SZMC Property (These subsidiary companies include but are not limited to: Shenzhen Metro Qianhai International Development Co., Ltd. (referred to as "Qianhai International"), Shenzhen Langtong Real Estate Development Co., Ltd. (referred to as "Langtong Company"), Shenzhen Metro Nordisk Shenzhen Metro Vanke Investment Development Co., Ltd. (abbreviated as "Shen Tie Nuode"), Shenzhen Metro Vanke Investment Development Co., Ltd. (abbreviated as "Shenzhen Vanke"); the SZMC is the only or main shareholder of all these companies.) [35]. In the case of the Huide Tower project, the collaboration with the China Railway Group further fortified the competent power, given CRG's provision of technical resources in dealing with all sorts of construction difficulties in an HSR project [37].

Given the involvement of cross-municipality governments, the legitimate empowerment of a local agency was necessary to allow such a single agency to lead the project. In July 2010, the Guangdong provincial government authorized its provincial railway investment company to collect real estate revenues and to transfer it to the regional transit company (i.e., the Guangzhou–Shenzhen–Hong Kong Passenger Dedicated Line Co., Ltd.). This firstly legitimized the practice of higher-level government entities sharing land development benefits with municipal governments in China, removing the cross-jurisdictional concerns that were inevitable regarding this type of R + P development [13]. As for the state, the joint venture between the local municipality (the SZMC) and the state (the CRG) did not only establish a plausible market approach to recoup the enormous fiscal investment from the central government, but also added to the authoritativeness of the SZMC in the subsequent development.

Induced power is essential for a successful R + P model to activate the engagement of other stakeholders in the coalition. Cervero and Murakami [28] describe the R + P as "a carefully conceived process for planning, supervising, implementing, and managing station-area development and tapping into the land price appreciation that results". To achieve the implementation, two sources of induced power were utilized through the market and administrative mechanism. The first is associated with the choice of station location. The SZNRS ended up with a peripheral location outside the built-up area, which could reduce land-related expenditure for the governments (land concession fee, demolition fee, and resettlement fee). Although proximity to urban centers may precipitate a larger potential passenger flow, municipal governments lack the incentive to do so as it is divorced from the operational deficit of the national HSR system [13]. Transit agency engagement is facilitated by this development-based station placement decision, as a large proportion of vacant state-owned land (formally consolidated by government using coercive power) around the station paves the way for succeeding development, and boosts land lease revenue. The government also contributes to a large proportion of urbanization campaign along with HSR investment, launching a number of subsequent development strategies such as the integration with the local rail transit network (in June 2011, six months before the HSR inauguration, metro line 4 and line 5 were opened, connecting Futian and Luohu, two urban centers to the HSR station), district boundary reorganization (in 2011, the Longhua New District (LHND) was separated from the original Bao'an district, enabled with the higher political power of planning and financing affairs), and new town development.

Another source of induced power comes from supportive land zoning regulation. A supportive, compatible, consistent, and specific land zoning system contributes to mitigate project risks, thus encouraging transit participation in TOD projects [38]. As previously stated, a peripheral location choice of the SZNRS circumvents its development from planning restrictions as in highly urbanized areas. Land density bonus and floor area ratio (FAR) transfer practices are allowed at the land parcel level in order to enable developers to enjoy higher development density around transits, ranging from a 20% to an 80% increase from the baseline density parameter [29]. In this way, the coalition between local governments and the SZMC, and even the private developers, have benefited from the R + P and land reproduction. Only concerns have shifted from "whether feasible" to "whether sustainable", and to "whether justifiable", as such a mega-project consumes immense quantities of state-owned land resources in such a high-density city where land means everything.

5. The Hong Kong Case

5.1. A Government-Led Model Where the Role of MTRC Is Marginalized

XRL (the Hong Kong section) is the world's first all-underground high-speed railway project. As a mega-transport project, it terminates at the Hong Kong West Kowloon Station (HKWKL), with a footprint of 110,000 m^2. It consists of a ground floor with four lower levels beneath it, and the lowest housing 10 railway platforms. The gross floor area is 380,000 m^2. The trains run in parallel tunnels, which extend underground to the Shenzhen Futian district [39]. The Hong Kong section of the XRL project firstly connects Hong Kong with the national HSR network in China, enabling passengers to travel between Hong Kong and Mainland cities at speeds of over 200 km/h. Thereby, it is recognized as a project of strategic importance that will enhance Hong Kong's status as a gateway to Mainland China [39].

Prior to the XRL project (Hong Kong section), most mass transit railway financing in Hong Kong adopted an "ownership approach", where the MTRC was responsible for the funding, design, construction, and operation of projects [23]. However, the Hong Kong government adopted a "concession approach" in the case of XRL, in which government owns the railway assets, pays for the project, assumes the construction risks, and assigns the MTRC to manage all aspects of the whole project [39]. Once railway construction is completed, the whole railway project is transferred back to the government, while the MTRC continues to operate in the form of a railway franchise, paying a concession fee to the government for cost recovery [40].

The authority to decide on the railway financing arrangement is largely held by the government. A subcommittee of the Legislative Council Panel on Transport takes the charge of overseeing and examining proposed railway financing arrangements, largely under the principle of financial viability [23]. With a default option of ownership approach (known as the "R + P" model), case-by-case examination is required to figure out the most appropriate financing mode. In this case, with a concession approach being prioritized, Hong Kong adopts alternative value capture instruments, i.e., it can sell preserved land above the terminus station through public bidding. On 26 November 2019, a piece of land development right above the West Kowloon station was sold at a price of HKD 42.2 billion to a local property developer, the Sun Hung Kai Properties Limited (SHKP), who proposed to make use of this land parcel for a TOD-featured landmark integrated complex project [41]. Apart from land auctioning, Hong Kong captures increased land value from existing properties through its well-established tax administrative system [16], which contributes as a secondary public revenue source. In an HSR study, Bao and Mok [42] noted that "land sales accounted for 27% of government revenue in 2018, whereas tax from profits accounted for 22% in Hong Kong." They also evaluated the aggregate increase in property values to be HKD 46.6 billion, owing to the HKWKL project, which accounted for 55% of the total project construction cost of HKD 85.3 billion. This property premium could be captured through multiple taxation tools, i.e., tax rates (5% of estimated annual rent revenues), government rent (3% of estimated annual rent revenues), property tax (15% of net rent revenues), etc. In the following sections, we will examine latent factors that have prompted the MTRC to forfeit the leading role in the HSR project.

5.2. Power Direction: From Cooperative to Competitive/Unsupportive

As indicated in Section 2.3, the MTRC plays a critical role in R + P projects. The unique business framework in which the MTRC heavily influences the planning and coordinates station site development, was once thought to be one market-oriented feature of the best advantages of this model [30]. Specifically, the site development details were worked out by the MTRC after aligning with the public interests of government departments and the private interests of the developers [23,30]. However, in this case, it was discovered that both the government and the private sector had transformed their attitudes into being unsupportive of an MTRC-led R + P model.

From a government stand, an R + P model implies that the MTRC will be responsible for the finance, design, construction, operation, and maintenance of the new railway project, and ultimately owns the railway. Due to the political risks involved in the cross-border cooperation, the Hong Kong government decided to retain full ownership of the HSR infrastructure. To better implement the blueprint designed for the HSR area, i.e., to secure a low-density, high-quality public space around new HSR stations [31], the government preferred to bypass the MTRC during development to have a direct conversation with real estate developers. Past experiences show that the MTRC retains a market-oriented feature when facilitating above-station development in order to fully leverage land resources (i.e., the Tung Chung project, the Tseung Kwan O station project (according to Tang et al. [30], in the Tung Chung above-station development, the MTRC improved the government planning and design with the maximization of the sea-view potential of land resources; in the Tseung Kwan O station project, the MTRC proposed a change in land use to satisfy rising market needs). By rejecting the R + P model, the Town planning board (the TPB) could specify a comprehensive development area to guide the localized land development as well as deny some "inappropriate" development proposals (termed as "master layout plan") prepared by private developers [43]. For example, in January 2021, the proposed master layout plan prepared by SHKP was rejected by the TPB because the proposed development plan "fails to demonstrate the significant planning or design gains to justify proposed relaxation of building height restrictions and breakthroughs in the ridge line from a strategic viewpoint" [44].

For private developers, their alliance with the MTRC has gradually broken down since the real estate crisis in 1997. This crisis has resulted in a wave of privatization of large public facilities and the deregulation of some monopolistic sectors, leading to a power shift towards big property groups and business elites [31]. In 2000, nearly a quarter (23%) of the capital of the MTRC was privatized through public flotation [4]. As a result, the MTRC was required to operate on commercial principles, receiving increasing scrutiny from civil society and the Hong Kong Stock and Security Market (HKSSM); meanwhile, they continued to assume government oversight [4,28,29]. The R + P model has been accused of "making too excessive profits from property development", "not providing enough social housing", and "squeezing small private dwellings out of prime transit areas" [5]. Moreover, the list application in 2004 enabled private developers to freely acquire land from the government with the submission of future development operations, thus shifting their attitude towards the MTRC, from seeing it as an ally to a major competitor in obtaining land grants [31].

5.3. Loss of Power Strength for MTRC: Through Market and Administrative Mechanisms

For its lack of experience in engaging in HSR development, the competence power of the MTRC has seen a decline in the HSR project. The full-line underground design and the dense building foundations surrounding the station have escalated the engineering challenges to this HSR project (Lam Sai-hung, Chief Engineer of Railway Development Office, Hong Kong Highways Department) (See details of the online report at http://www.chkri.hk/seminar/ (accessed on 23 February 2021)). Rising labor costs have jointly led to constant project delays as well as budget overrun. The Entrustment Agreement in 2010 (EA2) specified that the whole project would be completed by August 2015 with a total cost of around HKD 65 billion. In 2014, the MTRC announced that the project would have to be postponed to 2017; in November 2015, the Entrustment Agreement 3 (EA3) revealed that the Hong Kong government would bear a maximum cost of HKD 84.4 billion, the excess being undertaken by the MTRC, except for prescribed expenses in EA2 [39].

The MTRC has also suffered from a legitimate power downsizing through the administrative mechanism. The XRL was co-built and co-operated by the MTRC and mainland operators, with a majority section of the rail line built by mainland ventures. For the implementation of the co-location arrangement (according to the Guangzhou–Shenzhen–Hong Kong Express Rail Link (Co-location) Ordinance (Cap 632), a Co-location arrangement is similar to the Juxtaposed Controls between two states, except that in this case, it is between two separate customs territories within the same sovereign state), the West Kowloon Mainland Port Area was delineated (the Mainland Port Area is the demarcated area on the underground second floor—the arrival level, the underground third floor—the departure level, and the underground fourth floor—the platform level of the West Kowloon HSR station), in which everyone is subject to the law of mainland China. Moreover, the ticket fare was established based on the Chinese Yuan, while the Hong Kong dollar fare would be adjusted monthly according to the prevailing exchange rate [45]. The actual ticket revenues are heavily influenced by the de facto cross-border regulations, which is also beyond the jurisdiction of the transit agency. Overall, the legitimate power held by the MTRC as well as the Hong Kong government was impaired.

The lack of competency and legitimate power have resulted in higher risks associated with the R + P model. Traditionally, in the metro-based R + P model, land size granted for property development is viewed as the key to combating financial risks and to yielding potential profits for the MTRC [29,32]. According to the MTRC [46], in a typical R + P establishment procedure, the government and the MTRC first jointly decide the railway alignment. After that, lifecycle costs and operational incomes are estimated by third-party consultants commissioned by the government, thus deriving a "funding gap" (a funding gap in the Hong Kong R + P practice is the difference between total fixed asset investment in subway construction and the present value of cash flows of subway operation over the next 50 years, where the total fixed asset investment in subway construction is the present value of subway capital investments plus 30% risk premiums, and the present value of cash flows over the next 50 years could be simply viewed as the operation revenues (i.e., farebox revenues, advertising, etc.) minus railway operation costs); the final step is to negotiate on the land parcel sizes granted to the railway company based on a "rule of thumb" approach and under the "optimistic market scenario" [32]. An R + P model will be adopted only when there is an agreement between the government and the MTRC. However, increasing uncertainty in aspects of both cost and profit has made the estimation of funding gaps unlikely.

The loss of induced power of the MTRC is attributed to the collective effects through market and administrative mechanism. The designated West Kowloon station is located very close to the existing city center, with almost 30% of the total population and 50% of the working population concentrated within a 5 km radius [47]. Proximity to the potential passenger market as well as potential destination sites helps to meet the realistic travel demand and transport-sector revenues. However, the central location has pushed up the sunken costs of land acquisition fees, and has thus, by market principles, restricted the room for land development and its benefits for an R + P model. Moreover, because of the vicinity of the nearby West Kowloon cultural district, the planning authority envisages the synergistic effect of a high-level integration of railway and cultural facilities, benefiting the transport, tourism, and hostel sectors, thus branding a new city image. Consequently, high-rise residential development around the station area, which is at the heart of the MTRC's R + P model [28], is believed to contradict quality-based planning objectives, and is forced to give way to office development and green public spaces [47].

6. Summary and Implications

6.1. Summary of Findings

This study has compared different property development practices around HSR station areas by benchmarking with the concept of land value capture, i.e., the rail plus property model. In both Shenzhen and Hong Kong, high-speed rail has been highly valued by planning authorities as a stimulus for sustainable growth and is closely associated with property development activities. However, different stakeholder relations that have emerged with different social and institutional contexts have led to contrasting choices in the application of the LVC to this new railway program.

Shenzhen chooses to upgrade rather than to abandon the R + P model, in which the transit company continues to play the role of a pivotal stakeholder as in a metro-based R + P model (Figure 3). The biggest difference to the prototype model in Hong Kong is that the SZMC operates as a state-owned enterprise, shifting its business focus from profit-making in the real estate industry [29]. The transit agency has received legitimate power and induced power from the local authority to maintain a cooperative power direction with diverse stakeholders, given a complex multi-governmental financing engagement. Plus, it mitigates potential risks from a close, negotiable relationship with local government based on a relatively simple funding principle (Table 2).

In comparison, Hong Kong opts for an alternative model led by the government. The MTRC, as an enterprise listed in the HKSSM, has been substantially privatized, thus being more inclined to operate as a profit-seeking entity, and more sensitive to the potential risks related to HSR construction [4,29]. The political risks and strategic importance of this cross-border transport project has impelled the government to take a more critical view of an MTRC-led model. In addition, the competent power of MTRC has become insufficient in the face of such a financially and technically challenging railway project (Figure 3). To this end, the government has prioritized public goals in terms of railway station placement and overall planning, marginalizing the lucrative real estate development proposals. A public-led model thus stands out.

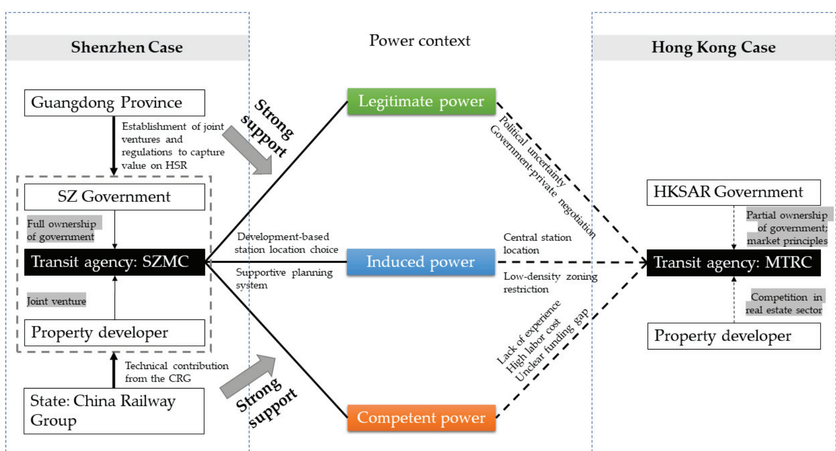


Figure 3. Power relations in the two cases of Shenzhen and Hong Kong, from a transit agency perspective.

Table 2. Comparison of property projects above the HSR stations in Shenzhen North and Hong Kong West Kowloon. Source: authors.

	Shenzhen North Station (HBC Center)	Shenzhen North Station (Huide Tower)	Hong Kong West Kowloon (SHKP-Owned Land Project)
Gross land area (GLA)	2.0 ha	1.9 ha	5.97 ha
Gross floor area (GFA)	14.24 ha	17.35 ha	17.64 ha–29.4 ha
Land development rights transfer	Land equity investment	Land equity investment	Public auction
Floor Area Ratio	7.0	9.0	3.0–5.0
Real estate developer	SZMC plus Vanke	SZMC plus CRG	Sun Hung Kai Properties (SHKP)
Development type	Office, shopping mall	Office, shopping mall, hotel, apartment	Office, shopping mall, hotel (proposed)
Land size grant under R + P	Under a rough guideline in which government makes 50% of the capital contribution using a land equity instrument		Government uses a conservative land grant calculation method

6.2. Policy Outlook for Future Railway Financing

The public transport system, regarded as a form of social good, is calling for an increasing amount of capital investment and a higher-level engagement of private capital. For railway investors, property development on formerly state-owned undeveloped land has been seen as an important source of revenue; a so-called "rail plus property" model represents a financially viable solution for the public capture of increased land value due to public investment [17,31]. However, this property-oriented financing model has been facing increasing challenges as the stock of available land continues to shrink, and land granting and the turning over of zoning power from the public to the transit agencies have incurred general society's suspicion of corruption [9,38,48,49].

A realistic implication for future railway financing is to explore alternative LVC tools and to prepare a flexible LVC menu for a comprehensive decision-making assessment. In the longer term, tax-based instruments (such as property tax) may adapt to the land transfer restriction problem, enabling railway investors to share the economic development fruits of the railway project in the form of higher productivity, property development, and the increase of income [50]. Land adjustment may be another promising policy instrument because it is effective in facilitating large-scale urban redevelopment programs, as certified by successful applications in Japan, Korea, Germany, Spain, and the Netherlands [7].

For the intercity railway program, a reconfiguration of various stakeholders' roles among governments, transit agencies, and real estate developers may be essential in the initial stage. In fact, some innovative institutional moves have been taken. In some cities, new governmental bodies have been established to manage regional transport planning and financing: these agencies work closely with state (in France and the UK), provincial (in Canada), and city (in San Francisco) governments to develop taxation instruments for the LVC [9]. From the perspective of intergovernmental collaboration, the establishment of a new LVC institution is thought to be necessary in carrying out ex-ante assessment and decision-making, to facilitate the engagement of critical stakeholders in mega transport projects such as the HSR, and to reconcile the conflicts of interest among the involved entities [10,23]. In the future, how these institutions will contribute to the implementation of LVC, and how they can obtain and enforce their power through the power relation framework are interesting topics worth continuous academic attention.

Author Contributions: Conceptualization, W.G. and M.K.N.; data curation, W.G.; formal analysis, W.G.; funding acquisition, J.L.; methodology, W.G.; supervision, J.L.; validation, M.K.N.; visualization, W.G. and J.L.; writing—original draft, W.G. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by the United College Endowment Fund Research Grant #CA11307.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Squires, G.; Javed, A.; Trinh, H.H. Housing charges to fund bulk infrastructure: Innovative or traditional? *Reg. Stud. Reg. Sci.* **2021**, *8*, 65–84. [CrossRef]
2. Global Infrastructure Outlook. Oxford Economics. 2017. Available online: https://www.oxfordeconomics.com/recent-releases/Global-Infrastructure-Outlook (accessed on 3 May 2021).
3. Yen, B.T.; Mulley, C.; Zhang, M. Equity in financing public transport infrastructure: Evaluating funding options. *Transp. Policy* **2020**, *95*, 68–77. [CrossRef]
4. Newman, P.; Davies-Slate, S.; Jones, E. The Entrepreneur Rail Model: Funding urban rail through majority private investment in urban regeneration. *Res. Transp. Econom.* **2018**, *67*, 19–28. [CrossRef]
5. He, S.Y.; Tao, S.; Hou, Y.; Jiang, W. Mass Transit Railway, transit-oriented development and spatial justice: The competition for prime residential locations in Hong Kong since the 1980s. *Town Plan. Rev.* **2018**, *89*, 467–493. [CrossRef]
6. Su, S.; Zhang, J.; He, S.; Zhang, H.; Hu, L.; Kang, M. Unraveling the impact of TOD on housing rental prices and implications on spatial planning: A comparative analysis of five Chinese megacities. *Habitat Int.* **2021**, *107*, 102309. [CrossRef]
7. Gielen, D.M. Proposal of land readjustment for the Netherlands: An analysis of its effectiveness from an international perspective. *Cities* **2016**, *53*, 78–86. [CrossRef]
8. Sun, J.; Chen, T.; Cheng, Z.; Wang, C.C.; Ning, X. A financing mode of Urban Rail transit based on land value capture: A case study in Wuhan City. *Transp. Policy* **2017**, *57*, 59–67. [CrossRef]
9. Salon, D.; Shewmake, S. *Opportunities for Value Capture to Fund Public Transport: A Comprehensive Review of the Literature with a Focus on East Asia*; SSRN: Rochester, NY, USA, 2011.
10. Mathur, S. An evaluative framework for examining the use of land value capture to fund public transportation projects. *Land Use Policy* **2019**, *86*, 357–364. [CrossRef]
11. Yin, M.; Bertolini, L.; Duan, J. The effects of the high-speed railway on urban development: International experience and potential implications for China. *Prog. Plan.* **2015**, *98*, 1–52. [CrossRef]
12. Zhang, M.; Xu, J.; Chung, C.K.L. Scalar politics and uneven accessibility to intercity railway in the Pearl River Delta, China. *Ann. Am. Assoc. Geogra.* **2020**, *110*, 1260–1277. [CrossRef]
13. Li, G.; Luan, X.; Yang, J.; Lin, X. Value capture beyond municipalities: Transit-oriented development and inter-city passenger rail investment in China's Pearl River Delta. *J. Transp. Geogra.* **2013**, *33*, 268–277. [CrossRef]
14. Wang, W.; van Noorloos, F.; Spit, T. Stakeholder power relations in Land Value Capture: Comparing public (China) and private (US) dominant regimes. *Land Use Policy* **2020**, *91*, 104357. [CrossRef]
15. Batt, H.W. Value capture as a policy tool in transportation economics: An exploration in public finance in the tradition of Henry George. *Am. J. Econ. Sociol.* **2001**, *60*, 195–228. [CrossRef]
16. Medda, F. Land value capture finance for transport accessibility: A review. *J. Transp. Geogra.* **2012**, *25*, 154–161. [CrossRef]
17. Gielen, D.M.; Salas, I.M.; Cuadrado, J.B. International comparison of the changing dynamics of governance approaches to land development and their results for public value capture. *Cities* **2017**, *71*, 123–134. [CrossRef]
18. Wang, J.; Samsura, D.A.A.; van der Krabben, E. Institutional barriers to financing transit-oriented development in China: Analyzing informal land value capture strategies. *Transp. Policy* **2019**, *82*, 1–10. [CrossRef]
19. Mathur, S. *Innovation in Public Transport Finance: Property Value Capture*; Routledge: Milton Park, UK, 2016.
20. Cascetta, E.; Cartenì, A.; Pagliara, F.; Montanino, M. A new look at planning and designing transportation systems: A decision-making model based on cognitive rationality, stakeholder engagement and quantitative methods. *Transp. Policy* **2015**, *38*, 27–39. [CrossRef]
21. Roukouni, A.; Macharis, C.; Basbas, S.; Stephanis, B.; Mintsis, G. Financing urban transportation infrastructure in a multi-actors environment: The role of value capture. *Eur. Transp. Res. Rev.* **2018**, *10*, 1–19. [CrossRef]
22. Zhao, Z.J.; Das, K.V.; Larson, K. Joint development as a value capture strategy for public transit finance. *J. Transp. Land Use* **2012**, *5*, 5–17. [CrossRef]
23. Suzuki, H.; Murakami, J.; Hong, Y.H.; Tamayose, B. *Financing Transit-Oriented Development with Land Values: Adapting Land Value Capture in Developing Countries*; World Bank Group: Washington, DC, USA, 2015.
24. Zhu, J.; Li, B.; Pawson, H. The end of 'toleration'? Policy ambiguity and converted-housing occupancy in China. *Hous. Stud.* **2019**, *36*, 479–499. [CrossRef]
25. Wilcox, R.K. An introduction to basic mechanics. *Curr. Orthop.* **2006**, *20*, 169–175. [CrossRef]
26. Wrong, D. *Power, its Forms, Bases, and Uses*; Harper and Row Publishers: New York, NY, USA, 1979.
27. Saito, H.; Ruhanen, L. Power in tourism stakeholder collaborations: Power types and power holders. *J. Hosp. Tour. Manag.* **2017**, *31*, 189–196. [CrossRef]

28. Cervero, R.; Murakami, J. Rail and property development in Hong Kong: Experiences and extensions. *Urban Stud.* **2009**, *46*, 2019–2043. [CrossRef]
29. Yang, J.; Zhu, L.; Duan, Y.; Zhou, J.; Ma, H. Developing metro-based accessibility: Three aspects of China's Rail + Property practice. *Transp. Res. Part D Transp. Environ.* **2020**, *81*, 102288. [CrossRef]
30. Tang, B.S.; Chiang, Y.H.; Baldwin, A.N.; Yeung, C.W. *Study of the Integrated Rail-Property Development Model in Hong Kong*; Hong Kong Polytechnic University: Hong Kong, 2004.
31. Aveline-Dubach, N.; Blandeau, G. The political economy of transit value capture: The changing business model of the MTRC in Hong Kong. *Urban Stud.* **2019**, *56*, 3415–3431. [CrossRef]
32. Xue, L.; Fang, W. *Rail Plus Property Development in China: The Pilot Case of Shenzhen*; World Resource Institute: Washington, DC, USA, 2017.
33. Hui, E.C.M.; Ho, V.S.M.; Ho, D.K.H. Land value capture mechanisms in Hong Kong and Singapore: A comparative analysis. *J. Prop. Invest. Financ.* **2004**, *22*, 76–100.
34. SZMC 2019 Annual Report. Available online: https://www.szmc.net/jituagaikuang/touzizheguanxi/niandubaogao/ (accessed on 11 December 2020).
35. SZMC 2020 Corporate Bond Credit Rating Report. Available online: https://pdf.dfcfw.com/pdf/H2_AN202008061396793269_1.pdf?1596743308000.pdf (accessed on 26 January 2021).
36. Shenzhen Housing and Construction Bureau. Available online: http://zjj.sz.gov.cn/ztfw/zfbz/fpdx/fpcfpdx/content/post_3637608.html (accessed on 11 August 2021).
37. China Railway Group Limited, 2020 Annual Report. Available online: http://www.crecg.com/web/10089513/10090854/89ec0484/index10.html (accessed on 10 July 2021).
38. Cervero, R. *Transit-Oriented Development in the United States: Experiences, Challenges, and Prospects*; Transportation Research Board: Washington, DC, USA, 2004.
39. Report of the Hong Kong Section of the Guangzhou-Shenzhen-Hong Kong Express Rail Link. Independent Expert Panel: 2014. Available online: https://www.gov.hk/en/theme/iep-xrl/pdf/IEP-report.pdf (accessed on 8 September 2021).
40. MTRC 2019 Annual Report. Available online: https://www.mtr.com.hk/ch/corporate/investor/ (accessed on 4 February 2021).
41. SHKP News 2019. Available online: https://www.shkp.com/en-US/media/press-releases/shkp-wins-tender-for-commercial-site-atop-high-speed-rail-west-kowloon-station (accessed on 4 February 2021).
42. Bao, H.X.; Mok, D.K.C. A link between east and west: How the Guangzhou–Shenzhen–Hong Kong Express Rail Link affects property prices in Hong Kong. *Int. Real Estate Rev.* **2020**, *23*, 993–1021. [CrossRef]
43. Town Planning Board, HKSAR. Available online: https://www.elegislation.gov.hk/hk/cap131 (accessed on 17 October 2020).
44. SCMP News 2021. Available online: https://www.scmp.com/business/article/3126335/sun-hung-kai-properties-amend-west-kowloon-plan-after-town-planning-board?module=perpetual_scroll&pgtype=article&campaign=3126335 (accessed on 8 September 2021).
45. Hong Kong Legislative Council Committee. *Regarding Matters Concerning the Operation of the Hong Kong Section of the Guangzhou-Shenzhen-Hong Kong High-Speed Railway*; Hong Kong Legislative Council Committee: Hong Kong, 2018.
46. MTRC. *MTRC 2000 Report—Hong Kong SAR Government MTR Privatisation Share Offer Prospectus, 25 September*; MTRC: Hong Kong, 2020.
47. Hong Kong Legislative Council Committee. *Station Location Selection and Supporting Facilities of Hong Kong West Kowloon Station*; Hong Kong Legislative Council Committee: Hong Kong, 2009.
48. Zhu, J.; Tang, W. Conflict and compromise in planning decision-making: How does a Chinese local government negotiate its construction land quota with higher-level governments? *Environ. Urban.* **2018**, *3*, 155–174. [CrossRef]
49. Zhu, J.; Li, B.; He, B.J. Is linked migration overlooked in peri-urban Shanghai? Uncovering the domino effect of driving away interregional migrants. *Habitat Int.* **2019**, *94*, 102046. [CrossRef]
50. Yoshino, N.; Helble, M.; Abidhadjaev, U. *Financing Infrastructure in Asia and the Pacific: Capturing Impacts and New Sources*; Asian Development Bank Institute: Tokyo, Japan, 2018.

sustainability

Article

Profiling Residents' Mobility with Grid-Aggregated Mobile Phone Trace Data Using Chengdu as the Case

Xuesong Gao [1], Hui Wang [2,*] and Lun Liu [3]

[1] College of Resources, Sichuan Agricultural University, Chengdu 611130, China; Gxs80@126.com
[2] School of Architecture, Tsinghua University, Beijing 100084, China
[3] School of Government, Peking University, Beijing 100871, China; liu.lun@pku.edu.cn
* Correspondence: wh-sa@mail.tsinghua.edu.cn

Abstract: People's movement trace harvested from mobile phone signals has become an important new data source for studying human behavior and related socioeconomic topics in social science. With growing concern about privacy leakage of big data, mobile phone data holders now tend to provide aggregate-level mobility data instead of individual-level data. However, most algorithms for measuring mobility are based on individual-level data—how the existing mobility algorithms can be properly transformed to apply on aggregate-level data remains undiscussed. This paper explores the transformation of individual data-based mobility metrics to fit with grid-aggregate data. Fifteen candidate metrics measuring five indicators of mobility are proposed and the most suitable one for each indicator is selected. Future research about aggregate-level mobility data may refer to our analysis to assist in the selection of suitable mobility metrics.

Keywords: mobile phone data; aggregate data; mobility indicator; travel frequency; travel range

Citation: Gao, X.; Wang, H.; Liu, L. Profiling Residents' Mobility with Grid-Aggregated Mobile Phone Trace Data Using Chengdu as the Case. *Sustainability* **2021**, *13*, 13713. https://doi.org/10.3390/su132413713

Academic Editors: Mengqiu Cao, Claire Papaix, Tianren Yang and Benjamin Büttner

Received: 23 October 2021
Accepted: 1 December 2021
Published: 12 December 2021

1. Introduction

With the proliferation of mobile phone use in recent years, it has become possible to track the movements of people through mobile phone signals so that human behavior and a range of social issues can be better understood. This data presents a major new source for urban studies in the era of big data [1,2]. While the individual-level mobility trace has facilitated a number of groundbreaking studies [3–5], growing concerns about privacy are discouraging the distribution of individual-level mobile phone trace data. Instead, most data holders are now distributing mobile phone trace data aggregated to grids or administrative units so that user privacy can be better protected. Such a trend presents researchers with the challenge of effectively analyzing people's travel behavior and related social issues with aggregated mobility data.

Human mobility patterns are an important aspect of the socioeconomic system, and studying them could yield important insights into many socioeconomic issues. In the past, studies of mobility patterns were mainly based on travel surveys [6,7] or global positioning system data produced by a small sample of carriers [8,9]. The wide use of mobile phones provides a powerful source of data for collecting large amounts of individual tracking information for studying the whereabouts of people over space and time. The data are wide coverage, being retrieved from all mobile phone users in a given area, and can be harvested over a long period for more reliable results. This new data source has been used by many studies about understanding human mobility patterns [10,11].

However, recent studies have shown that even anonymous mobile phone trace data poses a serious threat to personal privacy. De Montjoye et al. [12] conclude that four spatio-temporal points are enough to uniquely identify 95% of individuals. Xu et al. [13] show that an attack system is able to recover users' trajectories with an accuracy of 73–91% at a scale of tens of thousands to hundreds of thousands users. As an emerging trend, researchers are proposing using aggregate information about people's mobility [14].

Our work therefore aims to explore the effective transformation of individual-based mobility metrics to suit aggregate data so that meaningful mobility and social indicators can be extracted. Many indicators and metrics for measuring mobility have been developed at the individual level [10,15,16], but how relevant information could be represented when only aggregate mobility data are available remains undiscussed. This work would be informative for future research using aggregate mobile phone data in urban studies and other social sciences.

In this study, we develop our aggregate-level mobility metrics based on the grid-aggregate data provided by China Unicom, one of the largest mobile phone service providers in China. In this data set, all mobility information is provided at the grid level (the size could range between hundreds to a thousand meters), including hourly flow between grids, the home grids of travelers travelling between any two grids, etc. We use Chengdu, China, as the case study. Specifically, we use the mobility data of the residents living outside the central city of Chengdu and apply our grid-based metrics to evaluate the mobility patterns and well-being of residents in suburbs and rural areas. Therefore, the contribution of this work is two-fold. First, we develop a series of metrics for the analysis of grid-level mobility data, so that similarly meaningful mobility analysis can be conducted with grid-level data as it can be with individual-level data. Second, using the methods developed, we examine the mobility patterns of residents in city suburbs and rural areas surrounding a large Chinese city, which to date has been seldom studied.

The rest of the paper is divided into five parts. Section 2 reviews related work. Section 3 introduces the data and methodology, including the basic information about the study area, the data set and the candidate aggregate-level mobility metrics. Section 4 presents a comparison of candidate metrics and an analysis of mobility patterns in the study area. Section 5 discusses the findings and Section 6 concludes.

2. Related Work

2.1. Characterizing Human Mobility

The term human mobility encompasses many aspects of travel behavior, which helps operationalize the concept. The measurement and analysis of key aspects of human mobility is a fundamental component of travel research. Key aspects considered by previous research include travel frequency [15,17,18], travel distance [17,19,20], destination choice [17,21,22] and travel mode [17,23]. These aspects of mobility have been at the center of travel behavior modelling (e.g., activity-based modelling) and the analysis of related social issues such as social inequality, energy use, and health [24–26].

Another strand of relevant research follows the paradigm of complexity science and explores universal laws of human mobility. Similar aspects of human mobility are at the center of analysis in these studies. For example, the classic gravity model sets up a law that explains the frequency of travel with the distance between the origin and destination [27]. A more recent model explaining human mobility (the exploration and preferential return model) focuses on an individual's choice of travel destinations and the resulting distribution of destinations [28]. The most recent *Nature* publication in this field explores the distribution of mobility flows to a location in relation with visitors' home distance from the location and the frequency of visits [4]. A slightly earlier work in *Nature* explores the relationship between the probability of visiting a location and the distance between locations [29]. The above-mentioned studies suggest that travel frequency, distance and destination distribution, among others, are commonly analyzed key aspects of human mobility.

It should be noted that these characteristics can be analyzed in terms of both entire travel profiles (one day or multi-day) and individuals' trajectories. For example, in terms of travel distance, some studies analyze the space covered by the destinations visited by a person in a certain period [20], while some deal with the distance of individual trips in a trajectory [30]. Based on the continuous trajectory of individuals, some studies also explore a trajectory-based characterization of daily mobility, namely mobility motif. For example, Jiang et al. [11] studied the daily motifs derived from mobile phone trajectories in Singapore. While both approaches could help reveal informative patterns of mobility, the latter is not supported by depersonalized grid-aggregate mobility data, since the information about an individual's consecutive travel trajectory is lost in the aggregation process.

2.2. Related Metrics in Existing Studies

To more concretely characterize the key aspects of mobility, a number of metrics have been employed by existing studies. In a comprehensive review of studies of mobile phone data, Wang et al. [10] identified four commonly used indicators of mobility, which are displacement of trips, radius of gyration of travel destinations, Shannon's entropy of destinations and eccentricity of the shape of destination distribution. In a work examining the robustness of mobility measurement, Zhao et al. [19] employed a similar set of mobility metrics, including daily travel frequency, radius of gyration, entropy index and eccentricity index. When studying the relationship between mobility and socioeconomic status, Xu et al. [20] used five metrics of mobility, namely radius of gyration, k-radius of gyration, number of destinations, origin-destination diversity and unicity (uniqueness of destination). Similar metrics are also applied in Yuan and Raubal [16] (radius, approximated ellipse shape and Shannon's entropy index of individuals' travel destinations), Xu et al. [15] (frequency of movements, daily activity range and number of activity anchor points) and other research.

In recent studies, metrics of human mobility are also applied to understand the response to COVID-19 and other disasters. Pan et al. [18] developed a composite index measuring the level of mobility behavior during COVID-19, composed of five specific metrics: percentage of residents staying home, daily work trips per person, daily non-work trips per person, distances travelled per person and out-of-county trips. Chan et al. [31] used the number of visits to different places to represent mobility in COVID-19. El Shoghri et al. [32] focused on radius of gyration to analyze how mobility patterns drive disease spread. In addition, in a study on hurricane impact, Ahmouda et al. [33] analyzed changes in trip distance, trip counts in different distance bands and radius of gyration.

The key aspects of human mobility and commonly used metrics are summarized in Table 1. All the studies reviewed conduct relevant research on individual-level mobility data, so it remains unclear how these metrics could be transformed to suit grid-aggregate mobility data in a time of growing privacy concerns. We will fill in this gap by proposing candidate metric transformations, testing these metrics on our dataset and discussing the theoretical and technical appropriateness of the transformed metrics.

Table 1. Summary of key aspects and common metrics of human mobility.

Type	Aspect	Common Metrics
Wholistic	Frequency	Trip number Trip number by purpose
	Destination distribution	Number of destinations Entropy of destinations
	Spatial range	Radius of gyration Eccentricity of shape
Trajectory	Not applicable for grid-aggregate data	

3. Methodology

3.1. Study Area and Data

We chose Chengdu city as the case study, which is the largest city in southwest China. It should be noted that the city refers to the administrative area composed of a central city and surrounding areas, the latter of which are further composed of a system of towns, villages and farmland. The city extends across an area of 14,335 square kilometers, 95.4% of which is rural. The total population was 16 million in 2017 when the data was collected, with 5.8 million of this population living in rural areas [34]. Chengdu is an interesting case for analysis as it is a mixture of urban, suburban and rural contexts, so diverse mobility patterns might be revealed through the analysis.

We used mobile phone trace data collected between 12 and 18 April 2017 from China Unicom. One may doubt whether the usage of mobile phones is wide enough outside the central city to collect meaningful data, but due to the availability of low-price devices and the government's infrastructure investments, the proportion of mobile phone users had reached 83% and the mobile phone signal coverage was 95% even in rural Chengdu when the data was collected [35]. Since the estimation of position based on mobile phone signals is not always accurate [36], especially in areas where signal towers are sparse, the positions were estimated into grids of one square kilometers (1 km × 1 km, 14,856 in total). We focused on the 14,209 grids outside the central city.

For each mobile phone user in the records, a grid cell was identified as the home place if this was where the user stayed for the longest time between 21:00 and 7:00 throughout the study period and the user goes there on more than three days. Phone users with homes in the non-central city grids were thus included in our analysis. A total number of 0.97 million non-central city residents were identified.

As mentioned in the introduction, we only acquired the aggregate sum of the hourly flow between grids and the home grids of the movers, instead of individual users' moving trajectories. Moreover, counts less than five were removed to further protect privacy; if there were less than five people who lived in grid A and moved from grid B to C in a certain hour, these movement records were omitted from our dataset. A total of 1.98 million movements were identified throughout the study period (a week). 60% of the identified movements were within the same grid on weekdays and 76% are within the same grid on weekends.

3.2. Candidate Aggregate-Level Mobility Metrics

The candidate aggregate-level metrics were transformed from the commonly used metrics identified in Table 1. Among those metrics, trip number by purpose was difficult to analyze with grid-aggregate mobile phone data since trip purpose was not directly available and could not be inferred without individuals' spatio-temporal trajectory. Therefore, we were left with five mobility metrics to be transformed. For each metric, we started from the simplest transformation and then added more elements to increase theoretical appropriateness and reduce potential bias. The original formula and candidate transformations are explained below.

3.2.1. Frequency

The frequency of travel was measured as the number of movements made by a person in a given time when using individual-level data, which was a relatively straightforward process [15]. The simplest transformation is to calculate the total number of movements made by all the residents of a grid. However, the total number of movements is likely to be correlated with the population in a grid, especially when there are significant differences in grid population size. To account for this, there could be a second metric that divides the total number of movements with a formula of the grid population. The formula could be a linear, logarithm or exponential transformation of population, corresponding to linear, decreasing or increasing movements of population, which needs to be examined with empirical data.

$$\text{Trip number metrics 1: } N_M \quad (1)$$

$$\text{Trip number metrics 2: } N_M/f(P) \quad (2)$$

where N_M denotes the movements made by the residents of a grid and P denotes the population of a grid.

3.2.2. Destination Distribution

In the two commonly used metrics for destination distribution in Table 1, the number of destinations measured the diversity of destinations visited by an individual, and the entropy of destinations measured whether one's activities were evenly distributed among all destinations or concentrated on a few destinations, in other words the regularity of visits [10]. The transformation for the destination number metrics is similar to that of the frequency metrics. Two candidate transformations are proposed. The first is simply taking the number of different locations visited by the residents of a grid; the second is normalizing this with a formula of grid population. The normalization factor, if necessary, may be different from that of the frequency metrics, which also needs to be examined with empirical data.

$$\text{Destination diversity metric 1: } N_D \quad (3)$$

$$\text{Destination diversity metric 2: } N_D/f(P) \quad (4)$$

where N_D denotes the number of distinct destinations visited by the residents of a grid and P denotes the population of a grid.

When using individual-level data, the Shannon's entropy of destinations is computed as follows: $-\sum_{i=1}^{N_D} p_i log_2 p_i$, where p_i is the probability that destination i is visited by an individual, and N_D stands for the total number of distinct destinations i [10]. When most visits are concentrated at one location, the entropy index is close to 0; and when visits are evenly distributed among all locations, the entropy index is equal to $log_2 N_D$, the highest possible value of this index. The direct transformation of this metric is to replace p_i as the percentage of visits to destination i made by the residents of a grid and N_D as the total number of destinations visited by grid residents. Further, the entropy index is also likely to correlate with grid population and the number of destinations (considering that the maximum value varies with N_D). Therefore, we will examine the correlation and identify the appropriate factor to normalize the entropy value.

$$\text{Destination regularity metrics 1: } -\sum_{i=1}^{N_D} p_i log_2 p_i \quad (5)$$

$$\text{Destination regularity metrics 2: } -\sum_{i=1}^{N_D} p_i log_2 p_i / f(P) \quad (6)$$

$$\text{Destination regularity metrics 3: } -\sum_{i=1}^{N_D} p_i log_2 p_i / f(N_D) \quad (7)$$

3.2.3. Spatial Range

The two metrics for spatial range in Table 1 measure the size and shape of the space covered by daily travel. The size of the travel space is usually measured by the radius of gyration, which refers to the root mean squared distance between each staying location in an individual's trajectory and the center of mass of the trajectory, expressed as:

$$r_g = \sqrt{\frac{\sum_{i=1}^{N_D} \left(\vec{r}_i - \vec{r}_{cm}\right)^2}{N_D}} \quad (8)$$

where $\vec{r}_i$ denotes the $i = 1, \ldots, N_D$ positions recorded for an individual and $\vec{r}_{cm} = 1/N_D \sum_{i=1}^{N_D} \vec{r}_i$ is the center of mass of the trajectory [3,19]. Some studies also propose using the axes of standard deviational ellipse for this purpose, which refers to the mean of the semi-major and semi-minor axes of the approximated ellipse of an individual's daily movement [16]. For the two individual-level metrics, we propose three transformations. The first is a direct transformation by replacing the staying locations in an individual's trajectory with all the locations visited by the residents of a grid. However, the locations may receive different numbers of visits, which may not show in an individual's one-day travel record but could be prominent in aggregate data. Therefore, the second transformation considers the number of visits received by each location and computes the weighted radius of gyration and the axes of weighted deviational ellipse. Furthermore, the space covered by residents' movements may also increase with grid population. Hence, the third transformation involves a normalization with grid population as used for previous metrics.

Space size metrics 1: same as Formula (8)

$$\text{Space size metrics 2: } \sqrt{\frac{\sum_{i=1}^{N_D} v_i \left(\vec{r}_i - \vec{r}_{cm}^{\,w}\right)^2}{\sum_{i=1}^{N_D} v_i}} \tag{9}$$

$$\text{Space size metrics 3: } \sqrt{\frac{\sum_{i=1}^{N_D} \left(\vec{r}_i - \vec{r}_{cm}\right)^2}{N_D}} / f(P) \tag{10}$$

$$\text{Space size metrics 4: } (l_a + l_b)/2 \tag{11}$$

$$\text{Space size metrics 5: } (l_a^w + l_b^w)/2 \tag{12}$$

$$\text{Space size metrics 6: } (l_a + l_b)/2 \times f(P) \tag{13}$$

where $\vec{r}_i$ denotes the locations visited by the residents of a grid; $\vec{r}_{cm}$ and $\vec{r}_{cm}^{\,w}$ denote the center of mass of the locations and the center of mass weighted by the number of visits; v_i denotes the number of visits to location i; l_a and l_b are the lengths of the major and minor axes of the standard deviational ellipse covering all locations visited by grid residents; ${l_a}^w$ and ${l_b}^w$ are the lengths of the axes of the weighted standard deviational ellipse. l_a, l_b, ${l_a}^w$ and ${l_b}^w$ are computed with the R package "aspace".

The eccentricity of shape measures how much the travel space deviates from a circle, showing whether trips are evenly distributed in each direction or tend to be longer in certain direction. It is defined as

$$e = \sqrt{1 - (l_a/l_b)^2} \tag{14}$$

where l_a and l_b are the lengths of the major and minor axes of the standard deviational ellipse covering all locations visited by grid residents [16]. However, at least three destination grids are needed to derive non-zero l_a and l_b, while in our data, 53% of the grids do not meet the criteria, which is also likely to be a problem for other grid-aggregate data. In light of this, we propose two alternative metrics which serve similar purpose but are not constrained by the number of destination grids:

Space shape metrics 1: direction from a grid to the centroid of all destination grids

Space shape metrics 2: direction from a grid to the weighted centroid of all destination grids

The directions are measured in relation to north and range between 0 and 359 degrees, showing the dominant direction of the trips generated from a grid.

4. Results

4.1. Frequency

The total number of movements observed for the residents of each grid were strongly correlated with the population of the grid and the relationship appears to be linear (Figure 1). After normalizing the number of movements with grid population, their correlation was evidenced to be small (Table 2). Therefore, the second algorithm ($N_M/f(P)$) is more appropriate for analyzing travel frequency using grid-aggregate data.

The analysis result for the travel frequency of suburban and rural residents in Chengdu is as follows. For the grids that are identified with any movements of residents, the average number of daily trips was 1.27 per person on weekdays. The spatial distribution of the travel frequency shows a highly mixed pattern, with multiple dark "hot spots" all around the region (Figure 2). Some of these active areas are located around the central city and some are at town centers, while there are also some "hot spots" far away from the central city.

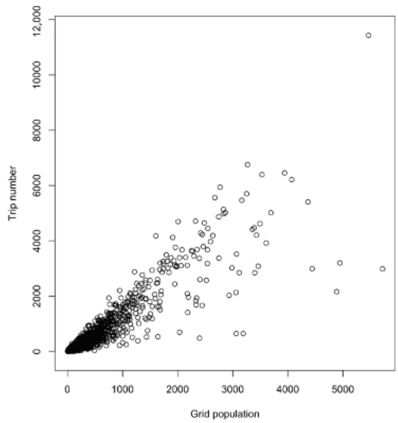


Figure 1. Relationship between grid population and trip number.

Table 2. Correlation between results of candidate metrics on frequency.

	N_M	N_M/P	P
N_M	-	0.31 ($p < 0.01$)	0.80 ($p < 0.01$)
N_M/P	-	-	0.11 ($p < 0.01$)

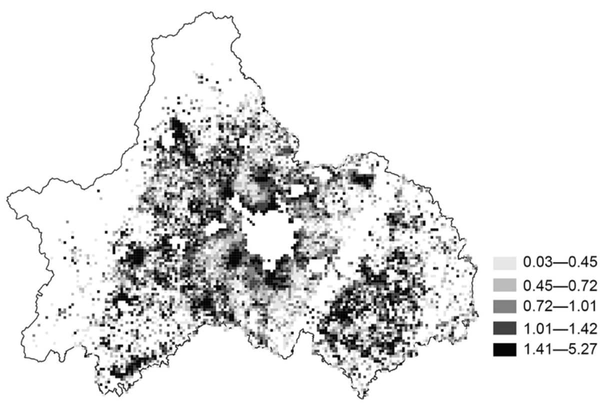


Figure 2. Analysis result: frequency of travel.

4.2. Destination Distribution

Of the two indicators for destination distribution, diversity was also strongly correlated with the population of a grid and the correlation appears to be linear (Figure 3 and Table 3). Therefore, researchers should also normalize this metric with grid population when using grid-aggregate data (choosing destination diversity metric 2). The entropy index shows a log-normal relationship with grid population and correlates strongly with $log_2 N_D$ since mathematically it is the maximum value of the entropy index (Figure 4 and Table 3). The entropy index needs to be normalized with $log_2 N_D$ to provide more reasonable comparison among grids (choosing destination regularity metric 3). After excluding the size effects, the frequency, diversity and regularity are only very weakly correlated (Pearson's $r < 0.2$), suggesting that the three indicators bear different information about residents' mobility.

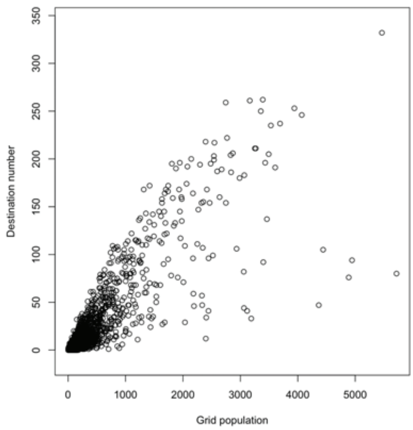


Figure 3. Relationship between grid population and destination number.

Table 3. Correlation between results of candidate algorithms on diversity and randomness.

	Destination Diversity				Destination Regularity		
	N_D	N_D/P	P		Shannon's entropy	Shannon's entropy/log_2N_D	log_2N_D
N_D	-	0.01 (p = 0.50)	0.83 ($p < 0.01$)	Shannon's entropy	-	0.05 (p = 0.40)	0.80 ($p < 0.01$)
N_D/P	-	-	−0.10 ($p < 0.01$)	Shannon's entropy/log_2N_D	-	-	0.02 ($p < 0.01$)

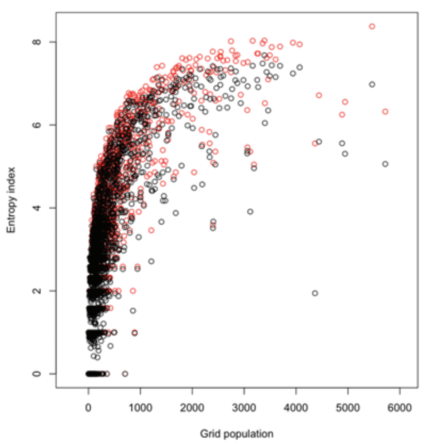


Figure 4. Relationship between grid population, entropy index and destination number. (black: entropy index, red: log_2N_D).

The analysis results of our study area are presented in Figure 5. Different from the pattern of travel frequency, diversity of travel destination was generally higher around the central city. This could be because there are many more locations in the central city providing jobs, products and services within an accessible distance so that the residents in the same grid are likely to visit more places. Residents in more suburban or rural areas do not have as many choices. The randomness indicator generally takes a high value (mean = 0.97), suggesting that there is no significant difference in the number of visits to different activity locations associated with each home grid.

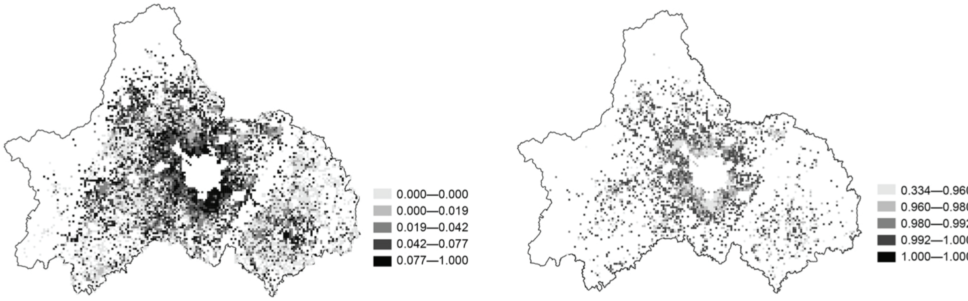


Figure 5. Analysis result: diversity and regularity of travel destinations. (**left**: diversity, **right**: randomness).

4.3. Spatial Range

We first examined the outputs of space size metrics 1, 2, 4 and 5, which were not normalized by grid population. The outputs of metric 1 (unweighted radius of gyration), metric 2 (weighted radius of gyration), and metric 4 (mean axis length of the unweighted standard deviational ellipse) were highly correlated with each other (Pearson's r = 0.80–1, Table 4). The mean axis length of the weighted ellipse of travel destination was the least similar to the other metrics (lowest Pearson's r = 0.16) since it measured only the dispersion of activity locations. Nonetheless, it was still highly correlated with the output of metrics 1. Further, all the metrics were lowly correlated with grid population, suggesting that the spatial extent of residents' activities does not increase with resident numbers and population normalization is not necessary (Figure 6). Among the four metrics, the output of metric 1 is both technically the simplest and highly correlated with all other four algorithms, and thus encompasses most information produced by other metrics. Therefore, we recommend metric 1, the standard radius of gyration of all destinations visited by the residents of a grid, as the most appropriate metric for measuring the size of travel space with grid-aggregate data.

Table 4. Correlation between results of candidate algorithms on range.

	Metrics 1	**Metrics 2**	**Metrics 4**	**Metrics 5**	***P***
Metrics 1	-	0.99 ($p < 0.01$)	0.79 ($p < 0.01$)	0.77 ($p < 0.01$)	0.11 ($p < 0.01$)
Metrics 2	-	-	0.94 ($p < 0.01$)	0.21 ($p < 0.01$)	0.09 ($p < 0.01$)
Metrics 4	-	-	-	0.16 ($p < 0.01$)	0 ($p = 0.95$)
Metrics 5	-	-	-	-	0.27 ($p < 0.01$)

Note: Metrics 3 and 6 are not included since the results are lowly correlated with grid population.

Regarding the two metrics for the shape of travel space, the outputs are again highly correlated (Pearson's r = 0.90), suggesting that the weighted and unweighted center of the destinations do not deviate much from each other. Since the first metric (direction from a grid to the unweighted center of all destination grids) is technically simpler, we consider it preferable.

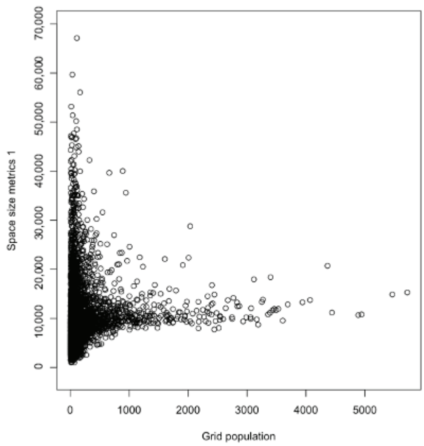


Figure 6. Relationship between grid population and output of metric 1.

In our study area, the average value of the spatial range of mobility in all grids was 6.40 km on weekdays. For the grids that were identified with at least one travel destination outside the grid (67%), the average value of mobility range was 9.63 km. In terms of the spatial pattern, the areas surrounding the central city showed a uniform pattern of medium mobility ranges, while the areas farther away from the central city are highly mixed with large and small values of mobility ranges (Figure 3). The analysis of the shape of travel space shows that the movements in a large proportion of the grids around the central city and the county centers are directed towards these urban areas and the central city (Figure 7). The directions of the grids farther away from the city are more varied and irregular.

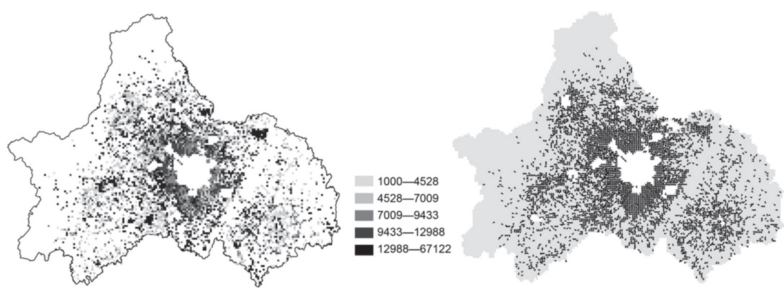


Figure 7. Analysis result: size and shape of travel space.

5. Discussion

This work explored the transformation of human mobility metrics on individual-level data to be used with grid-aggregate data. After identifying key aspects and common metrics for measuring individual mobility in existing studies, we proposed fifteen metrics for grid-aggregate data and compare their outputs with our data set. The proper transformation of mobility metrics involves the following methodological issues: (1) how travel frequency, destination diversity, regularity and space size change with the number of people being aggregated; (2) whether there are new factors that need to be considered with group mobility data and how much they impact the measurement; and (3) whether the reduction of spatial resolution by grids hinders the measurement of certain mobility aspects.

The experiment with our data set provides evidence to address the above issues. In terms of the relationship between group size and the mobility indicators, we found that travel numbers and destination numbers increased linearly with group size, the entropy index (regularity) increased linearly with the logarithm of destination number (and group size), yet the size of the space travelled barely changed with group size. While the trend of change in travel frequency and entropy index was consistent with theoretical deduction, the change in destination number and space size was interesting. It is reasonable to suppose that people living in the same grid would visit similar destinations (shops, restaurants, etc.), so the number of destinations visited would not increase significantly with grid population. Nonetheless, our results suggest a linearly increasing relationship, which may be explained by the high diversity of job locations. It is also reasonable to suppose that the size of a travel space would increase with grid population, since there would be a higher chance of observing people making long trips. Our results again suggest the opposite, which is consistent with some previous findings on individual mobility that one's travel space becomes stable after being recorded for certain amounts of time [3]. Therefore, these findings may reflect underlying laws of human mobility.

The weight of destinations in computing the travel space size is an additional factor that needs to be considered. When analyzing individuals' one-day travel records, it is common that each destination is visited only once, so there is no need to consider the weight of each destination. For group-level travel records, the destinations might be visited a different number of times, so it is reasonable to take the visit numbers into consideration. However, our results suggest that the unweighted radius of gyration is able to encompass most information in other more complex metrics. In other words, the weights of destinations do not need to be a major consideration when measuring group-level mobility patterns.

Regarding the third issue, we find that there is not much difference in the regularity indicator (entropy index of the number of destination visits) across the grids in our study area. This might be because the irregularity in an individual's mobility is averaged out in group-level data. Therefore, measuring irregularity of travel is not particularly meaningful when using group-level mobility data.

The application of these metrics on the data from Chengdu demonstrates that group-level mobility data, when analyzed with the proposed metrics, are able to reveal meaningful spatial patterns in people's mobility. For example, the analysis results reveal clear differences in travel frequency, destination diversity and size of travel space across the study area. The patterns pose further questions about the factors that influence these aspects of residents' mobility, which, though beyond the scope of the mobility algorithms proposed in this paper, need to be analyzed upon the results acquired from the mobility algorithms.

These mobility metrics are limited in probing the social well-being related to daily travel. Among the five mobility indicators, we can only deduce that high diversity of travel destinations suggests a rich choice of places within reach that are suitable for activities, which could be considered a condition of well-being. However, the relationship between other mobility indicators and social well-being is not completely clear. For example, a large travel space might indicate that roads and vehicles are easily accessible, while it may also indicate low opportunity accessibility, which means that people need to travel a far distance to fulfill their needs. Therefore, surveys would be needed to understand how certain mobility indicators relate to the social well-being of residents, which may also vary across regions and countries [20].

6. Conclusions

This paper explores the transformation of individual-level mobility metrics to work with grid-aggregate mobility data in response to growing concerns about privacy leakage through mobility data. We identify three key aspects of human mobility analyzed by existing studies, which are travel frequency, destination distribution and spatial range of travel, and five common metrics for measuring these aspects. Developing from the commonly used individual-level metrics, we propose fifteen candidate metrics to fit with grid-aggregate data. Based on theoretical soundness and technical costs, we identify the most appropriate transformation for each of the five metrics, which are: (1) number of movements made by all residents of a grid divided by resident number for measuring travel frequency, (2) number of distinct locations visited by all residents of a grid divided by resident number for measuring destination diversity, (3) Shannon's entropy of all the locations visited by the residents of a grid divided by the logarithm of the location number for measuring travel regularity, (4) unweighted radius of gyration of all the trips made by the residents of a grid for measuring the size of travel space and (5) direction from a grid to the center of all the locations visited by residents for measuring the shape of travel space. These metrics are able to encompass most of the information captured by other candidate metrics, and are relatively easy to implement. Further, through our empirical data, we provide evidence of three major methodological issues in developing group-level mobility metrics, which reflects some general rules of human mobility. Future research using grid-aggregate mobility data could refer to these recommended metrics to profile people's mobility patterns without relying on highly privacy-sensitive individual-level data.

Author Contributions: Conceptualization, X.G.; methodology, X.G., L.L.; writing—original draft preparation, X.G., H.W.; writing—review and editing, X.G., H.W., L.L.; funding acquisition, H.W. All authors have read and agreed to the published version of the manuscript.

Funding: This study is funded by the National Natural Science Foundation of China (52008005) and Tsinghua-Toyota Joint Research Institute Cross-discipline Program.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Jiang, S.; Fiore, G.A.; Yang, Y.; Ferreira, J., Jr.; Frazzoli, E.; González, M.C. A review of urban computing for mobile phone traces: Current methods, challenges and opportunities. In Proceedings of the 2nd ACM SIGKDD international workshop on Urban Computing, Chicago, IL, USA, 11 August 2013.
2. Calabrese, F.; Ferrari, L.; Blondel, V.D. Urban Sensing Using Mobile Phone Network Data: A Survey of Research. *ACM Comput. Surv.* **2015**, *47*, 1–20. [CrossRef]
3. González, M.C.; Hidalgo, C.A.; Barabási, A.-L. Understanding individual human mobility patterns. *Nat. Cell Biol.* **2008**, *453*, 779–782. [CrossRef]
4. Schläpfer, M.; Dong, L.; O'Keeffe, K.; Santi, P.; Szell, M.; Salat, H.; Anklesaria, S.; Vazifeh, M.; Ratti, C.; West, G.B. The universal visitation law of human mobility. *Nat. Cell Biol.* **2021**, *593*, 522–527. [CrossRef] [PubMed]
5. Calabrese, F.; Diao, M.; Di Lorenzo, G.; Ferreira, J.; Ratti, C. Understanding individual mobility patterns from urban sensing data: A mobile phone trace example. *Transp. Res. Part C Emerg. Technol.* **2013**, *26*, 301–313. [CrossRef]
6. Dijst, M. Two-earner families and their action spaces: A case study of two dutch communities. *GeoJournal* **1999**, *48*, 195–206. [CrossRef]
7. Chen, J.; Shaw, S.-L.; Yu, H.; Lu, F.; Chai, Y.; Jia, Q. Exploratory data analysis of activity diary data: A space–time GIS approach. *J. Transp. Geogr.* **2011**, *19*, 394–404. [CrossRef]
8. Shoval, N.; Isaacson, M. Sequence Alignment as a Method for Human Activity Analysis in Space and Time. *Ann. Assoc. Am. Geogr.* **2007**, *97*, 282–297. [CrossRef]
9. Shen, Y.; Kwan, M.-P.; Chai, Y. Investigating commuting flexibility with GPS data and 3D geovisualization: A case study of Beijing, China. *J. Transp. Geogr.* **2013**, *32*, 1–11. [CrossRef]
10. Wang, Z.; He, S.; Leung, Y. Applying mobile phone data to travel behaviour research: A literature review. *Travel Behav. Soc.* **2018**, *11*, 141–155. [CrossRef]
11. Jiang, S.; Ferreira, J.; Gonzalez, M.C. Activity-Based Human Mobility Patterns Inferred from Mobile Phone Data: A Case Study of Singapore. *IEEE Trans. Big Data* **2017**, *3*, 208–219. [CrossRef]
12. De Montjoye, Y.-A.; Hidalgo, C.; Verleysen, M.; Blondel, V.D. Unique in the Crowd: The privacy bounds of human mobility. *Sci. Rep.* **2013**, *3*, 1376. [CrossRef] [PubMed]
13. Xu, F.; Tu, Z.; Li, Y.; Zhang, P.; Fu, X.; Jin, D. Trajectory recovery from ash: User privacy is not preserved in aggregated mobility data. In Proceedings of the 26th International Conference, Perth, Australia, 3–7 April 2017.
14. De Montjoye, Y.-A.; Gambs, S.; Blondel, V.; Canright, G.; De Cordes, N.; Deletaille, S.; Engø-Monsen, K.; Garcia-Herranz, M.; Kendall, J.; Kerry, C.; et al. On the privacy-conscientious use of mobile phone data. *Sci. Data* **2018**, *5*, 180286. [CrossRef] [PubMed]
15. Xu, Y.; Shaw, S.-L.; Zhao, Z.; Yin, L.; Lu, F.; Chen, J.; Fang, Z.; Li, Q. Another Tale of Two Cities: Understanding Human Activity Space Using Actively Tracked Cellphone Location Data. *Geogr. Mobilities Pract. Spaces Subj.* **2018**, *106*, 246–258. [CrossRef]
16. Yuan, Y.; Raubal, M. Analyzing the distribution of human activity space from mobile phone usage: An individual and urban-oriented study. *Int. J. Geogr. Inf. Sci.* **2016**, *30*, 1594–1621. [CrossRef]
17. Boyce, D.E.; Williams, H.C. *Forecasting Urban Travel: Past, Present and Future*; Edward Elgar Publishing: Cheltenham, UK; Northampton, MA, USA, 2015.

18. Pan, Y.; Darzi, A.; Kabiri, A.; Zhao, G.; Luo, W.; Xiong, C.; Zhang, L. Quantifying human mobility behaviour changes during the COVID-19 outbreak in the United States. *Sci. Rep.* **2020**, *10*, 1–9. [CrossRef]
19. Zhao, Z.; Shaw, S.-L.; Yin, L.; Fang, Z.; Yang, X.; Zhang, F.; Wu, S. The effect of temporal sampling intervals on typical human mobility indicators obtained from mobile phone location data. *Int. J. Geogr. Inf. Sci.* **2019**, *33*, 1471–1495. [CrossRef]
20. Xu, Y.; Belyi, A.; Bojic, I.; Ratti, C. Human mobility and socioeconomic status: Analysis of Singapore and Boston. *Comput. Environ. Urban Syst.* **2018**, *72*, 51–67. [CrossRef]
21. Zhang, S.; Liu, X.; Tang, J.; Cheng, S.; Wang, Y. Urban spatial structure and travel patterns: Analysis of workday and holiday travel using inhomogeneous Poisson point process models. *Comput. Environ. Urban Syst.* **2019**, *73*, 68–84. [CrossRef]
22. Castiglione, J.; Bradley, M.; Gliebe, J. *Activity-Based Travel Demand Models: A Primer*; The National Academies Press: Washington, DC, USA, 2014.
23. Zhang, M.; Zhao, P. Literature review on urban transport equity in transitional China: From empirical studies to universal knowledge. *J. Transp. Geogr.* **2021**, *96*, 103177. [CrossRef]
24. Houston, D.; Lo, A. Do Compact, Accessible, and Walkable Communities Promote Gender Equality? *J. Transp. Geogr.* **2018**, *68*, 42–54.
25. Zhu, J.; Fan, Y. Daily travel behavior and emotional well-being: Effects of trip mode, duration, purpose, and companionship. *Transp. Res. Part A Policy Pract.* **2018**, *118*, 360–373. [CrossRef]
26. Li, P.; Zhao, P.; Brand, C. Future energy use and CO2 emissions of urban passenger transport in China: A travel behavior and urban form based approach. *Appl. Energy* **2018**, *211*, 820–842. [CrossRef]
27. Erlander, S.; Stewart, N.F. *The Gravity Model in Transportation Analysis: Theory and Extensions*; VSP: Utrecht, The Netherland; Tokyo, Japan, 1990.
28. Song, C.; Koren, T.; Wang, P.; Barabási, A.-L. Modelling the scaling properties of human mobility. *Nat. Phys.* **2010**, *6*, 818–823. [CrossRef]
29. Alessandretti, L.; Aslak, U.; Lehmann, S. The scales of human mobility. *Nat. Cell Biol.* **2020**, *587*, 402–407. [CrossRef] [PubMed]
30. Xia, F.; Wang, J.; Kong, X.; Wang, Z.; Li, J.; Liu, C. Exploring Human Mobility Patterns in Urban Scenarios: A Trajectory Data Perspective. *IEEE Commun. Mag.* **2018**, *56*, 142–149. [CrossRef]
31. Chan, H.F.; Skali, A.; Savage, D.A.; Stadelmann, D.; Torgler, B. Risk attitudes and human mobility during the COVID-19 pandemic. *Sci. Rep.* **2020**, *10*, 1–13. [CrossRef] [PubMed]
32. El Shoghri, A.; Liebig, J.; Gardner, L.; Jurdak, R.; Kanhere, S. How Mobility Patterns Drive Disease Spread: A Case Study Using Public Transit Passenger Card Travel Data. In Proceedings of the 2019 IEEE 20th International Symposium on "A World of Wireless, Mobile and Multimedia Networks" (WoWMoM), Washington, DC, USA, 10–12 June 2019.
33. Ahmouda, A.; Hochmair, H.H.; Cvetojevic, S. Using Twitter to Analyze the Effect of Hurricanes on Human Mobility Patterns. *Urban Sci.* **2019**, *3*, 87. [CrossRef]
34. Chengdu Bureau of Statistics. *Statistical Communiqué of Chengdu on the 2017 Economic and Social Development*; Chengdu Bureau of Statistics: Chengdu, China, 2018. (In Chinese)
35. Chengdu Directing Office for Cyber Security and Informationisation. *Chengdu Internet Development Report*; Chengdu Directing Office for Cyber Security and Informationisation: Chengdu, China, 2016. (In Chinese)
36. Calabrese, F.; Pereira, F.C.; Di Lorenzo, G.; Liu, L.; Ratti, C. The Geography of Taste: Analyzing Cell-Phone Mobility and Social Events. In *Database Systems for Advanced Applications*; Springer: New York, NY, USA, 2010; pp. 22–37.

sustainability

MDPI

Article

Engaging Smallholders in Flower Agribusiness for Inclusive Rural Development: The Case of Yunnan, China

Jieming Zhu [1], Chen Chen [1] and Lie You [2,*]

[1] Department of Urban Planning, Tongji University, Shanghai 200092, China; jmzhu@hotmail.com (J.Z.); tjupchenchen@tongji.edu.cn (C.C.)
[2] School of Design, Shanghai Jiao Tong University, Shanghai 200240, China
* Correspondence: youlie@sjtu.edu.cn; Tel.: +86-152-2125-7127

Abstract: Serious farmland scarcities make smallholders a default mode for China's agriculture, which makes efficient and equitable rural development a great challenge. Tensions lead to alternation between autonomous family farming and coordinated collective agriculture. Rapid urbanization since the 1980s has strongly stimulated flower-growing and agribusiness in Yunnan, China. The organization for commercial flower-farming is, however, an issue. Officially promoted for collective farming, voluntary cooperatives are wrecked by the free-riding problem. Grower associations nevertheless spontaneously emerge, with the flexible entry and exit of members without binding joint-assets and joint-ownership, which is facilitated by technological changes to the transaction. Empirical investigation in Tonghai, Yunnan, unveiled the institution of agribusiness–smallholder partnership for inclusive rural development. Smallholders have actively participated in flower agriculture, which has contributed significantly to the development of rural economies. The high casualty of micro-smallholders suggests that farm size is an important and crucial factor for sustainable farming. Effective rural development has to be supported by endogenous non-agricultural jobs so that farm size can be increased.

Keywords: flower agribusiness; smallholders; inclusive rural development; social well-being; social equity

Citation: Zhu, J.; Chen, C.; You, L. Engaging Smallholders in Flower Agribusiness for Inclusive Rural Development: The Case of Yunnan, China. *Sustainability* **2022**, *14*, 2614. https://doi.org/10.3390/su14052614

Academic Editors: Piotr Prus and Marc A. Rosen

Received: 7 November 2021
Accepted: 26 January 2022
Published: 24 February 2022

1. Introduction

Due to farmland resources made increasingly scarce by burgeoning population growth, China has become a country with one of the lowest arable land areas per capita in the world. In 2016, China's agricultural land accounted for 10.9% of the world's total [1] (https://data.worldbank.org/indicator/AG.LND.AGRI.K2, accessed on 18 March 2019); however, its population was 18.6% of the world total [2] (https://www.prb.org/wp-content/uploads/2016/08/prb-wpds2016-web-2016.pdf, accessed on 18 March 2019), resulting in farmland holdings per capita 58% of the world average. Taking the level of urbanization into consideration, China's rural population's farmland per capita is only 9% that of Brazil's, another developing country (https://www.cia.gov/library/publications/resources/the-world-factbook/, accessed on 6 April 2019). Therefore, serious farmland scarcity makes smallholding a default model for China's agriculture.

Efficient and equitable rural development has always been a great challenge to agrarian China throughout upheavals in history caused by cyclical land aggregation and redistribution. Small landholdings because of land scarcity give rise to turbulent changes in agricultural organization. The collective People's Communes, responding to small landholdings created by the 'land to the tillers' reform in the 1950s, were disbanded after existing for three decades and replaced by autonomous family farming in the early 1980s. Commune farms were dissolved into fragmented smallholders again and fragmented families struggled to sustain small farms [3]. Farming cooperatives are actively promoted top-down in order to address the rural spatial and social fragmentation, where rural elites play an important role [4]. This demonstrates that institutions conducive to efficient and equitable rural development are crucial in the setting of severe land scarcity. Intensive farming because of small landholding is productive to a certain extent, i.e., before agricultural involution sets in, which inhibits productivity. Cooperatives and collective self-governance are promising, but local contexts are critical for those schemes to be successful [5]. Contract farming between agribusiness firms and smallholders, the so-called 'core–satellite' model, is prevalent in many developing countries, but its contextual constraints need to be emphasized.

This paper addresses the question of productive rural development in the context of farmland scarcity, because the consolidation of farmland under collectivism or privatization is not conducive to inclusive rural development that should engage smallholders. We identify the institutions and mechanisms for engaging smallholders in rural development by presenting a case of flower-growing agribusiness in rural Yunnan, an underdeveloped province in China. Flower farming has been growing in Yunnan in tandem with rapid urbanization, which results in a large middle-income class with personal consumption commensurate with their tastes and lifestyles. Potentially, huge demand will develop in future; thus, how smallholders on the supply side should be organized in order to capitalize on the market opportunities is at issue. Due to the ubiquitous free-rider problem and substantial transaction costs, smallholders tend to be organized as associations, instead of cooperatives encouraged by the socialist authorities. Smallholder associations and agribusiness firms collaborate based on mutual interests without being bound by contracts, and the agribusiness–smallholder partnership is a helpful institution for inclusive rural development. Despite this, non-farm employment caused by urbanization is still considered crucial for increasing farm size and making rural development sustainable.

The research methodology adopted was an intensive case study that intended to discover insights how institutional change has occurred in the development of the flower-growing agriculture in Yunnan. During 2017–2019, we conducted several on-site investigations in Dounan and Tonghai, Yunnan, to conduct interviews with smallholder farmers, smallholder associations and agribusiness firms engaged in flower agriculture. There was no overall population information available about the numbers of agri-business firms and smallholder farmers in Tonghai; therefore, we used the snowball technique for sample selection.

2. Institutions for Efficient and Inclusive Rural Development in the Context of Small Landholding

Efficient production and equitable development are two pressing and challenging goals for both developed and developing countries, although it is well recognized that pursuing these two together is a formidable task for the latter. It is indisputable that sustainable development for developing countries hinges on the efficiency of their economic development. Inefficient economic development wastes resources unnecessarily, adds to tension in social relations and heightens pressure on the eco-environment. Deficiencies of wealth often exacerbate social injustice and environmental unsustainability. Inequality undoubtedly generates social conflicts that undermine the purposes of productivity.

The harsh scarcity of farmland has always been one of the greatest challenges to China's rural development. The widening gap between the 'haves' and the 'have-nots' in terms of farmland holding created many landless peasants prior to 1949. The nature of landlords as a rentier class gave rise to a highly unproductive agricultural economy that made peasants poorer over time. Abject poverty weakened traditional social cohesion in the villages. A natural disaster, such as a flood and drought, was often the straw which broke the camel's back, and peasant uprisings brought down old dynasties and ushered in new ones. The cycle repeated itself in China's history and prevented the country from advancement. Although the farmland holdings by the rich landlords were about 30 times larger than those owned by the poor peasants, which stirred up violent revolution for land redistribution in the early 1950s, the average farmland holding per household was merely 3.3 mu (one hectare is equal to 15 mu) that was achieved by the land redistribution in the course of the 'land to the tiller' reform [6]. So-called landlords, the richest and largest farmland holders among the rural social strata, owned only 26.3 mu (less than 2 ha) on average, considered smallholders in other countries. Even in India as the second most populous nation are farmers with less than two hectares of land considered poor, and thus qualify for cash benefits from the state (Econo-mist, 2019) [6–9]. Scarce endowments of farmland have made subsistence farming a principal mode of agricultural production that give rise to prevalent and persistent rural poverty in China. Techniques of intensive farming have increased land productivity and helped to slightly mitigate the abject poverty, but the growth rate of productivity could not match with that of the population. Agricultural output per land unit has increased, whereas output per capita has remained the same or even dropped; thus, the production mode was agricultural involution rather than evolutional change [10].

The 'land to the tillers' reform dissolved highly concentrated land holdings by the landlords and landless peasants received their fair shares. Nevertheless, subsequent household farming resulted in land fragmentation that prevented the scaled production and adequate provision of farming infrastructure, such as irrigation, that needed collective action. A series of top-down agrarian collective movements eventually created the People's Communes in 1958, when only recently privatized farmlands were converted into collective land ownership. Peasants began collective farming on consolidated farmland with economies of scale. No longer was it smallholder farming, but collective farming, although egalitarian, did not give strong incentives to its members for wealth creation. Subsistence farming have remained a predominant mode of rural economies. Mired in political turmoil and ideological battles, the whole countryside was on the brink of economic collapse and social breakdown by the late 1970s. People's Communes had to be disbanded in the early 1980s and replaced by the Household Production Responsibility Scheme (HPRS), that leased farmland evenly to village households. Village households became basic farming units, and smallholder farming was restored again after three decades of failed efforts in bringing up agricultural productivity.

The HPRS has proven much more productive than People's Communes, but the tension between smallholders and scaled farming lingers. Agricultural involution led by smallholders' intensive farming eventually makes marginal productivity falling to zero. This does not hold promise for sustainable rural development. Voluntary farmers' cooperatives are thus advocated by China's Cooperatives Law (2007) as an alternative for smallholders to collectively scale up their production [11]. As an organizational arrangement, bottom-up cooperatives are characterized as voluntary and open memberships, autonomous management and members' active participation in the economic management [12]. Although a cooperative can serve its members' economic needs in certain social contexts, it as an organization has intrinsic problems breeding members' short-termism. Short-termism is caused by the free-rider problem, horizon, and transaction costs in decision-making [13,14].

When property rights are not transferable and not clearly in the cooperatives of open membership, the free-rider problem occurs [15]. Ambiguous property rights encourage the over-use or abuse of resources where effective control is absent. The horizon problem arises when the productive life of collective resources is longer than the timespan, and a shareholder can claim on the dividends generated, because the shareholder may leave or die [16,17]. Thus, there is a disincentive for members to contribute to long-term investments and an incentive for members to maximize the short-term dividends. Due to the democratic member-controlled system, there could be high transaction costs in reaching management decisions, and the cost of group decision-making increases with the size and diversity of the cooperative [18]. Cooperative management may not be able to react to market opportunities in a timely manner, likely leading to management inaction. An official estimation is that about 40% of China's rural households nationwide belonged to cooperatives by 2015 [19] (http://www.xinhuanet.com//politics/2015-12/08/c_128509962.htm, accessed on 20 March 2019). Nevertheless, an in-depth investigation discovered that as many as 96% sampled cooperatives were neither genuine nor successful [20]. The findings are not unexpected. Ostrom [21] advocates the management of collective resources with neither centralized government control nor privatization. However, contextual variables, such as the relative scarcity of the resource and the size of the collective involved, are emphasized as critical for effective collective self-governance [22]. High population density and land scarcity constitute a tough challenge to collective governance over common land resources.

Engaging smallholders for productive agriculture remains a great challenge, whereas small farms are still recognized as important for rural development and food production [9,23]. Contract farming has been considered beneficial to smallholders in general, because such arrangements could facilitate the transfer of technology and provide access to markets to smallholders [24]. Through empirical investigation, Miyata, Minot and Hu [25] determined that the incomes of smallholders who grew apples and green onions in Shandong, China, increased when participating in contract farming. There are also caveats about the drawbacks of those schemes. Relationships established by contracts could be problematically unfavorable to the growers, and the poorest farmers could be excluded in some cases [26,27]. Certain economic, technical and social conditions are crucial for contract farming models to work beneficially for smallholders [28]. Mistrust and a lack of transparency can disrupt contract farming [29]. It appears that market-oriented contract farming is more workable than collective-based cooperatives, because the former tends to have a better access to markets that are crucial for commercial farming.

Figure 1 shows the historical path along which the farming modes have evolved. Farming institutional changes are driven by problem-solving initiatives as well as socioeconomic changes. Smallholder farming creates problems of farmland fragmentation and lacks economies of scale, whereas collective farming (such as the People's Commune and cooperatives) is either low in productivity or breeds the free-rider problem. On the demand and supply sides, urbanization has created a demand for commercial agricultural produce, and has also generated non-farm jobs for peasants who leave farming and pass on their farmland to fellow smallholders, thus increasing the economies of landholding scales. Lowder, Skoet and Raney [30] discovered that the average farm size decreases in most developing countries and increases in many developed countries because of urbanization and industrialization.

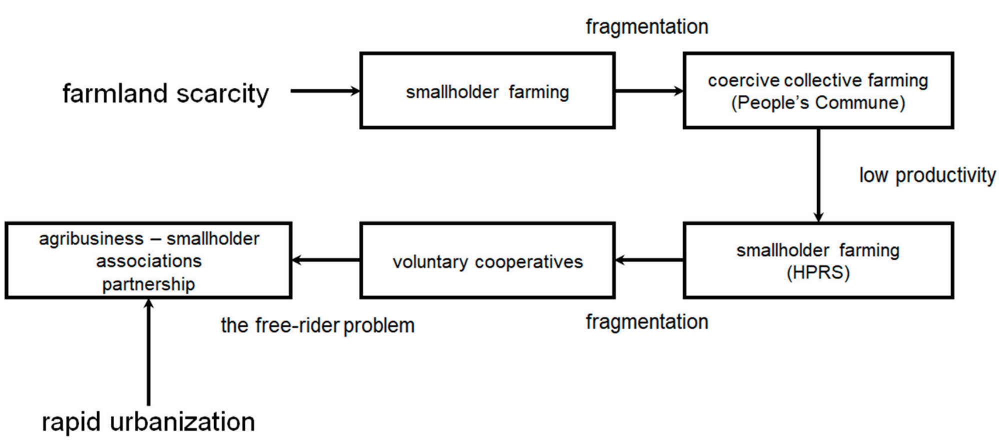


Figure 1. The evolution of farming modes driven by problem-solving initiatives and socioeconomic changes.

The actual form of institutions for partnerships between smallholders and agribusinesses should depend on the type of commercial commodities, their related market conditions, and the size of family farms. Agribusiness emerges in China responding to robust demand from the regional, national and even international markets, along with a rising urban middle-class and improved transport connectivity because of consistent investment by the state in infrastructure. Farming is undergoing profound restructuring such that vertical integration occurs in the production process of agricultural commodities where agribusiness firms are linked to farmers [31,32]. Firms have access to markets and productive technologies for commodity quality, whereas farmers have secured farmland thanks to collective landownership. A new institution, agribusiness–smallholder associations, has evolved from the dysfunctional cooperatives, linking smallholders to agribusiness firms so that smallholder farmers can productively participate in the rural development.

3. Emerging Flower Growers and Agribusiness in the Course of Rising Middle-Income Classes

Yunnan, situated in a high-altitude and low-latitude region, is endowed with a favorable climate which is conducive to flower-growing, although it is a hilly province with scarce arable land for its population. Only 3.3% of its mountainous territory (15,285 square kilometers) are basin plains where the 2.4 million people (2018) can inhabit and farm in Yuxi, one of its prefectures [33] (see Figure 2; http://www.yuxi.gov.cn/yxszfxxgk/tjgb/20190312/1025161.html, accessed 5 April 2019). Yunnan is one of the poorest provinces in China because of its underdevelopment in industrial economies and the rudimentary infrastructure of inter-regional road networks. Poor connectivity and isolation have hindered Yunnan's development. Historically, farmers did not grow flowers as commercial crops because there was no effective market demand when urban consumers consisted of small and scattered populations.

Figure 2. Location of Yunnan in China, with Yuxi and Tonghai shown.

In Tonghai, we interviewed 96 smallholder farmers, 13 smallholder associations and 7 agribusiness firms that are engaged in flower-growing agriculture. It was reported that flower-growing started by a peasant named Hua Zhongyi in 1983 on a tiny family land plot of 0.3 mu in Dounan township in the suburbs of Kunming, the provincial capital of Yunnan [34]. This was soon followed by a few villagers in the vicinity after a street market evolved in Dounan, where Kunming urbanites came to buy the flowers from the local growers. That was the beginning of Yunnan's flower plantation, at the humble size of

40 mu in Dounan by 1987. Thirty years later, the flower plantation areas had increased in size to 1,561,500 mu in 30 counties by 2017 (see Figure 3). Flower farming accounted for 11.6% of the total agricultural outputs in 2011, and the figure grew to 13.0% in 2017 [35,36]. The flower-growing cluster around Dounan mainly produces fresh-cut flowers that are transacted daily in Dounan Market within a three-hour driving distances, whereas farming clusters in the west region grow flowers for petals processed into products that do not rely on Dounan for swift delivery to customers.

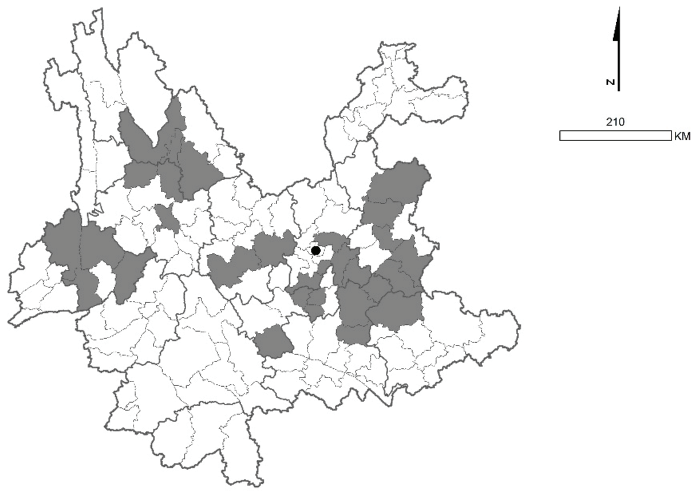


Figure 3. Location of 30 flower-growing counties in Yunnan. Note: The black dot indicates Dounan Market.

The demand for bouquets of fresh flowers has been strengthened by a rising urban middle-class along with rapid urbanization since the 1980s. The China Development Research Center of the State Council estimated that middle-income classes accounted for about 10.0% of the total population in 2002, and the figure rose to 28.9% in 2016 (http://www.drc.gov.cn/xscg/20180911/182-224-2896926.htm, accessed on 22 March 2019). During the period 2002–2016, the absolute number of middle-class people increased by 270 million, based on the above estimations. One of the most significant events for Yunnan's flower agribusiness has been the establishment of flower markets that link supply to demand. As early as in 1993, a few Dounan villagers ventured into marketing and trading in large cities such as Chengdu, Wuhan, Guangzhou, Beijing and Shanghai, where they set up shops promoting sales of Dounan flowers. At its peak, Yunnan contributed 70% of fresh-cut flowers to the markets in the major Chinese cities. This specialization added value by fetching higher prices of flowers than what could be obtained in Kunming, while those traders leased their own farmland to the fellow villages at home (APKPG and KRICH, 2018). The node linking flower supply to potentially substantial demand is the Dounan Market. The initially rudimentary street market had evolved into an indoor marketplace at a size of 3.7 ha in 1999, and the Kunming International Flora Auction (KIFA) trading center started operation in 2002, when flower transaction volumes had increased substantially. By reducing potentially high transaction costs associated with perishable commodities, KIFA has proven to be the most effective measure promoting flower transactions that increased in value by 15 times, growing at 20.2% per annum between 2003 and 2018 [37]. Another auction market, DFETC, commenced operation is 2015, when KIFA was reaching full capacity. Dounan provides crucial market accessibility to Yunnan's flower agribusiness.

4. Organization for Flower-Growing Micro-Smallholders: Cooperatives or Associations?

Tonghai is a county in Yuxi prefecture, about 140 kilometers to the south of Kunming (see Figure 2). Approximately 77% of its territory (721 square kilometers) is composed of mountainous areas; thus, farmland is extremely scarce against its farming population (see Figure 4). Farmland holding is 0.7 mu (0.05 ha) per capita and 2.1 mu (0.14 ha) per rural household on average [38]. Its agricultural industry consists of smallholders that are considered to be micro-size, as a result of socialist collectivism that distributes farmland equally. A few farmers started growing flowers in the late 1990s, spurred by the Dounan Market, which is easily accessible. Bi Chaochun was one of them. After two years of flower-growing on his own tiny land plot, Bi believed that smallholders should be organized collectively to embark on market-oriented commercial farming, and initiated the Lianqing Rose Cooperative together with 42 other micro-smallholders on a total aggregated area of 76 mu (5.1 ha) farmland in 2004 (1.8 mu/member), so as to improve agribusiness efficiency by increasing economies of scale. There were 45 flower-growing cooperatives, genuine or nominal, established during 2002–2017 in Tonghai, according to revelations by an informant. In total, 4791 micro-smallholders joined those so-called cooperatives, the largest having 582 members and smallest having 5 members [39]. By estimation, the farmland scale per cooperative was about 220 mu (15 ha) on average; the largest was 1220 mu (80 ha) and the smallest was 10 mu (0.6 ha).

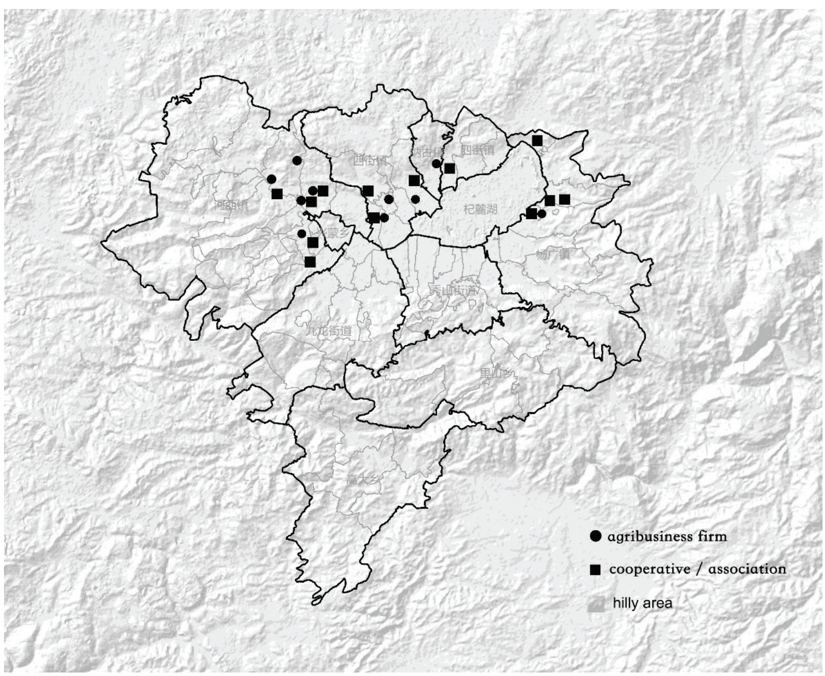


Figure 4. Locations of sampled agribusiness firms and cooperatives/associations in Tonghai.

With only a tiny fund of CNY 30,000 (USD 4500 at the exchange rate in April 2019) collected from the members as collective investment, Lianqing managed to rent a disused and dilapidated temple for his office and storage. The cooperative organized sessions for members to learn about commercial flower farming and managing technical problems, such as temperature control and pest-prevention. Fresh-cut roses were assembled, packaged and transported to Dounan by the cooperative, and sold under the same brand that was the namesake of the cooperative. By 2007, Lianqing had expanded to 140 members and 260 mu farmland (1.9 mu/member). Due to tiny household landholding farming, growers tended to farm the land intensively with heavy applications of fertilizers and pesticides so as to increase flower productivity. After two to three years' intensive farming, the land became salinized, and the quality of crops declined drastically. Farmers would not have any income if lands had to lie fallow for a year or two, or farming continued and yielded low-quality flowers. Members whose lands were not yet salinized still produced good-quality roses. Collective sales distributed sale proceeds equally per bundle between members, regardless of quality variations in the roses. It thus generated the free-rider problem, and it did not give incentives for members to keep up the good quality of rose growing. Free-riding was exacerbated by the expansion of the cooperative that was too diversified with too many members. The cooperative could not hold members together. By 2014, Lianqing was all but dismantled, broken down by the problems similar to People's Communes, although Lianqing was spontaneously organized in a bottom-up manner. The same fate befell Lianxin (51 members initially), another cooperative interviewed.

We interviewed 13 so-called cooperatives in early 2019, and found that only two of them, Lianqing and Lianxin, were genuine cooperatives with collective investment and cooperative assets (see Figure 3). It is not surprising that most of the cooperatives are not genuine, elaborated by Hu, Zhang and Donaldson [20] in their extensive investigation. Many nominal cooperatives are actually associations. Most organizations for flower-growing micro-smallholders are therefore associations in nature. Associations are flexible in terms of the entry and exit of members, because there are no binding joint-assets and joint-ownership. Associations provide services paid for by members who use them with no other obligations. Sold in Dounan under the brand provided by the association, flowers are collectively transacted through the association's trading account, and the same free-rider problem can occur, as with the cooperatives. Although associations have a mechanism to remove undesirable members who provide inferior products to spoil association's collective sales, this exercise could not be easy in village settings where people tend to be socially close. However, those with better flowers can leave the associations, and only 'lemons' stay on. The sustainability of associations depends on the collective management of flower quality.

Based on the list compiled by the Agricultural Office of Tonghai County Government, 45 cooperatives or associations were founded during 2004–2017; 32 of them are still in operation, and 13 have closed. A significant event occurred on 2015, when another auction center, DFETC, was opened. This ushered in a technological change that offers every flower smallholder an individual trading account; thus, flowers are no longer transacted collectively under association accounts. This solves the free-rider problem that destroys cooperatives and associations. The survival rate of associations has improved remarkably since 2015. Before 2015, the survival rate was only 62.5%, and after 2015, it increased to 92.3% (see Table 1). This technological change allows free association, and thus helps hold micro-smallholders together as farming communities. Our on-site investigation revealed that associations do benefit farmers greatly, through the sharing of farming techniques and expertise between fellow members. The number of members frequently communicating with fellow members for information exchange accounts for 82.3% of the total, with only 4.2% who never communicate with other members. Without the free-rider problem besetting the organization, associations of free membership become real social communities of smallholders for mutual help and collective learning (see Table 2).

Table 1. Survival rates of cooperatives/associations.

Time	Number of Cooperatives/Associations Established	Number of Cooperative/Associations in Operation	Survival Rates of Cooperatives/ Associations
2002–2017	45	32	71.1%
2002–2014	32	20	62.5%
2015–2017	13	12	92.3%

Source: Authors' 2019 fieldwork.

Table 2. Sources of consultation to smallholders for flower-farming techniques and expertise.

Association	Agribusiness Firm	Fellow Association Members	Internet	Relatives/ Friends	Others
20.8%	29.2%	58.3%	3.1%	14.6%	14.6%

Source: Authors' questionnaire survey of smallholders in January 2019.

5. Institution for Inclusive Rural Development: Agribusiness–Smallholder Partnership

Agribusiness firms usually provide flower-packaging and flower-delivery services, quality seedlings and training and consultation to the smallholder associations. Between 2006 and 2015, seven flower-farming firms grew out of associations (see Table 3). The initial organizers of those associations were fledgling entrepreneurs who managed the associations by providing services in addition to their own flower-growing. The services expanded after a few years in business, which helped produce agribusiness firms. Associations have become incubators in this case. In addition to this paradigm, there are two other models for firm–association unions. One is agribusiness firms setting up associations to recruit steady clients as an important part of business operation, and the other is firms linking up associations as joint-partners (see Table 3). Still providing services of flower packaging and transportation to Dounan Market, agribusiness firms have expanded their landholdings so that smallholders are transformed to commercial farms. Ten agribusiness firms have aggregated 8080 mu (539 ha) farmland in total, each having 800 mu on average; the largest at about 3500 mu, and the smallest at 50 mu. Large-scale farming allows firms to invest in farming facilities and R&D for growing high-quality flowers. Large firms also diversify into specialization in developing rose seedlings that are provided to smallholder farmers, so as to extend the flower production chain that enhances flower-farming productivity.

Table 3. Formation of agribusiness–association partnerships.

Association	Year of Founding	Number of Members	Agribusiness Firm	Year of Founding	Landholdings in Tonghai, mu	Landholdings Outside Tonghai, mu
Associations bringing up agribusiness firms						
Yangliren	2004	582	Yangliren	2012	-	300
			Ruiyuan	2006	300	-
Yunxiu	2006	310	Yunxiu	2009	2000	1490
			Lianyi	2012	50	-
Jiayuan	2008	224	Jiayuan	2012	-	130
Jiaoyang	2009	234	Jinhai	2010	475	125
Tianyuan	2009	154	Tianyuan	2015	50	-
Agribusiness firms setting up associations						
Baiji	2012	85	Xinhaihui	2012	280	3000
Jianong	2016	110	Jiahai	2015	120	-
Agribusiness firm—association joint-venture						
Lianxin	2008	148	Xiangyun	2008	-	60

Source: Authors' fieldwork conducted in January 2019.

Based on a sampled survey conducted in January 2019 of 96 flower-farming smallholders, we discovered that the average landholding area per farmer is 3.8 mu (0.25 ha). Almost half have as little as 1.7 mu, with the rest clearly renting farmland to increase their own family land areas from villagers who do not farm (see Table 4). Farmland transfer by leasing has been facilitated by an institutional change to collectively owned farmland [40]. According to China's constitution, there is a dual landownership scheme: urban land belonging to the state, and rural land being collectively owned. Since the founding of the People's Republic in 1949, farmland owned by landlords has been confiscated and re-distributed to landless peasants under the Rural Land Reform. In 1956, the People's Commune movement abolished the private ownership of farmland and replaced it with collective ownership. Although rural land is collectively 'owned' ostensibly, rural communities 'own' the land on the condition that it is only used for their own production (farming and non-farming) and habitation. It is considered that in the countryside, lands are held by villages based on the Marxist principle of land as 'a means of production', which suggests that land should not be considered an economic asset. The notion of land being 'a means of production' grants land use rights only to the holders; the collective has neither the right to derive income from land by letting it out, nor the right to change its form and substance by developing it for non-agricultural uses without approval from the government at the county level or above. The right to alienate collective land for urban uses is restricted in situations where the other party in the transaction is the state. Therefore, collective rural land as assets is owned by the state. Only recently has agricultural land leasing been allowed. The conversion of farmland to nonagricultural uses for leasing remains illegitimate and controversial. Farmland transfer by leasing allows subsistence farming to evolve into commercial agriculture, in the setting of urbanization that creates non-farm jobs for rural–urban migrants. Some farmlands are left behind for sub-leasing as those farmers have migrated to cities to take up urban jobs.

Table 4. The size of landholdings for the sampled smallholders.

Number of Smallholders (%)	Landholding on Average, mu
48.4	1.7
25.8	3.7
14.0	5.3
9.7	8.9
3.1	18.5

Source: Authors' questionnaire survey of smallholders in January 2019.

Substantial expenses occur upfront for building greenhouse facilities, and daily maintenance costs on fertilizers and pesticides are two great concerns by those farmers. There is a marked cleavage between the size of landholdings in relation to concerns over the costs of fertilizers and pesticides. Those farmers under heavy cost pressure with land areas under 4 mu account for 70% of that cohort, and with between 4–8 mu 58% of that group. Only 36% of those above 8 mu are worried about these expenses. It is likely that smaller farms will utilize more fertilizers and pesticides in order to raise productivity. The concern over the upfront outlay on building greenhouses is negatively correlated with the number of years growing flowers. Three-quarters of the farmers who have been involved in flower-growing for 1–2 years strongly feel the burden. The ratio declines to 50% for those who have farmed for 3–9 years, and down further to one-quarter of those who have worked for over 10 years. This suggests that crucial and expensive greenhouse facilities are gradually improved over the years, along with the savings accumulated.

The years spent as a flower-farming smallholder is positively correlated with the size of the landholding (see Table 5). The longer the farmers have been involved in growing flowers, the larger their land holdings. This suggests that the casualty rate should be high for smallholders in their early years of farming, due to their tiny farmland plots and the intensive farming approach. The initial outlays are relatively high in relation to the outputs restricted by the small size of the farmland. Inadequacy in facilities is compensated by the heavy usage of fertilizers and pesticides. This unsustainable farming method expedites land salinization, and the quality of crops degrades in a downward spiral. In the KIFA auction center, high-quality roses (classes A and B) only accounted for 30%, and low-quality (classes C, D and E) comprised the remaining 70% in 2018 (unpublished report by KIFA, 2019). The average prices of low-quality roses are only 46% of those of the high-quality ones. Those low-quality roses are most likely supplied by smallholder farmers; the data reveal that 70% of flowers in the Dounan Market are provided by smallholders [34]. A vicious cycle is created by unsustainable intensive farming and ended in shrinking incomes, a kind of involution associated with small-landholding. In the first few years, many micro-smallholders are squeezed out of the flower market. The composition of associations is fluid, with a high frequency of entry and exit of members, which also explains why flower-growing cooperatives are not sustainable. The chance of smallholders surviving the first five years is only one in three (see Table 5).

Table 5. The number of years in flower-farming and the landholding of micro-smallholders.

	Number of Smallholders (%)	Landholding on Average, mu
1–2	38.5	2.4
3–5	28.1	3.7
6–9	12.5	4.1
10–17	20.9	5.4

Source: Authors' questionnaire survey of smallholders in January 2019.

The severe scarcity of farmland and resultant micro-smallholdings represent great challenge to sustainable and inclusive rural development. Associations seem more applicable than cooperatives to flower-farming by micro-smallholders. Agribusiness firms with large farmland stocks have thus become crucial anchors for flower-growing agriculture. With financial capacity, firms have invested in techniques of wastewater recycling and soilless cultivation, which prevent the pollution of soils, so that land degradation is mitigated. Agribusiness firms also make great efforts in cultivating new varieties of roses, which allows growers to command price premiums. According to a report by KIFA, there were 200 kinds of roses available in the auction market in 2016, and the figure rose to 356 in 2018, a valuable contribution by the flower-growing firms (unpublished report by KIFA, 2019). Auction centers also serve as protectors of intellectual property over newly invented flower varieties. Royalties are automatically deducted from the proceeds of sold flowers, therefore the practice promotes research and invention. Flower-growing firms have become steady providers of quality fresh-cut flowers in a market that is expanding daily.

Due to volatile fluctuations in market prices and the perishable nature of fresh-cut flowers, contract farming is not prevalent for flower-growing smallholders. The agribusiness–association model works well. Agribusiness firms provide commercial services and professional advice, whereas farmers' associations provide a platform to smallholders for mutual help and fellowship. Smallholders are effectively engaged in rural flower-growing development, although smallholders need to work competitively and productively to gradually expand the size of their landholdings. We have derived an agricultural development index (ADI): the formula for ADI is 0.8 $\times$ agricultural product per farmworker/50,000 + 0.2 $\times$ farmland per farmworker/50, where CNY 50,000 agricultural product per farmworker is designated as 100 and 50 mu farmland per farmworker as 100. This tool measures farming-based rural growth. The ADI stood at 27.2 in 2010, and it rose to 71.8 in 2017, a substantial improvement. Flower agribusiness is promising for rural development.

6. Sustainable Rural Development: Endogenous Non-Agricultural Jobs

Flower-growing agribusiness has changed the rural economy of Tonghai significantly. Agricultural outputs per capita increased by 181.7% between 2010 and 2017. However, Tonghai is still predominantly an agrarian economy, where the agricultural labor force represented 61.6% of the total labors in 2017, only declining slightly from 66.0% in 2010 [41]. The state of micro-smallholding remains little changed. Smallholder subsistence farming is not promising in leading peasantry to prosperity. Non-agricultural economies seem the only way to reduce the number of farmers so as to increase the scale of farms for high-density land-scarce regions, paving the way for effective rural development. The shift of the agricultural labor force into non-agricultural sectors is considered de-agriculturalization [42], and many land-scarce agricultural countries have made efforts in searching for non-farm income sources [43]. Sharma [44] claims that India's urban settlements are keys to development and inclusive growth in its rural areas.

Rural industrialization since the early 1980s has had great economic and social impacts on China's countryside under the auspices of grand economic reforms. The collective township–village enterprises flourished, providing industrial employment to those who were underemployed in farming [45]. Although collective enterprises reached the zenith in the mid-1990s and declined thereafter, non-agricultural jobs grew continuously. Most of those privatized enterprises remained in operation in the rural areas. In 2016, Kunshan county, in the Yangtze River Delta, saw only 8.0% of its total laborers working in the agricultural sector, and Nanhai county, in the Pearl River Delta had as low as 4.7% after four decades of rural industrialization [46,47]. The Yangtze River Delta and Pearl River Delta are the two of the most dynamic industrializing regions; however, rural industrialization is not evenly developed across the country. A regional disparity is clearly displayed in a similar pattern as national economic development, where the eastern regions are the most dynamic and the western regions the least developed.

On the one hand, in situ urbanization provides non-farm jobs to peasants in dynamic regions that witness urbanization-led rural development. On the other hand, urbanization offers numerous economic opportunities to those seeking non-farm employment. According to the 1990 population census, the number of peasant migrant workers (inter-county migration) was estimated at 13.0 million, which accounted for 1.5% of the total rural population then. This ratio rose to 6.3% in 2000 [48,49]. The number of peasant migrant workers jumped to 168.8 million, representing 28.0% of the total rural population in 2015 [50,51]. Rural–urban migrants should have become better-off economically than they were in the countryside. Nevertheless, the hardships associated with migration have been overwhelmingly reported by both the conventional and social media. Those peasants in the less dynamic regions need to travel longer distance to find non-farm jobs. Among 166.1 million peasant migrants, 46.6% and 53.4% of them were inter-provincial and intra-provincial travelers, respectively. Rural–urban migrants seem to be traveling shorter distances recently. Rural non-farm laborers working in their hometowns stood at 36.8% of the total in 2009, which rose to 39.2% in 2015 [51,52]. Changing preferences suggest a new generation of rural migrants making balanced choices between economic benefits and social costs in a new set of conditions that are quite different from those made decades earlier. In Tonghai, 14.0% of rural labors took on non-farm jobs by moving to urban areas, and those inter-county migrants only accounted for 2.9%; and those within Tonghai accounted for 11.1% (2016) [53].

Yunnan is an agricultural province with weak secondary and tertiary industries, and 85.0% of its labors were involved in farming in 1980. The proportion only dropped to 50.8% in 2017 after nearly four decades of market-oriented development [36], whereas it was 11.8% in Zhejiang and 16.8% in Jiangsu in 2017, two provinces in the Yangtze River Delta [54,55]. Exogenous non-agricultural development led by outside investments has become few and far between since the new millennium. Localities, whether advanced or underdeveloped, need to rely on bottom-up endogenous growth initiatives. Liu [56] described how Taihu region in the Yangtze River Delta had developed silk and textile cottage industries since the Ming dynasty, driven by the ever-deteriorating farmland resources. Many small towns specializing in making and trading those products emerged, connected by canals for inter-linkage. The processing of the agricultural produce added value and production chain was extended to allow specialization. Those towns became the rural centers of manufacturing and trading, stimuli for rural agricultural and non-agricultural growth.

The initial farm size is a crucial factor for the survival of smallholders. It has been discovered that the use of fertilizers decreases along with the increase in farm size [57]. Wu et al. [58] found that there is a strong inverse-correlation between the farm size and use intensity of agricultural chemicals in China, and "a 1% increase in farm size is associated with a 0.3% and 0.5% decrease in fertilizer and pesticide use, respectively, and an almost 1% increase in agricultural labor productivity" (p. 7010). The relationship also exists in other countries, based on an international panel analysis of 74 countries, also proven by an empirical survey in Tonghai. The total stock of farmland is fixed, which suggests that jobs should be created to attract farmers out of flower-growing.

The production chain and value chain of flower agribusinesses can be extended so as to deepen specialization of the links in the chains. It is promising to see that some endogenous non-agricultural jobs have been created in the areas of flower-packaging, flower-delivery, e-commerce (i.e., selling flowers online), and the making of rose cakes and rose essences. Rose cakes are already available in the retail markets of major cities in China. Research and development in cultivating quality flowers, seeds and seedlings, as well as developing growing techniques, are crucial steps which further the deepening of the industry value chain and flower clusters. Flower firms' managers have complained about poor infrastructure and facilities that impinge on the progress of flower industries, and the difficulties in recruiting educated workers. Town amenities, or lacks thereof, have become one of the main stumbling blocks to attracting professionals to work in agribusiness firms that are usually located in rural areas. Improving town facilities and amenities should promote flower agribusiness and thus inclusive rural development.

7. Conclusions

Serious scarcities of farmland make smallholding a default model for China's agriculture, posing a great challenge to efficient and equitable rural development. Subsistence farming thanks to smallholders has given rise to prevalent and persistent rural poverty in China. It seems that intensive farming, although helpful, tends to lead to agricultural involution because of the slower growth in productivity than that of population. Tensions lead to alternations between family-coordinated farming with even landholding, and community-managed farming with aggregated landholding. Rapid urbanization under the grand economic reforms has changed the conditions for China's agriculture. A growing middle-income class triggers the development of commercial farming.

Flower-growing and agribusiness in Yunnan provide an enlightening case to shed light on how commercial agriculture should be organized with a backdrop of pervasive smallholders. Farming modes are adopted and heavily dependent on what agricultural produce is available and its accessibility to the market. Yunnan flower growing is a case for reference. Officially promoted so as to encourage collective farming, voluntary flower-growing cooperatives are crippled by the free-rider problem. Associations of growers nevertheless spontaneously emerge with the flexibility of entry and exit of members without binding joint-assets and joint-ownership. Technological innovation in the transaction market also critically facilitates the operation of associations. Partnership between agribusiness and smallholder associations have become the institution for inclusive rural development. Agribusiness firms with large farmland stocks are anchors for the flower-growing agriculture, whereas memberships of smallholder associations are fluid, with a high occurrence of entry and exit, because of unsustainable farming adopted by micro-smallholders. Although smallholders have actively participated in flower agriculture, which has contributed significantly to the rural economy, the high casualty of micro-smallholders remains an issue. Sustainable rural development must be supported by endogenous non-agricultural jobs so that exiting farmers can transfer lands to growers in order to increase the landholding size of farms. Through a detailed case analysis, this paper examines the endogenous development logic of farmers, agricultural films and agricultural associations, which enriches the theory of inclusive rural development.

Author Contributions: Conceptualization, J.Z.; Data curation, L.Y.; Formal analysis, J.Z., C.C. and L.Y.; Funding acquisition, C.C. and L.Y.; Investigation, C.C. and L.Y.; Methodology, J.Z.; Writing—original draft, J.Z.; Writing—review & editing, J.Z. and L.Y. All authors have read and agreed to the published version of the manuscript.

Funding: National Natural Science Foundation of China (NSFC51978478); National Natural Science Foundation of China (NSFC51908350).

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Not applicable.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Agricultural Land. Available online: https://data.worldbank.org/indicator/AG.LND.AGRI.K2 (accessed on 18 March 2019).
2. 2016 World Population Data Sheet with a Special Focus on Human Needs and Sustainable Resources. Available online: https://www.prb.org/wp-content/uploads/2016/08/prb-wpds2016-web-2016.pdf (accessed on 18 March 2019).
3. Tang, W.; Zhu, J. Informality and rural industry: Rethinking the impacts of E-Commerce on rural development in China. *J. Rural Stud.* **2020**, *75*, 20–29. [CrossRef]
4. Li, Y.; Fan, P.; Liu, Y. What makes better village development in traditional agricultural areas of China? Evidence from long-term observation of typical villages. *Habitat Int.* **2019**, *83*, 111–124. [CrossRef]
5. Liu, Y.; Long, H.; Chen, Y.; Wang, J.; Li, Y.; Li, Y.; Yang, Y.; Zhou, Y. Progress of research on urban-rural transfor-mation and rural development in China in the past decade and future prospects. *J. Geogr. Sci.* **2016**, *26*, 1117–1132. [CrossRef]
6. Zou, Y.C. *Contemporary China's Land Management*; Contemporary China Press: Beijing, China, 1998.
7. The World Bank. *Reaching the Rural Poor: A Renewed Strategy for Rural Development*; World Bank Publications: Washington, DC, USA, 2003.
8. Salami, A.; Kamara, A.B.; Brixiova, Z. *Smallholder Agriculture in East Africa: Trends, Constraints and Opportunities*; African Development Bank: Tunis, Tunisia, 2010.
9. Graeub, B.E.; Chappell, M.J.; Wittman, H.; Ledermann, S.; Kerr, R.B.; Gemmillherren, B. The State of Family Farms in the World. *World Dev.* **2016**, *87*, 1–15. [CrossRef]
10. Geertz, C. Agricultural Involution: The Processes of Ecological Change in Indonesia. *Popul. Stud.* **1965**, *18*, 331.
11. Song, Y.; Qi, G.; Zhang, Y.; Vernooy, R. Farmer cooperatives in China: Diverse pathways to sustainable rural development. *Int. J. Agric. Sustain.* **2014**, *12*, 95–108. [CrossRef]
12. Hendrikse, G.; Veerman, C.P. Marketing cooperatives and financial structure: A transaction costs economics analysis. *Agric. Econ.* **2001**, *26*, 205–216. [CrossRef]
13. Cook, M.L. The Future of U.S. Agricultural Cooperatives: A Neo-Institutional Approach. *Am. J. Agric. Econ.* **1995**, *77*, 1153–1159. [CrossRef]
14. Royer, J.S. Potential for cooperative involvement in vertical coordination and value-added activities. *Agribusiness* **1995**, *11*, 473–481. [CrossRef]
15. Mancur, O. *The Logic of Collective Action: Public Goods and the Theory of Groups, Second Printing with a New Preface and Appendix*; Harvard University Press: Cambridge, MA, USA, 1965.
16. Porter, P.K.; Scully, G.W. Economic Efficiency in Cooperatives. *J. Law Econ.* **1987**, *30*, 489–512. [CrossRef]
17. Vitaliano, P. Cooperative Enterprise: An Alternative Conceptual Basis for Analyzing a Complex Institution. *Am. J. Agric. Econ.* **1983**, *65*, 1078–1083. [CrossRef]
18. Staatz, J.M. The structural characteristics of farmer cooperatives and their behavioral consequences. *Coop. Theory New Approach.* **1987**, *18*, 33–60.
19. Information Office of Agriculture. 1.47 Million Cooperatives Cover 40% of the Country's Farmers. Available online: http://www.xinhuanet.com//politics/2015-12/08/c_128509962.htm (accessed on 20 March 2019).
20. Hu, Z.; Zhang, Q.F.; Donaldson, J.A. *Farmers' Cooperatives in China: A Typology of Fraud and Failure. Contemporary China Centre*; Australia National University: Canberra, Australia, 2017.
21. Ostrom, E. *Governing the Commons: The Evolution of Institutions for Collective Action*; Cambridge University Press: Cambridge, MA, USA, 1990.
22. Ostrom, E. Collective Action and the Evolution of Social Norms. *J. Econ. Perspect.* **2000**, *14*, 137–158. [CrossRef]
23. Wiggins, S.; Kirsten, J.; Llambí, L. The Future of Small Farms. *World Dev.* **2010**, *38*, 1341–1348. [CrossRef]
24. Glover, D.J. Contract farming and smallholder outgrower schemes in less-developed countries. *World Dev.* **1984**, *12*, 1143–1157. [CrossRef]
25. Miyata, S.; Minot, N.; Hu, D. Impact of Contract Farming on Income: Linking Small Farmers, Packers, and Supermarkets in China. *World Dev.* **2009**, *37*, 1781–1790. [CrossRef]
26. Glover, D.J. Increasing the benefits to smallholders from contract farming: Problems for farmers' organizations and policy makers. *World Dev.* **1987**, *15*, 441–448. [CrossRef]
27. Ton, G.; Vellema, W.; Desiere, S.; Weituschat, S.; D'Haese, M. Haese Contract farming for improving smallholder incomes: What can we learn from effectiveness studies? *World Dev.* **2018**, *104*, 46–64. [CrossRef]
28. Goldsmith, A. The private sector and rural development: Can agribusiness help the small farmer? *World Dev.* **1985**, *13*, 1125–1138. [CrossRef]
29. Ruml, A.; Qaim, M. Smallholder Farmers' Dissatisfaction with Contract Schemes in Spite of Economic Benefits: Issues of Mistrust and Lack of Transparency. *J. Dev. Stud.* **2021**, *57*, 1106–1119. [CrossRef]

30. Lowder, S.K.; Skoet, J.; Raney, T. The Number, Size, and Distribution of Farms, Smallholder Farms, and Family Farms Worldwide. *World Dev.* **2016**, *87*, 16–29. [CrossRef]
31. Voll, S.P. *A Plough in Field Arable Western Agribusiness in Third World Agriculture*; University Press of New England: Lebanon, NH, USA, 1980.
32. Freeman, O.L.; Karen, R. The farmer and the money economy: The role of the private sector in the agricultural development of LDCs. *Technol. Forecast. Soc. Chang.* **1982**, *22*, 183–200. [CrossRef]
33. Statistical Bulletin of National Economic and Social Development of Yuxi in 2018. Available online: http://www.yuxi.gov.cn/yxszfxxgk/tjgb/20190312/1025161.html (accessed on 5 April 2019).
34. Advisory Panel, Culture and History Research Center of Kunming. *No. 1 Asia's Flower Capital: An Oral History of Flower Agribusiness Development in Dounan, Kunming*; Yunnan People's Press: Kunming, China, 2018.
35. Bureau of Statistics of Yunnan. *Yunnan Statistical Yearbook, 2011*; China Press of Statistics: Beijing, China, 2012. Available online: http://stats.yn.gov.cn/tjsj/tjnj/201901/t20190121_834609.html (accessed on 10 February 2019).
36. Bureau of Statistics of Yunnan. *Yunnan Statistical Yearbook, 2017*; China Press of Statistics: Beijing, China, 2018. Available online: http://stats.yn.gov.cn/tjsj/tjnj/201810/t20181030_809120.html (accessed on 10 February 2019).
37. Kunming Dounan Flower Market. Available online: https://baike.baidu.com/item/%E6%98%86%E6%98%8E%E6%96%97%E5%8D%97%E8%8A%B1%E5%8D%89%E5%B8%82%E5%9C%BA/6926824?fr=aladdin (accessed on 10 February 2019).
38. Natural Resources in Tonghai County. Available online: http://www.tonghai.gov.cn/zhjs/20190306/562377.html (accessed on 26 March 2019).
39. Tonghai Agricultural Office. Statistics of Tonghai's Cooperatives. 2018. Available online: http://www.tonghai.gov.cn/thxzfxxgk/thxnyj/ (accessed on 20 March 2019).
40. Zhu, J.; Li, B.; He, B. Is linked migration overlooked in peri-urban Shanghai? Uncovering the domino effect of driving away interregional migrants. *Habitat Int.* **2019**, *94*, 102046. [CrossRef]
41. Bureau of Statistics of Tonghai. *Tonghai Yearbook of Statistics, 2017*; China Press of Statistics: Beijing, China, 2018. Available online: http://www.tonghai.gov.cn/thxzfxxgk/thtjgbzl/20180403/810229.html (accessed on 20 March 2019).
42. Mcgee, T.G.; Guldin, G.E. *Farewell to Peasant China: Rural Urbanization and Social Change in the Late Twentieth Century*; Routledge: London, UK, 1997; Volume 42, p. 144.
43. Bryceson, D.F. Deagrarianization and rural employment in sub-Saharan Africa: A sectoral perspective. *World Dev.* **1996**, *24*, 97–111. [CrossRef]
44. Ajay, S. Urban Proximity and Spatial Pattern of Land Use and Development in Rural India. *J. Dev. Stud.* **2016**, *52*, 1593–1611.
45. Chang, C.; Wang, Y. The Nature of the Township-Village Enterprise. *J. Comp. Econ.* **1994**, *19*, 434–452. [CrossRef]
46. Bureau of Statistics of Kunshan. *Kunshan Yearbook of Statistics, 2016*; China Press of Statistics: Beijing, China, 2017. Available online: http://www.ks.gov.cn/kss/bmdt/201710/c5599f771e26475aba7838a2219b377d.shtml (accessed on 20 March 2019).
47. Bureau of Statistics of Nanhai. *Nanhai Yearbook of Statistics, 2016*; China Press of Statistics: Beijing, China, 2017. Available online: http://www.nanhai.gov.cn/fsnhtjj/gkmlpt/content/2/2153/post_2153575.html#1854 (accessed on 20 March 2019).
48. Fan, C.C. *China on the Move: Migration, the State, and the Household*; Routledge: London, UK, 2007.
49. National Bureau of Statistics of China. *China Statistical Yearbook*; China Statistical Publishing House: Beijing, China, 2001. Available online: http://www.stats.gov.cn/english/statisticaldata/yearlydata/YB2001e/ml/indexE.htm (accessed on 20 March 2019).
50. National Bureau of Statistics of China. *China Statistical Yearbook*; China Statistical Publishing House: Beijing, China, 2016. Available online: http://www.stats.gov.cn/tjsj/ndsj/2006/indexeh.htm (accessed on 20 March 2019).
51. National Bureau of Statistics of China. Monitoring and Investigation Report on Migrant Workers in 2015. Available online: http://www.stats.gov.cn/tjsj/zxfb/201604/t20160428_1349713.html (accessed on 31 July 2017).
52. National Bureau of Statistics of China. Monitoring and Investigation Report on Migrant Workers in 2009. Available online: http://www.stats.gov.cn/ztjc/ztfx/fxbg/201003/t20100319_16135.html (accessed on 31 July 2017).
53. Bureau of Statistics of Tonghai. *Tonghai Yearbook of Statistics, 2016*; China Press of Statistics: Beijing, China, 2017. Available online: http://www.tonghai.gov.cn/thxzfxxgk/thtjgbzl/20170609/577466.html (accessed on 20 March 2019).
54. Bureau of Statistics of Jiangsu. *Jiangsu Yearbook of Statistics, 2017*; China Press of Statistics: Beijing, China, 2018. Available online: http://tj.jiangsu.gov.cn/col/col64418/index.html (accessed on 20 March 2019).
55. Bureau of Statistics of Zhejiang. *Zhejiang Yearbook of Statistics, 2017*; China Press of Statistics: Beijing, China, 2018. Available online: https://zjjcmspublic.oss-cn-hangzhou-zwynet-d01-a.internet.cloud.zj.gov.cn/jcms_files/jcms1/web3077/site/flash/tjj/Reports1/2020%E7%BB%9F%E8%AE%A1%E5%B9%B4%E9%89%B420200929/2017%E7%BB%9F%E8%AE%A1%E5%B9%B4%E9%89%B4%E5%85%89%E7%9B%98%E6%94%B9%E5%90%8E20200929/indexch.htm (accessed on 20 March 2019).
56. Liu, S.J. *A Study on Jiangnan's Towns in Ming and Qing Dynasties*; China Social Sciences Press: Beijing, China, 1987.
57. Ju, X.; Gu, B.; Wu, Y.; Galloway, J.N. Reducing China's fertilizer use by increasing farm size—ScienceDirect. *Glob. Environ. Chang.* **2016**, *41*, 26–32. [CrossRef]
58. Wu, Y.; Xi, X.; Tang, X.; Luo, D.; Gu, B.; Lam, S.K.; Vitousek, P.M.; Chen, D. Policy distortions, farm size, and the overuse of agricultural chemicals in China. *Proc. Natl. Acad. Sci. USA* **2018**, *115*, 7010–7015. [CrossRef]

sustainability

MDPI

Article

Is "Attending Nearby School" Near? An Analysis of Travel-to-School Distances of Primary Students in Beijing Using Smart Card Data

Cong Liao [1,2] and Teqi Dai [3,*]

[1] Institute of Remote Sensing and Geographical Information Systems, Peking University, No. 5 Yiheyuan Road, Haidian District, Beijing 100871, China; liaocong233@pku.edu.cn
[2] Beijing Key Laboratory of Spatial Information Integration & Its Applications, Beijing 100871, China
[3] Beijing Key Laboratory for Remote Sensing of Environment and Digital City, School of Geography, Faculty of Geographical Science, Beijing Normal University, No. 19, Xinjiekouwai Street, Haidian District, Beijing 100875, China
* Correspondence: daiteqi@bnu.edu.cn

Abstract: The distance between home and school is crucial for children's mobility and education equity. Compared with choice-based enrollment systems, much less attention has been given to the commuting distance to school in proximity-based systems, as if the institutional arrangement of assigning children to nearby schools can avoid the problem of long commuting distances. Using student-type smart card data, this study explored the spatial characteristics of the commuting distance to primary schools by public transport and the residence-school spatial pattern under the proximity-based system in Beijing. The relationships between long school commutes and house price/age were investigated under the context of school gentrification. For the identified primary student users, fewer than 35% of the students travelled fewer than 3 km to school, while more than 80% of students travelled long distances greater than 5 km, which indicated that the policy of "attending nearby school" did not guarantee a shorter commuting distance to school. Long distances to school greater than 5 km correlate negatively with a lower average house price/building age and fewer students. This finding verified the assumptions from China's school gentrification that people might buy older school-district houses but live far from the school district for a new house. These findings provide a complementary view of previous survey studies and reveal the actual commuting distance by public transport for a group of primary students in a proximity-based enrollment system.

Keywords: educational equality; house price; proximity-based system; commuting modal; children's mobility

Citation: Liao, C.; Dai, T. Is "Attending Nearby School" Near? An Analysis of Travel-to-School Distances of Primary Students in Beijing Using Smart Card Data. *Sustainability* **2022**, *14*, 4344. https://doi.org/10.3390/su14074344

Academic Editors: Mengqiu Cao, Claire Papaix, Tianren Yang and Benjamin Büttner

Received: 10 March 2022
Accepted: 4 April 2022
Published: 6 April 2022

1. Introduction

Access to education is one important aspect for individual development and social sustainability. Generally, travel to school is a daily activity for children to access education. Analyzing the travel characteristics of students is an important prerequisite for understanding children's mobility and further space intervention in educational inequality. The distance between home and school is a crucial factor for a wide range of topics on children's mobility and travel characteristics. The distance between home and school is a main correlating factor in acquiring the admission qualification of primary schools, and in influencing travel mode choice and has been associated with equal educational opportunity [1–3], academic achievement [4,5], active school transport and health benefits [6–8]. Moreover, it affects a city's spatial and functional structure and contributes to urban problems such as transport congestion [9]. Therefore, the distance between home and school becomes a key element for policy making in educational equity, children mobility and urban planning.

A common trend of increasing distance has been observed in many Western developed countries, such as the USA, England, Canada, Australia, Sweden and Ireland [10–14]. This trend has often been placed in the context of liberal educational reforms pertaining to school choice in many Western countries since the late of 1980s. Most studies of travel-to-school distances assume that the distance between home and school increases as the price of more school choices towards choice-based systems [13,15]. The social status of families and other factors of travel-to-school distance have been investigated and have rich implications for school choice, student health or educational equity [16–19].

In contrast, the distance from home to school under the proximity-based enrollment system has been under studied, although equity issues under the nearby enrollment policy have received an increasing amount of attention in recent years. Existing studies have explored the complex issues of the nearby enrollment policy on educational equity, such as the unbalanced distribution of education resources or social stratification from parents' bidding on residence properties for high-quality schools, focusing on education gentrification [20–22], school district distortion [23], or education-led spatial disparities [24–26]. Few studies have discussed school distance under a proximity-based enrollment system. One reason may be that the institutional arrangement of assigning children to nearby schools is automatically regarded as strictly implemented and could effectively avoid the problem of long commuting distance. However, this situation may not hold in reality [27,28]. The study found that the ratio of long school commuting distances under the proximity-based enrollment system in China was rather high, approximately 13% to 27% across Beijing for distances greater than 5 km [29]. This finding was echoed by Yang et al. and Xiang et al. [30,31]. Zhang et al. revealed that long school commuting distances greater than 6 km in Beijing were mostly travelled by public transport [32]. Compared with the situation of travelling by car or school bus, this group is worthy of further research and would well fit the advantage of spatial analysis with geospatial big data of public transport.

With the rapid development of information and communications technology (ICT), the individual-based geospatial big data collected by various location-aware devices, such as mobile phones, subway smart cards and social media check-ins, have been employed to offer observations of human mobility, although there is not a clear and widely accepted definition [33,34]. Big data provide good opportunities to understand the characteristics of commuting distances between home and school. Compared with the low frequencies and vast workload of survey data, big data can broaden the knowledge on commuting and gain insights that are previously unattainable through traditional datasets [35,36]. There is a rapid growth of literature in conducting empirical studies on human mobility patterns and their dynamics characteristics by using geo-tagged big data [37,38]. Most papers have focused on the mismatch of work commuting patterns [39–41]. Certain papers have discussed specific groups of people, such as extreme travelers and elderly people [42–44]. Although there was a "spatial turn" in education [45], studies of spatial analyses in education research are still limited [46]. Moreover, few studies have applied geospatial big data to analyze the characteristics of the school commuting behaviors of basic education student groups. To the best of our knowledge, in social sensing research by geo-tagged big data, only one paper addressed university students [47] and only one addressed children's school commuting behaviors [48]. Both papers did not relate their studies to educational policy or equity.

The group of students with long commuting distance to school means the law of "attending nearby school" may not be complied with. We prefer to focus this research with a different assumption than previous research, that is, the nearby enrollment policy is not a panacea to ensure nearby enrollment, and at least two groups should be distinguished. The first group comprises those who comply with the policy, while the second group includes those who do not comply with the policy. The latter group might use very different spatial strategies to obtain educational resources, and existing studies have revealed that the proportion of this group is not small, at least in Beijing [29–31]. However, this group was largely disregarded in previous studies. Both the approaches of survey and big data can be utilized in this study. Considering that an interviewee may provide a school-district address instead of their actual residential address, this study uses smart card data (SCD).

Certain limitations, such as a lack of personal information or possible errors from the algorithm, may arise. However, big data may reflect the overall situation, and public transportation reflects the majority of students with long commuting distances [32].

This study aims to use student-type smart card data to explore the spatial characteristics of long school commuting by public transport in Beijing and to explore the relationships between school commuting and residence in the context of school gentrification.

The remainder of this article is organized as follows. We first describe our methodology, followed by the results analysis. The discussion section presents the implications for policy making, and the final section presents the conclusions.

2. Methodology

2.1. Study Area

As the capital of China, Beijing has a special political symbolism. We expect that Beijing could be representative of Chinese cities in educational institutional arrangements [49]. More than 86.5% of Beijing's population was classified as urban in 2015, most of which lived in six urbanized areas of Beijing. As shown in Figure 1, the six urbanized districts include Dongcheng District, Xicheng District, Chaoyang District, Fengtai District, Shijingshan District and Haidian District. Dongcheng District and Xicheng District are regarded as core districts of Beijing. The study spans an area of 1369 square kilometers, inhabited by 12.8 million people, which is subdivided into 103 subdistricts and 5429 residential quarters as of 2015. There were 550 primary schools within six urbanized areas of Beijing in 2015, with a total of 521,277 students. Among them, the core districts have 144 primary schools and 115,939 students.

Beijing has a convenient public transport system, and the transit price is quite low due to large subsidies by the government. Approximately 780 bus lines pass through the case study area and more than 3000 bus stations are within the study area. In terms of subway system, there are 17 subway lines and 256 subway stations within the study area.

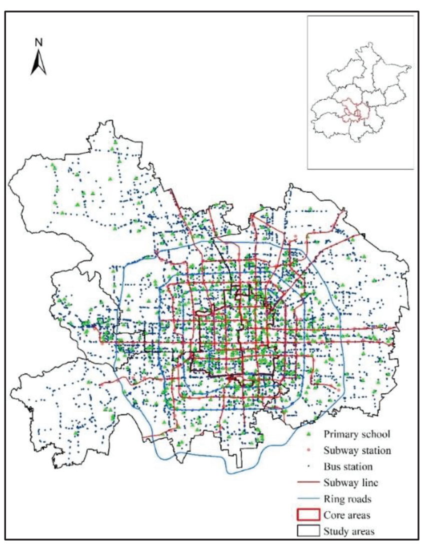


Figure 1. Overview of the study area.

2.2. Data Collection and Preprocessing

This work was supported by data of bus smart card records and subway card records of student type during workdays of one week from 13–17 June 2016, obtained from Beijing Public Transport Group. The dataset contains 6,080,225 and 879,089 records of bus and subway cards with card swiping times of pick-ups and drop-offs, respectively. Data preprocessing was conducted to remove irrelevant attributes or invalid records. After data preprocessing, the sample of each record contained 6 attributes, as listed in Table 1. The student-type card is used in this research, indicated by number 18 or 19. Student cards can only be used by students at primary schools, secondary schools and universities in Beijing. Student cards can provide a special transit price discount of 2.5%.

Table 1. Typical sample record of SCD.

Card ID	Swiping Time	Line Num.	Bus Stop to Get On	Bus Stop to Get Off	Card Type
19151591	20160614071535	331	12	18	18

The housing price/age data are extracted from the LIANJIA platform (https://bj.lianjia.com/, accessed on 30 January 2019), a widely employed housing trading platform in China. The housing price data include approximately 89,742 second-hand house transaction records of the study area in 2018.

Based on the preprocessed data, several steps were completed to investigate the residence-school spatial pattern, as shown in Figure 2.

Figure 2. Workflow of the study.

2.3. Identifying Primary Student Travelers

The first step of this study is to identify travelers who are primary students using public transport. The records of student-type SCD are extracted. In Beijing, primary school students are just one category of students who are eligible to use student cards. Other types of school students, such as college students and high school students, can also own student cards. Therefore, distinguishing different travel characteristics between primary school students and other types of students is critical.

In existing studies, temporal information, spatial information and frequency in travel behavior are commonly employed to describe the travel regularity and identify of the specific groups [50]. In this research, we use this kind of information to identify primary students, focusing on the following special features of Beijing primary schools. In Beijing, primary schools start at 8 o'clock in the morning and end at 3 o'clock in the afternoon. The end time of primary school is different from that of other types of schools. According to this special regular pattern of Beijing primary schools, we set the following four rules to distinguish primary students from other types of students:

(1) The card type is a student card, which excludes the travel records of nonstudent cardholders;
(2) The swiping time is between 5:00 and 8:00 AM or 15:00–18:00 PM, which excludes travel behaviors of students who do not commute to school in the morning or afternoon bell times in Beijing;
(3) Cards are swiped two times a day and three days a week, which considers the periodicity of primary students' commuting to reduce the interference of other non-primary students;
(4) There is a primary school near the alighting station, which expresses that students' travel destinations are to primary schools.

Though students in Beijing go to school five days a week, we set the threshold as three, considering too high a threshold may miss some students who might use private cars or taxis in certain conditions. This threshold identifies regular school commuting and sets these student-card users as primary students.

Based on the above rules, there are 35,847 primary student cardholders on weekday commutes to primary schools by public transport. The ratio of primary students who commute to schools by public transport to all primary students is 6.88%. The ratio is close to the public transport travel data (approximately 9.4%) in the Pupil Travel Survey by the Beijing Municipal Commission of Transport in 2014.

After a card record is identified as the primary student type, the residence and corresponding school is allocated. The most frequently used daily boarding stations are identified as proxies of residence by examining the maximum frequency of all boarding stations during the week. As distance is one of the most important factors in inferring trip purposes [51,52], the distances from stations to schools are utilized to identify the residence and the school. In this research, following previous studies [47,53], the boarding station is set as the students' residence address and the nearest school to alighting stations as students' destination.

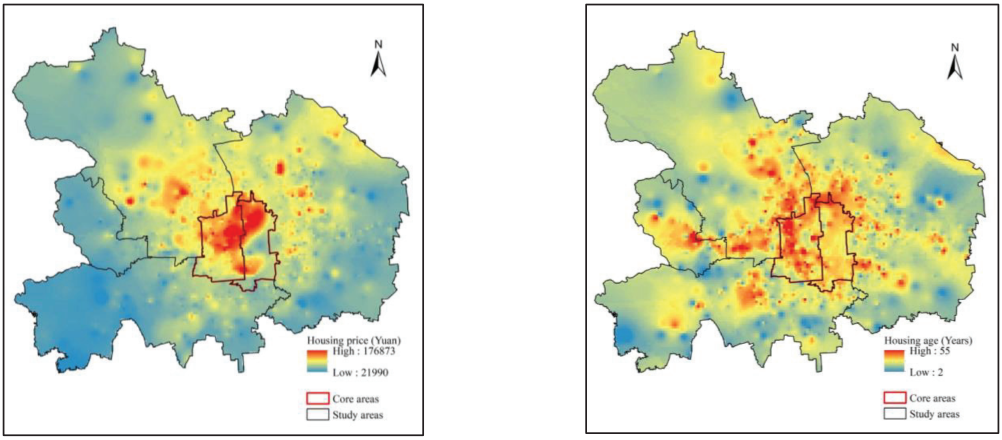
2.4. Defining Long-Distance Schooling Commuters

There are no distinct and consistent specifications for the distance threshold of "nearby". Although the policy of "attending nearby school" is obliged by the Compulsory Education Law of China, there is no official definition for "nearby". We address four key distance thresholds in Figure 2. The first two distance thresholds pertain to the standard of "near". The first threshold is the average shortest Euclidean distance from all residential locations to schools. The second threshold of 2 km or 3 km is obtained from existing papers [14,15,54]. The other two distance thresholds pertain to the standard of "far". The third distance threshold was set to 5 km, which is regarded as too far to commute for primary school pupils [55,56]. In this study, a distance of 5 km was selected as the threshold distance for long distance. To reveal extreme commuting, a distance of 10 km was also investigated.

2.5. Relating Long-Distance Commuting to House Price/Age

This study examines how the distribution of long commuting distances to school may correlate with the spatial variation in average housing price and building age based on the context of school gentrification in Beijing. According to the catchment zone policy for school enrollment, many well-off middle-class parents would seek to purchase house property in the catchment zone of a good school to obtain a school place for their child [20]. The competition for these houses within the school catchment areas of leading statement schools has led to a serious inflated price for school district houses [57]. Due to the short-term occupancy (generally nine years of elementary and junior middle schooling), these middle-class parents generally have no incentive to refurbish those old buildings before they sell them to the new gentrifying families [21,22]. Wu et al. referred to this variant form of gentrification as "Jiaoyufication" in the inner city [58], i.e., a middle-class makeover of inner-city districts connected with schools. Inflated prices and old buildings are two typical characteristics of "Jiaoyufication". The place dependence on schools drives gentrifying families to move home in Beijing [30]. Consistent with the above discussion, we accordingly hypothesize that a long commuting distance to school leads to a lower average house price and newer average building age.

The spatial interpolation method of the inverse distance weighted (IDW) technique is selected to calculate the house price data at locations without transaction records [59]. The search radius used in the interpolation method is set to 1 km. The method transforms the housing locations into a raster system, so that the relationship between housing price/age and distribution of students can be assessed at the same scale. Figure 3 illustrates the spatial data of housing price/age of the study area. The grid values are extracted to facilitate the correlation analysis.



(**a**) (**b**)

Figure 3. Spatial data of housing price/age; (**a**) housing price and (**b**) housing age.

3. Results

Figure 4 illustrates the distribution and cumulative proportions of primary student commuters with public transport by travel distances with a step of 1 km. The curve of distribution proportions showed an upwards trend first and then a downwards trend. The dividing point between the proportion of rising and falling is 5 km. Before 5 km, the number of students who use public transport increases with an increase in the commuting distance. Between 5 and 10 km, a high proportion of students is generally maintained, approximately 6%. The total number of students between 5 km and 10 km accounts for nearly 30% of students using public transport. At distances greater than 10 km, the number of students decreases with an increase in the commuting distance. The average shortest Euclidean distance from all residential locations to schools is 0.37 km. Approximately 96% of students who travel by public transport traveled over this threshold distance. The proportion of students with commuting distances within 2 km or 3 km is about 4.69% and 8.91%, respectively. This finding suggests the disadvantage of public transport in the modal competition for short commuting distance. The proportion of students with commuting distances greater than 5 km is approximately 81.19%. For extreme commuters, the corresponding ratio of students with distances greater than 10 km is approximately 51.89%. Overall, according to the various definitions of "near" or "far", the policy of "attending nearby school" was poorly implemented in the study area.

Figure 5 illustrates the kernel density distribution of students with commuting distances greater than 5 km by their boarding and alighting points. Using the Jenks method in ArcGIS, the density values are divided into five grades. This method can minimize the differences within each type and maximize the differences among each type. For the boarding points, there are several high-density regions around the core areas of Beijing. A relatively high-density band is formed between the second ring road and the fourth ring road. Due to the small number of students near to the peripheral areas, the overall density in these areas is also small. For the alighting points, the high-density areas are more concentrated. Compared with the density by boarding points, the density value of alighting points at the high level is greater. The core areas are important destinations for students with commuting distances greater than 5 km. In addition to the core areas, the east and northwest of the core areas are two other important high-density areas. On the whole, compared with the students' residences, the area covered by students' destination is more compact.

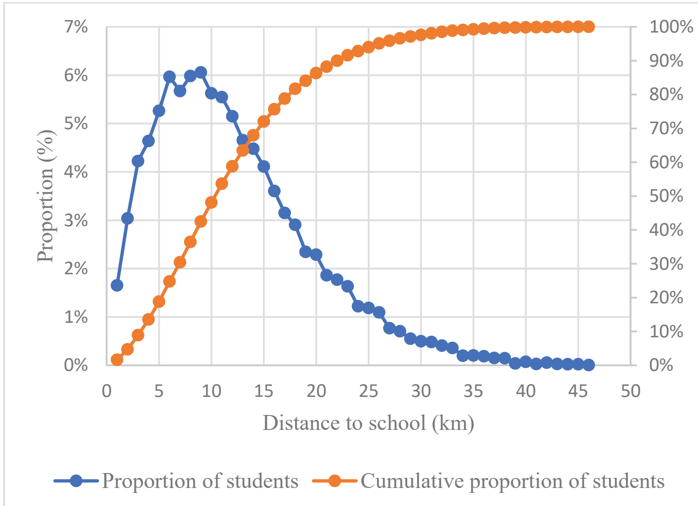
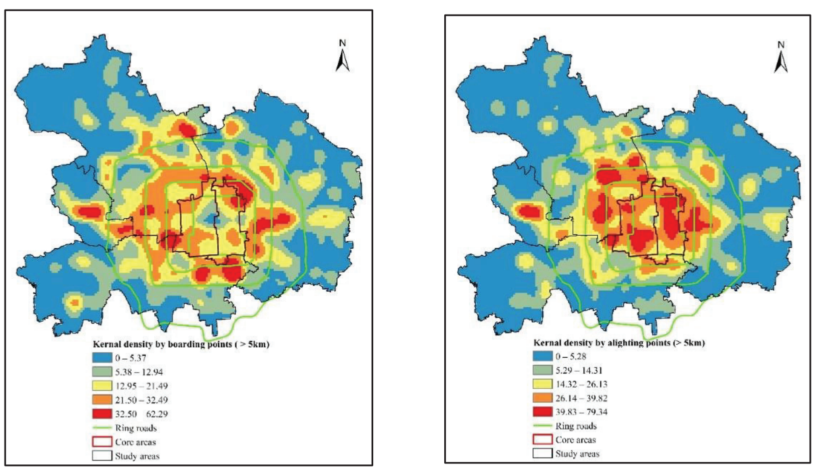


Figure 4. Distribution of commuters by distance.



(**a**) (**b**)

Figure 5. Kernel density of students' boarding (**a**) and alighting points (**b**) with commuting distance great than 5 km.

Figure 6 illustrates the relationship between the average house price and commuting distance to school that is greater than 5 km. All the data were segmented and aggregated at a step of 1 km. The abscissa represents the average distance to school. The ordinate represents the average house price within this distance interval. The size of the ball indicates the number of students in this range. There was an overall decreasing trend of house prices as the distance increased to values greater than 5 km. Average house prices decrease with average distance. The goodness of fit of the linear function is 0.88. This finding implies a similar tradeoff between school commuting and average housing price, as shown in the classic Alonso model on working, commuting and housing.

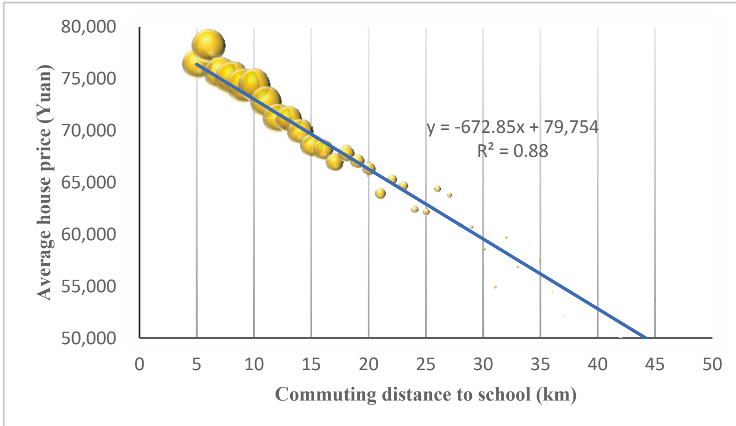


Figure 6. Relationship between average house price and long commuting distances to school.

Figure 7 illustrates the relationship between average building age and commuting distance to school that is greater than 5 km. All the data were segmented and aggregated at a step of 1 km. The abscissa represents the average distance to school. The ordinate represents the average building age within this distance interval. The size of the ball indicates the number of students in this range. There was an overall decreasing trend of average building age as the distance increases. The goodness of fit of the linear function is 0.95. This result implied a similar tradeoff between school commuting and average building age, as people might buy an older house in a school district but live in a new residence at a farther distance [58].

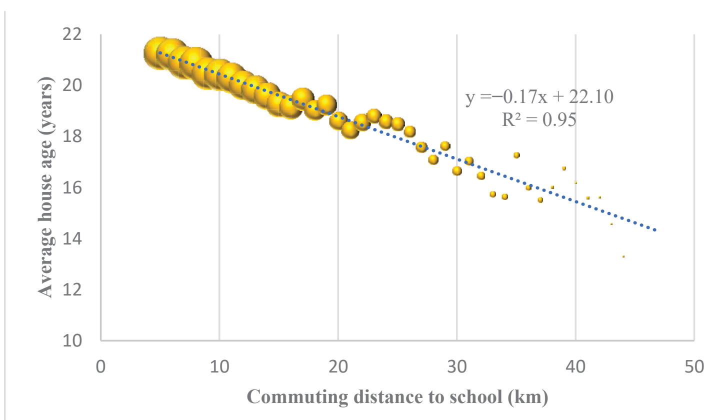


Figure 7. Relationship between average house age and long commuting distances to school.

4. Discussion

The results indicate that most students who travel by public transport do not attend their nearby schools. Only 34.89 % of students attend a school located fewer than 3 km from home, while 55.76 % of them attend a school more than 5 km from home. For students with commuting distances greater than 5 km, several high-density regions of boarding points around the core areas of Beijing appear. Compared with the density of boarding points, the density value of alighting points is more concentrated in the core areas. The commuting distance is significantly affected by housing prices and housing age. The analysis of the relationship between average house price and average commuting distance that is greater than 5 km and the number of students in these disadvantaged groups illustrates that higher house prices correlate negatively with long school distance. Existing Western literature also reveals that a rather high ratio of parents would send their children outside the nearby school district [27,28]. For this study, we restate another issue regarding different spatial strategies to obtain educational resources and the ambiguous and distorted district zoning [23].

Although the policy of "attending nearby school" has legal status in China, the results of the case study by public transport indicate that the policy was not well implemented. Under this proximity-based system, the efficiency of attending school is a priority. The eligibility to attend school is determined by school district, which is generally delineated according to the distance rule. A recent study by Xiang et al. explored the influencing factors on school distance under a proximity-based enrollment system, but the group of students with long school commuting distances were not analyzed separately [31]. The actual commuting distance to school is more complicated. Besides the unclear division rules of school district boundaries [23], this study revealed that inconsistencies exist between the actual residential address and the eligible registration address for enrollment. Many students may not actually live in these registered home addresses, as some school district housings are usually old, small and not suitable for living [22]. This study illustrated that actual commuting distance to school can be better captured by individuals' trajectory information of geo-tagged big data.

A long commuting distance has equality applications. The existing research reveals that geography has an important role in education [2,16]. The travel distance to schools, especially good schools, is related to students' equal access to opportunities [1]. Affordable housing prices and building age vary by space, and these two factors have a significant influence on a long commuting distance to school. In many cases, the ability of students to attend a good school is closely related to the social and cultural capital of their families [26,30]. A negative effect is discussed in the studies related to "capitalization of school district" and "Jiaoyufication" [57,58]. Institutional factors, such as registration status, complicate this issue [23]. To promote the equal allocation of educational opportunities in a proximity-based system, improvements in the spatial assignment mechanism towards equality are needed [60].

5. Conclusions

By using student-type SCD and other geo-tagged big data on housing prices and primary schools, this research investigates the residence-school spatial pattern of students in Beijing, focusing on the effectiveness of the proximity-based allocation system on commuting distance to school from an equity perspective. This research highlighted not only the importance of using SCD for transport analysis, but also social equity and educational policy making. The study contributes to the present literature on the geography of education and geo-tagged big data.

It was found that about 81.19% of students who commuted to school by public transport traveled a long distance of more than 5 km. Above the threshold distance of 5 km, the number of primary students decreased with the distance to school. In addition, there was a highly negative correlation between the house price/building age and distance to school. The analysis can offer information on spatial distribution of long-school-commuting students and may raise concerns on the effectiveness of the policy of "attending nearby school", as well as children's health, traffic congestion and other sustainability issues. In light of the close association to lower house prices far from school and old buildings near school, this study provides evidence for "Jiaoyufication" and has implications on complex location decisions for school commuting.

The analysis showed a comprehensive picture of the distance to school of all primary students by public transport, therefore providing a sound basis for further survey research. Future work could be extended in the following directions: First, this study only analyses the travel-to-school distance by public transport. An integrated analysis that combines other modes, such as walking and private cars will be valuable for revealing the system characteristics of students' commuting distance in the future. Second, students' attribute information, such as gender and household structure, can be further enriched by home interview surveys in addition to housing price/age. More attribute information better describes students' choices of attending school. Third, due to the lack of data to evaluate the quality of schools, this study cannot assess who is attending good schools. Fourth, dynamic analysis of the residence-school spatial pattern is necessary, and the development of computational tools to conduct periodical analysis and prognosis is interesting [61,62].

Author Contributions: C.L.: conceptualization, methodology, writing—original draft; T.D.: writing—review and editing, supervision, project administration and funding acquisition. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Not applicable.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Talen, E. School, Community, and Spatial Equity: An Empirical Investigation of Access to Elementary Schools in West Virginia. *Ann. Assoc. Am. Geogr.* **2001**, *91*, 465–486. [CrossRef]
2. Hamnett, C.; Butler, T. Geography matters: The role distance plays in reproducing educational inequality in East London. *Trans. Inst. Br. Geogr.* **2011**, *36*, 479–500. [CrossRef]
3. Thelin, M.; Niedomysl, T. The (ir)relevance of geography for school choice: Evidence from a Swedish choice experiment. *Geoforum* **2015**, *67*, 110–120. [CrossRef]
4. Falch, T.; Lujala, P.; Strøm, B. Geographical constraints and educational attainment. *Reg. Sci. Urban Econ.* **2013**, *43*, 164–176. [CrossRef]
5. Lin, J.J.; Huang, Y.C.; Ho, C.L. School accessibility and academic achievement in a rural area of Taiwan. *Child. Geogr.* **2014**, *12*, 232–248. [CrossRef]
6. Buliung, R.N.; Mitra, R.; Faulkner, G. Active school transportation in the greater Toronto area, Canada: An exploration of trends in space and time (1986–2006). *Prev. Med.* **2009**, *48*, 507–512. [CrossRef]
7. Hodgson, S.; Namdeo, A.; Araujo-Soares, V.; Pless-Mulloli, T. Towards an interdisciplinary science of transport and health: A case study on school travel. *J. Transp. Geogr.* **2012**, *21*, 70–79. [CrossRef]
8. Chillón, P.; Panter, J.; Corder, K.; Jones, A.P.; Van, E. A longitudinal study of the distance that young people walk to school. *Health Place* **2015**, *31*, 133–137. [CrossRef]
9. Marique, A.-F.; Dujardin, S.; Teller, J.; Reiter, S. School commuting: The relationship between energy consumption and urban form. *J. Transp. Geogr.* **2013**, *26*, 1–11. [CrossRef]
10. Hidde, P.; van Merom, D.; Corpus, G.; Bauman, A.E. Trends in Australian children traveling to school 1971–2003: Burning petrol or carbohydrates? *Prev. Med.* **2008**, *46*, 60–62.
11. Hine, J. The provision of home to school transport in Northern Ireland. *Res. Transp. Econ.* **2009**, *25*, 29–38. [CrossRef]
12. Andersson, E.; Malmberg, B.; Östh, J. Travel-to-school distances in Sweden 2000–2006: Changing school geography with equality implications. *J. Transp. Geogr.* **2012**, *23*, 35–43. [CrossRef]
13. McDonald, N.C. Active transportation to school—Trends among US school children, 1969–2001. *Am. J. Prev. Med.* **2007**, *32*, 509–516. [CrossRef] [PubMed]
14. van Goeverden, C.; de Boer, E. School travel behaviour in the Netherlands and Flanders. *Transp. Policy* **2013**, *26*, 73–84. [CrossRef]
15. Burgess, S.; Greaves, E.; Vignoles, A.; Wilson, D. Parental choice of primary school in England: What types of school do different types of family really have available to them? *Policy Stud.* **2011**, *32*, 531–547. [CrossRef]
16. Butler, T.; Hamnett, C.; Ramsden, M.J. Gentrification, Education and Exclusionary Displacement in East London. *Int. J. Urban Reg. Res.* **2013**, *37*, 556–575. [CrossRef]
17. Andre-Bechely, L. Finding Space and Managing Distance: Public School Choice in an Urban California District. *Urban Stud.* **2007**, *44*, 1355–1376. [CrossRef]
18. Wilson, E.J.; Marshall, J.; Wilson, R.; Krizek, K.J. By Foot, Bus or Car: Children's School Travel and School Choice Policy. *Environ. Plan. A Econ. Space* **2010**, *42*, 2168–2185. [CrossRef]
19. Loo, B.P.Y.; Lam, W.W.Y. Does neighbourhood count in affecting children's journeys to schools? *Child. Geogr.* **2015**, *13*, 89–113. [CrossRef]

20. Hu, S.; Song, W.; Li, C.; Lu, J. School-gentrifying community in the making in China: Its formation mechanisms and socio-spatial consequences. *Habitat Int.* **2019**, *93*, 102045. [CrossRef]
21. Wu, Q.; Cheng, J.; Chen, G.; Hammel, D.J.; Wu, X. Socio-spatial differentiation and residential segregation in the Chinese city based on the 2000 community-level census data: A case study of the inner city of Nanjing. *Cities* **2014**, *39*, 109–119. [CrossRef]
22. Wu, Q.; Edensor, T.; Cheng, J. Beyond Space: Spatial (Re)Production and Middle-Class Remaking Driven by Jiaoyufication in Nanjing City, China. *Int. J. Urban Reg. Res.* **2018**, *42*, 1–19. [CrossRef]
23. Bi, B.; Zhang, X. "Attending Nearby Schools" in Central Beijing: Influencing Factors and the Policy Distortion. *Int. Rev. Spat. Plan. Sustain. Dev.* **2016**, *4*, 31–48. [CrossRef]
24. Hu, L.; He, S.; Luo, Y.; Su, S.; Xin, J.; Weng, M. A social-media-based approach to assessing the effectiveness of equitable housing policy in mitigating education accessibility induced social inequalities in Shanghai, China. *Land Use Policy* **2020**, *94*, 104513. [CrossRef]
25. Zhang, Y.; Cheng, T. Inferring Social-Demographics of Travellers based on Smart Card Data. In Proceedings of the CARMA 2018—2nd International Conference on Advanced Research Methods and Analytics, Valencia, Spain, 12–13 July 2018.
26. Xiang, L.; Stillwell, J.; Burns, L.; Heppenstall, A.; Norman, P. A geodemographic classification of sub-districts to identify education inequality in Central Beijing. *Comput. Environ. Urban Syst.* **2018**, *70*, 59–70. [CrossRef]
27. Parsons, E.; Chalkley, B.; Jones, A. School catchments and pupil movements: A case study in parental choice. *Educ. Stud.* **2000**, *26*, 33–48. [CrossRef]
28. Mandic, S.; Sandretto, S.; Bengoechea, E.G.; Hopkins, D.; Moore, A.; Rodda, J.; Wilson, G. Enrolling in the Closest School or Not? Implications of school choice decisions for active transport to school. *J. Transp. Health* **2017**, *6*, 347–357. [CrossRef]
29. Li, S.; Zhao, P. The determinants of commuting mode choice among school children in Beijing. *J. Transp. Geogr.* **2015**, *46*, 112–121. [CrossRef]
30. Yang, Z.; Hao, P.; Wu, D. Children's education or parents' employment: How do people choose their place of residence in Beijing. *Cities* **2019**, *93*, 197–205. [CrossRef]
31. Xiang, L.; Gould, M.; Stillwell, J. What determines pupils' travel distance to school in China? A multilevel analysis of educational access in Beijing. *Urban Stud.* **2021**, *59*, 1048–1067. [CrossRef]
32. Zhang, R.; Yao, E.; Liu, Z. School travel mode choice in Beijing, China. *J. Transp. Geogr.* **2017**, *62*, 98–110. [CrossRef]
33. Batty, M. Big data, smart cities and city planning. *Dialogues Hum. Geogr.* **2013**, *3*, 274–279. [CrossRef] [PubMed]
34. Liu, Y.; Liu, X.; Gao, S.; Gong, L.; Kang, C.; Zhi, Y.; Chi, G.; Shi, L. Social Sensing: A New Approach to Understanding Our Socioeconomic Environments. *Ann. Assoc. Am. Geogr.* **2015**, *105*, 512–530. [CrossRef]
35. Liu, J.; Li, J.; Li, W.; Wu, J. Rethinking big data: A review on the data quality and usage issues. *ISPRS J. Photogramm. Remote Sens.* **2016**, *115*, 134–142. [CrossRef]
36. Welch, T.F.; Widita, A. Big data in public transportation: A review of sources and methods. *Transp. Rev.* **2019**, *39*, 795–818. [CrossRef]
37. Liu, X.; Kang, C.; Gong, L.; Liu, Y. Incorporating spatial interaction patterns in classifying and understanding urban land use. *Int. J. Geogr. Inf. Sci.* **2016**, *30*, 334–350. [CrossRef]
38. Egu, O.; Bonnel, P. Investigating day-to-day variability of transit usage on a multimonth scale with smart card data. A case study in Lyon. *Travel Behav. Soc.* **2020**, *19*, 112–123. [CrossRef]
39. Tao, S.; Rohde, D.; Corcoran, J. Examining the spatial–temporal dynamics of bus passenger travel behaviour using smart card data and the flow-comap. *J. Transp. Geogr.* **2014**, *41*, 21–36. [CrossRef]
40. Ma, X.; Liu, C.; Wen, H.; Wang, Y.; Wu, Y.J. Understanding commuting patterns using transit smart card data. *J. Transp. Geogr.* **2017**, *58*, 135–145. [CrossRef]
41. Manley, E.; Zhong, C.; Batty, M. Spatiotemporal variation in travel regularity through transit user profiling. *Transportation* **2018**, *45*, 703–732. [CrossRef]
42. Long, Y.; Liu, X.; Zhou, J.; Chai, Y. Early birds, night owls, and tireless/recurring itinerants: An exploratory analysis of extreme transit behaviors in Beijing, China. *Habitat Int.* **2016**, *57*, 223–232. [CrossRef]
43. Shao, F.; Sui, Y.; Yu, X.; Sun, R. Spatio-temporal travel patterns of elderly people—A comparative study based on buses usage in Qingdao, China. *J. Transp. Geogr.* **2019**, *76*, 178–190. [CrossRef]
44. Zhao, P.; Liu, D.; Yu, Z.; Hu, H. Long commutes and transport inequity in China's growing megacity: New evidence from Beijing using mobile phone data. *Travel Behav. Soc.* **2020**, *20*, 248–263. [CrossRef]
45. Taylor, C. Towards a geography of education. *Oxf. Rev. Educ.* **2009**, *35*, 651–669. [CrossRef]
46. Lubienski, C.; Jin, L. Geo-spatial analyses in education research: The critical challenge and methodological possibilities. *Geogr. Res.* **2017**, *55*, 89–99. [CrossRef]
47. Wang, M.S.; Zhou, J.P.; Long, Y.; Chen, F. Outside the ivory tower: Visualizing university students' top transit-trip destinations and popular corridors. *Reg. Stud. Reg. Sci.* **2016**, *3*, 202–206. [CrossRef]
48. Mei, D.; Xiu, C.; Feng, X.; Wei, Y. Study of the school—Residence spatial relationship and the characteristics of travel to school distance in Shenyang. *Sustainability* **2019**, *11*, 4432. [CrossRef]
49. Song, Y.; Ding, C.; Knaap, G. Envisioning Beijing 2020 through sketches of urban scenarios. *Habitat Int.* **2006**, *30*, 1018–1034. [CrossRef]

50. Kong, X.Q.; Liu, Y.; Wang, Y.X.; Tong, D.Q.; Zhang, J. Investigating Public Facility Characteristics from a Spatial Interaction Perspective: A Case Study of Beijing Hospitals Using Taxi Data. *ISPRS Int. J. Geo-Inf.* **2017**, *6*, 38. [CrossRef]
51. Wong, B.Y.-M.; Faulkner, G.; Buliung, R. GIS measured environmental correlates of active school transport: A systematic review of 14 studies. *Int. J. Behav. Nutr. Phys. Act.* **2011**, *8*, 1–22. [CrossRef]
52. Gong, L.; Liu, X.; Wu, L.; Liu, Y. Inferring trip purposes and uncovering travel patterns from taxi trajectory data. *Cartogr. Geogr. Inf. Sci.* **2015**, *43*, 103–114. [CrossRef]
53. Liu, Y.Z.; Cheng, T. Understanding public transit patterns with open geodemographics to facilitate public transport planning. *Transp. A Transp. Sci.* **2020**, *16*, 76–103. [CrossRef]
54. Kelly, J.A.; Fu, M. Sustainable school commuting—Understanding choices and identifying opportunities: A case study in Dublin, Ireland. *J. Transp. Geogr.* **2014**, *34*, 221–230. [CrossRef]
55. McDonald, N.C. School Siting—Contested Visions of the Comunity School. *J. Am. Plan. Assoc.* **2010**, *76*, 184–198. [CrossRef]
56. Dai, T.Q.; Wang, L.; Zhang, Y.C.; Liao, C.; Liu, Z.B. The Cost of School Consolidation Policy: Implications from Decomposing School Commuting Distances in Yanqing, Beijing. *Appl. Spat. Anal. Policy* **2019**, *12*, 191–204. [CrossRef]
57. Zheng, S.; Hu, W.; Wang, R. How much is a good school worth in Beijing? identifying price premium with paired re-sale and rental data. *J. Real Estate Financ. Econ.* **2016**, *53*, 184–199. [CrossRef]
58. Wu, Q.; Zhang, X.; Waley, P. Jiaoyufication: When gentrification goes to school in the Chinese inner city. *Urban Stud.* **2016**, *53*, 3510–3526. [CrossRef]
59. Wang, F. *Quantitative Methods and Socio-Economic Applications in GIS [M]*, 2nd ed.; CRC Press: Boca Raton, FL, USA, 2014.
60. Liao, C.; Scheuer, B.; Dai, T.; Tian, Y. Optimizing the spatial assignment of schools to reduce both inequality of education-al opportunity and potential opposition rate through introducing random mechanism into proximity-based system. *Socio-Econ. Plan. Sci.* **2020**, *72*, 100893. [CrossRef]
61. Kostrzewski, M. Sensitivity Analysis of Selected Parameters in the Order Picking Process Simulation Model, with Randomly Generated Orders. *Entropy* **2020**, *22*, 423. [CrossRef]
62. Capocchi, L.; Santucci, J.-F. Discrete Event Modeling and Simulation for Reinforcement Learning System Design. *Information* **2022**, *13*, 121. [CrossRef]

sustainability

MDPI

Article

Street Usage Characteristics, Subjective Perception and Urban Form of Aging Group: A Case Study of Shanghai, China

He Zhu [1], Qianyun Ji [2], Ying Lin [3,*], Ting Wang [1] and Jingqing Lu [2]

[1] School of Architecture and Urban Planning, Beijing University of Civil Engineering and Architecture, Beijing 100044, China; zhuhe@bucea.edu.cn (H.Z.); wangting@bucea.edu.cn (T.W.)
[2] School of Architecture, Tsinghua University, Beijing 100084, China; jqy20@mails.tsinghua.edu.cn (Q.J.); lujq11@mails.tsinghua.edu.cn (J.L.)
[3] School of Architecture and Urban Planning, Hubei Engineering and Technology Research Center of Urbanization, The Key Laboratory of Urban Simulation for Ministry of Natural Resources, Huazhong University of Science and Technology, Wuhan 430074, China
* Correspondence: ianlin@hust.edu.cn; Tel.: +86-10-18600211231

Abstract: Against the background of the aging trend in China, construction and regeneration strategies for an aging-friendly built environment are becoming common, led by urban governments, and public street spaces are the focus of these strategies. Exploring such planning and design strategies can help to improve the social welfare of the aging population and meet their diverse needs. Thus, this paper, through analyzing the determinants of the elderly's needs, examines the relationship between spatial perception and street form, using Shanghai, in China, as a case study. This study contributes to the current literature in two ways: first, it constitutes the first attempt to build a needs hierarchy for aging people in a Chinese developed city; second, our statistical analysis involves large-scale population surveys, which helps us to comprehensively and deeply understand the impact of detailed street forms on the elderly's various spatial perceptions. Our results indicate that the renovation of street space in different areas of cities can be improved by the control of street form, to meet the diverse needs of the local aging group.

Keywords: aging group; usage characteristic; subjective perception; urban form; street space

Citation: Zhu, H.; Ji, Q.; Lin, Y.; Wang, T.; Lu, J. Street Usage Characteristics, Subjective Perception and Urban Form of Aging Group: A Case Study of Shanghai, China. *Sustainability* **2022**, *14*, 5162. https://doi.org/10.3390/su14095162

Academic Editors: Mengqiu Cao, Claire Papaix, Tianren Yang and Benjamin Büttner

Received: 14 March 2022
Accepted: 22 April 2022
Published: 25 April 2022

1. Introduction

Population aging is an inevitable trend in the population age structure when the social economy develops to a certain stage. According to the proportional distribution of the elderly over 65 years old within the total population, the World Health Organization (WHO) classifies the aging society into three levels, namely the aging society (7%), the aged society (14%), and the super-aged society (20%) [1]. At the same time, in 2007, the WHO issued a programmatic document, Global age-friendly cities: A guide, which lists the basic characteristics of elderly-friendly cities according to eight aspects: outdoor space and architecture, transportation, housing, social participation, respect and tolerance, citizen participation and employment, information exchange, and community support and health services [2]. In this context, according to China's seventh national population census, in 2020, there were 190 million people over the age of 65, accounting for 13.5% of the total population, and China is currently in the later stage of an 'aging society'. From 2010 to 2020, the proportion of the population aged 60 and above increased by 5.44%, and the population aged 65 and above increased by 4.63% [3]. In August 2016, China developed and adopted the Outline of the Healthy China 2030 Plan [4]. In 2019, two important official documents from China's central government, Opinions of the General Office of the State Council on Implementing Healthy China Action and Implementation and Assessment Plan of Healthy China Action, were officially issued. Meanwhile, the institute of the Healthy China Action Promotion Committee was also established in the same year [5,6]. Therefore, as the core strategy, all the policies that belong to the theme of 'Healthy China' have aimed to respond to the aging society, and related policies have been continuously implemented since then.

Under the guidance of China's central government, the regeneration of the elderly-friendly built environment has recently become an important and necessary issue at the sub-national level, especially at the urban level. Based on these policies, spatial objects in the elderly-friendly built environment include privately owned houses for the elderly, other privately owned commercial facilities in the city, communities shared by multi-property owners, and public spaces and public service facilities shared by all citizens. Because of the differences in the types of public and private property rights, the responsibility of local governments focuses more on public spaces and public service facilities. Among the various types of public spaces, street space is undoubtedly the most commonly and frequently used type in the city, because the elderly use street space whenever they travel [7]. In addition to playing a basic role in citizens' ability to commute, the street space itself is also a place where various activities, such as social interaction, leisure activities, exercise, recreation, and visiting of the elderly, take place. Thus, due to the importance of street space in the daily activities of the elderly, and the operability of urban aging-friendly renovation under the leadership of the government, this study focuses on the elderly's subjective perception of the street form.

The street form is defined as a three-dimensional space formed by the intersection of the sidewalk, the driveway, and the building interface on both sides of the road, including road pavements, street furniture, transportation facilities, the green landscape, building facades, and other spatial elements [8,9]. The street form carries a traffic function and a life function [10]. The subjective perception of the street form among the elderly involves the psychological information collection and processing of the various spatial elements themselves in the built environment, as well as the interaction between these elements. Research within human–environment relations has shown that subjective perceptions reflect the degree to which the physical built environment matches the behavioral habits of the elderly [11]. The factors that affect psychological satisfaction include personal characteristics, personal preferences, and environmental characteristics [12]. With the rapid development of China's urban economy and the improvement in urban infrastructure, the travel needs of the elderly have increased, and the needs for street space are no longer limited to safety and convenience. The construction and regeneration of street space should achieve more diverse goals on the psychological level, such as improving local identity and inclusiveness. Given that related age-friendly research mostly concentrates on the aspects of housing, community, infrastructure, and public service facilities, there are fewer related studies to investigate the subjective perception at the street level. In addition, very little research has examined the relationship between the elderly group's perception and the detailed street form. Thus, our study focuses specifically on this type of public space, and aims to offer some suggestions for the improvement of their design strategies based on the elderly's perceptions.

This study aims to examine the diverse needs of the aging population for street space by focusing on hierarchically structured data. Accordingly, based on first-hand surveys, we explore the different priority sequences of needs, coming from different ages, genders, living conditions, and education levels. In particular, this study, by using a series of spatial indicators to describe street form, further examines the relationship between the aging population's subjective perception (satisfaction of needs found in the former survey) and the physical urban form. Our study is important because the government-led public space regeneration under aging-friendly policy occurs not only in China, but globally, especially in developed cities with aging societies [13–15]. However, regarding current urban regeneration practices, the construction behavior does not consider the value appeal of different stakeholders. In particular, the related planning and design does not take the psychological feelings of the elderly about the physical environment into account, resulting in a large amount of financial input and social discontent. Therefore, this paper can offer significant insights into the subjective perceptions of the aging population in developed cities regarding the daily use of the street. Furthermore, our study is also conducive to detailed design strategies' formulation and the enhancement of aging people's satisfaction with future street space regeneration. Moreover, our findings would promote a wider dialogue on the social sustainability of the specific social group in the attainment of a desirable city form.

This study contributes to existing knowledge in the following ways. First, it focuses on changes in aging people's priorities and needs regarding developed cities' streets, which is something that relatively few studies have previously explored. This study focuses on the social needs of the elderly beyond their basic traffic needs, as well as the differences and commonalities among elderly groups with different characteristics. Although the regeneration of the aging-friendly environment has been a prosperous topic in China, existing research on aging people's spatial needs mainly focuses on traffic safety or convenience, and the layout of old-age service facilities in cities. The analysis of needs could provide significant clues about how to understand and grasp the perceived focus of this group in more detail. Second, the study employs the semantic differential method, which can help us to better understand the detailed perception of the urban form [16]. Moreover, econometric method analysis also reveals the overall perception trend of the elderly for the street form at the macro-level for the first time. At the micro-level, we focus on individual psychological perceptions and geographical narration through interviews. Thus, the integration of different research methods is helpful to break the barriers between pure psychological cognition research and space design research.

2. Literature Review

This section discusses critical related works on streets from a historic perspective, to summarize the focuses of existing studies in different periods. Since the end of the 20th century, numerous studies have focused on street form's effect on human beings, and have explored the design principles of street space. Streets represent the vitality of a city. A vibrant street does not only have a strong transportation capacity, but allows the integration of multiple functions. This emphasizes that the street space design should be people-oriented, and pay more attention to the needs of street users [17]. Based on the analysis of excellent streets around the world, some scholars proposed that successful streets can contribute to good neighborhood relations and promote the establishment of safe and comfortable environments for residents [18]. In addition, some qualitative evidence also supports the related issues, and increasing studies have begun to focus on the impact of specific spatial characteristics on residents [19–22].

At the beginning of this century, many scholars studied the behavioral characteristics of the elderly in cities and streets, based on behavioral geography, spatio-temporal geography, social investigation, and other methods [23–25]. Vojnovic has shown that accessibility, comfort, safety, and entertainment in streets are more likely to attract people to non-motorized travel [26]. Purciel's research shows that if a street has a pleasant scale, a sense of place, a high degree of street recognition, high visibility, and a rich landscape configuration, it will attract people to travel actively [27]. Millington believed that the factors contributing to pedestrianism include street aesthetics, traffic safety, mixed land use, building density, pavement, street connectivity, service facilities, proximity to sports venues, and parks and greenery [28]. Among the many influencing factors, permeability is the main focus. Tan proposed that a street with high permeability means a high density, good connectivity, and a flat structure based on the permeability angle of the street space, which can bring more interest and choice to residents and stimulate the vitality of the city [29]. The permeable street form has five main basic characteristics: high layout density, good connectivity, many entrances and exits, a non-hierarchical nature, and a pleasant enclosure ratio [30]. Ewing selected eight perceptual characteristics that may affect the walking environment through a literature review, namely image, enclosure, human scale, transparency, complexity, recognizability, relevance, and coherence, and proposed a quantification method for the first five characteristics [31]. Sugiyama found that people living in a supportive environment tend to walk, and that influencing factors include the neighborhood space, the quality and openness of green space, comfortable environmental factors, and better health conditions, through a questionnaire survey of the elderly's outdoor activities [32]. Neighborhood environments can promote the health of the elderly in two ways: one is to make them more active, and the other is to provide them with places to socialize with others and enjoy nature.

Recently, under the concept of the healthy city, there have been numerous studies on the impact of street form on pedestrian activities. Winters et al. recorded the daily activity trajectories of the elderly based on the question of where and how to go, and found that the elderly in the accessibility community engage in a higher frequency of walking activities, more intensive social interactions, and more walking and physical exercise; the modes of transportation during these activities are more likely to be walking or public transportation [33]. Similarly, Elsawahli pointed out that permeability, accessibility, and walkability are key factors in age-friendly communities [34]. Burton et al. explored the influence of the outdoor environment on the perceptions of the elderly, and they introduced the concept of 'living street' to propose that an elderly-friendly living street should follow the principles of familiarity, legibility, uniqueness, accessibility, comfort, and safety [35], Sun et al., taking Hong Kong as an empirical case, put forward a similar view [36]. By establishing a measurement system for the quality of street walking activities, Xu and Shi analyzed the relationship between quality and the built environment, and found that continuous storefronts, dense road networks, greenery, seating facilities, high-quality building facades, historical buildings, and a pleasant scale are of great significance to the improvement of the quality of walking activities [37]. In addition, studies have shown that street space has a healing effect on users, which is related to the street's green vision rate and street interface, and increasing the street's green vision rate can improve the healing effect [38]. Han et al. analyzed the impact of street attractiveness on the feasibility of activities among the elderly, and found that in terms of street life, the density of street facilities can promote leisure and social activities; in terms of street aesthetics, street greenery can positively regulate their willingness to perform daily activities, and the interface continuity of the road helps to improve the frequency of leisure social activities [39]. Tan et al. showed that the intervention degree of the community walking environment can effectively express the health intervention performance of the walking environment regarding people's physical activity; a community walking environment with a dense road network, convenient public transportation, excellent service facilities, and high environmental quality has a higher degree of intervention for physical activity, which helps to improve the health of people [40].

Therefore, overall, various factors of street form can exert different effects on people, and the influential degree can be measured. However, as for the aging group, which detailed factors and which combinations of factors are determinants is still unclear. The internal difference in the aging group also does not obtain enough attention. In addition, in existing studies, the effects coming from street form, maintenance, management, and the land function layout outside the street, etc., usually are not well distinguished. Thus, in order to examine the spatial determinants related to elderly-friendly street design, this paper tries to build linear relationships between the spatial factors and perceptions of aging people by employing both space survey and social survey methods.

3. Methodology

3.1. Case Study

Shanghai is the most economically developed city in China, with a GDP of approximately USD 679.1 billion in 2021 [41]. Meanwhile, Shanghai is one of the most serious aging cities in China. It entered an aging society in 1979 [42]. At the end of 2019, the proportion of the elderly aged 65 and above in the household registration population reached 23.0%, and the proportion of the elderly population over 60 years old was as high as 34.4% [43], which means that, on average, one in every three members of the registered population is over 60 years old, and one in every five in the registered population is over 65 years old.

In addition, Shanghai is also the leading city in China in the construction of elderly-friendly spaces. Since 2009, China's central government has selected a number of cities with a serious aging phenomenon in the eastern region (the eastern coastal and northeast industrial bases), to carry out the experimental policy of building aging-friendly cities. The national policy encourages local governments to enhance the sustainable ability of cities to cope with the aging problem by improving the built environment [44]. Shanghai was one of them. Furthermore, in recent years, Shanghai has successively issued local policies to deal with the aging society, such as the Regulations on the Protection of the Rights and Interests of the Elderly in Shanghai and Guidelines for the Construction of Shanghai Elderly Friendly Cities (Trial), which specifically declared the requirements for the walking environment and traffic system to ensure the safety of the elderly, and the requirements for the improvement of the orientation and safety performance of the road system [45,46]. Thus, Shanghai constitutes a typical example of an aging society, with which we can explore the elderly's perceptions of streets.

3.2. Study Design

This study consists of two steps, as shown in Figure 1. The first stage is the research of the Shanghai aging population's needs and usage characteristics with street space. Through a questionnaire survey, preliminary statistics of the current travel habits and travel experiences of Shanghai's aging population are explored. Then, the needs system of the aging population is further refined, and the priority of the needs is ranked.

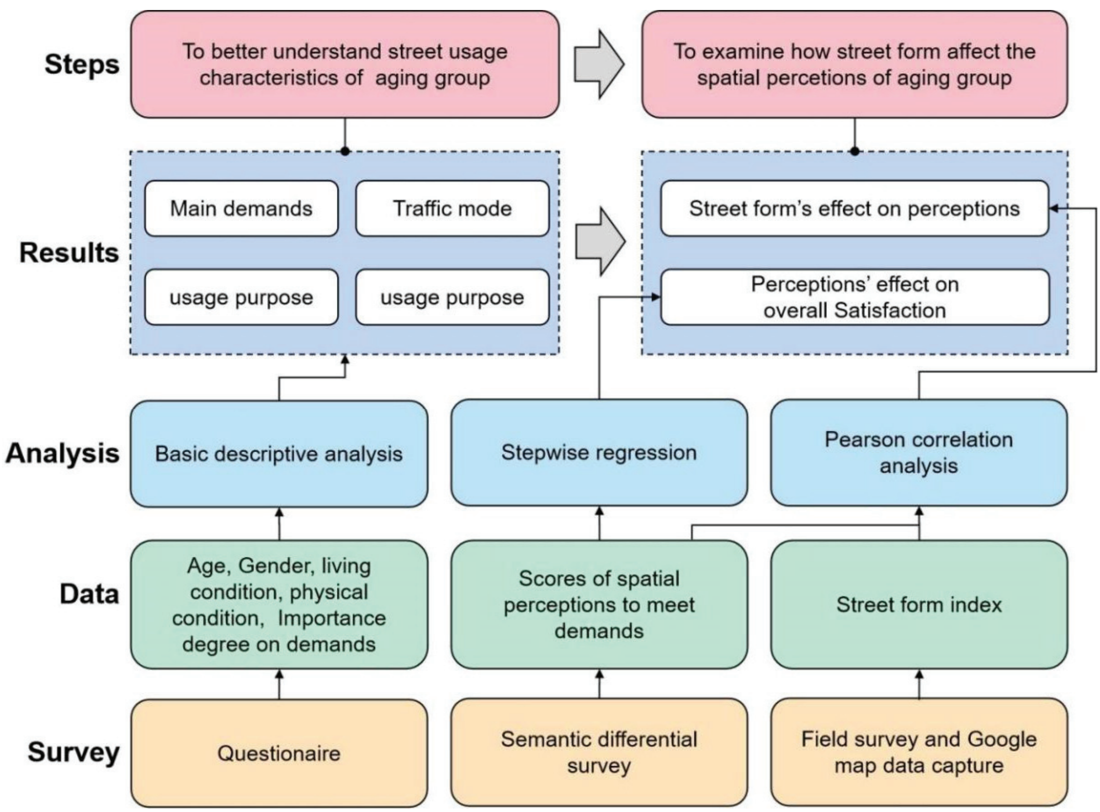


Figure 1. Framework of study. (Source: The Authors).

In the second stage, different types of streets in Shanghai are selected as empirical objects. Firstly, groups of adjectives that reflect the subjective perceptions of the aging population are identified via the semantic differentiation method. Moreover, stepwise regression analysis is employed to observe the variables that affect the overall satisfaction towards the streets. Then, the physical space indexes reflecting the built environment are selected, and the relationship between the physical space indexes and the subjective perception of the elderly is tested by Pearson correlation analysis. Finally, based on the above empirical analysis, spatial development and planning strategies are put forward to promote the social welfare of the aging population.

3.3. Social Survey

Our social survey is divided into two parts: the street usage characteristics and subjective perceptions of aging people. The two-part investigation is a gradual and in-depth process. The former focuses on the superficial behavioral habits of the elderly, while the latter focuses on the psychological causes.

First, a questionnaire is used to obtain basic information about aging people. In order to quantify the basic information, health level, and needs for different street qualities among the elderly, this paper compares the preferences of different age groups for various street elements through cross-analysis. The contents of the questionnaire include the basic personal information of the elderly (such as age, gender, living condition, and physical condition), and the investigation of the elderly's needs for street quality. We summarize the primary indexes of the physiological, psychological, and behavioral needs of the elderly for street space as 'safety, convenience, comfort, communicability, aesthetics, attribution, culture, entertainment, and inclusiveness'. The respondents are required to score 0 to 4 for each index factor (higher score indicating greater importance) so as to quantify and refine the needs of the elderly for street space.

Second, to quantify the elderly's diverse perceptions of streets, we employ a semantic differential survey, which was developed by psychologist Osgood in 1957 [47]. In the method, aiming at a given concrete or abstract research object, several opposite adjectives can be paired as a scale, and different magnitudes can then be set to quantitatively analyze and describe the research object [48]. The semantic differential method generally selects a number of adjectives related to the described object as evaluation factors, and each pair of antonyms can be used as the two extremes of an evaluation of street perception [49]. Based on the questionnaire results, this study selects 22 pairs of antonyms as factors, under 9 main needs, to evaluate street design, as shown in Table 1. In order to make the description more accurate, an evaluation scale with 7 magnitudes (1 point each magnitude) is selected, in which the median is set as 0 points and the positive and negative values are 3 magnitudes, respectively. Positive values represent positive feedback from the elderly, while negative values mean negative feedback.

Table 1. Factors selection.

Needs	Evaluation Factors
Attribution	1. Warm–Lonely
Aesthetics	2. Orderly–Messy
	3. More greenery–Less greenery
	4. Harmonious–Inconsistent
Safety	5. Flat–Bumpy
	6. Safe–Dangerous
	7. Convenient–Inconvenient (to cross street)
	8. Transparent–Blocked (vision)

Table 1. *Cont.*

Needs	Evaluation Factors
Convenience	9. Bright–Dim (in the night) 10. Unblocked–Blocked 11. Clear–Unclear (traffic sign) 12. Convenient–Inconvenient (to rest)
Comfort	13. Spacious–Narrow (pavement) 14. Mild–Dazzling (light) 15. Continuous–Discontinuous (building and wall) 16. Open–Closed
Culture	17. Distinctive–Featureless
Communicability	18. Willing to stay–Rush by 19. Lively–Deserted 20. Familiar–Indifferent
Inclusiveness	21. Inclusive–Exclusive
Entertainment	22. Interesting–Boring
Overall Satisfaction	23. Satisfied–Unsatisfied

3.4. Statistic Analysis

This paper adopts two statistical analysis methods. The first is stepwise regression. By capturing the hierarchical structure underlying the elderly's perceptions, as listed in Table 1, this method helps to explore the determinants of spatial perception and their effect on overall satisfaction. The basic idea of stepwise regression analysis is to select the most important variable from many variables and establish the prediction or interpretation model of regression analysis, and finally to establish an optimal multiple linear regression equation. Its basic process includes the following: the independent variables are introduced one by one, on the condition that the sum of partial regression squares is significant after being tested, and after each new independent variable is introduced, the old independent variables should be tested one by one, and the independent variables with insignificant partial regression squares should be eliminated until neither new variables are introduced nor old variables are deleted. The basic multivariate regression model is as follows:

$$S = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \cdots + \beta_i X_i + \epsilon \quad (1)$$

where S, the dependent variable, refers to the score of the elderly's overall satisfaction with the street. X_i is a set of variables (evaluation factors listed in Table 1). β is the vector of regression coefficients used for the estimations. ϵ is an error term. The calculation process begins with establishing univariate regression models for different independent variables and dependent variables, respectively, and calculating the value of the F-test statistic, $F_1^{(1)} \ldots F_P^{(1)}$. Then, we choose the maximum value:

$$F_{i_1}^{(1)} = max\left\{F_1^{(1)}, \ldots, F_p^{(1)}\right\}. \quad (2)$$

For a given level of significance α, we calculate the critical value as $F^{(1)}$. If $F_{i_1}^{(1)} \geq F^{(1)}$, then we introduce X_{i_1} into the regression model, and I_1 can be selected as the variable index set. The next step of the calculation is to build the binary regression models. However, one of the variables has been determined in the former calculation, and the same test process will be repeated to determine another variable. We keep introducing new independent variables, and thus we can obtain a relatively ideal multiple linear regression equation, which represents the spatial perceptions' quantified effect on satisfaction.

Second, Pearson correlation analysis is selected. This method is used to measure the linear relationship between distance variables. In our study, it helps to further examine the relationship between the subjective perceptions of the elderly and the objective index factors of street form. In the process of analysis, the research focuses on the variables determined in the previous stepwise regression model construction. Using the Pearson method, we can test the degree of influence based on the street form index on these important variables, which can provide a reference for urban planners to improve the current street's level of aging friendliness. Designers can also respond to the elderly's specific perceived emotions by controlling the specific spatial form.

3.5. Data Collection

The data are derived from two sets of social surveys, and fieldwork in Shanghai was conducted in 2020. Spatial data are captured by Google Maps, as a supplement to the field surveys. The design of the survey questions is based on interviews conducted in Shanghai in 2019. We derived the questions from the existing studies, but we develop them by considering more detailed spatial needs and quantifiable perceptions. Because of the different purposes of these two social surveys, the scope of the selected survey objects is also different. For the first, the basic object is the administrative district, while, for the second, it is a specific street.

In the first step, eight of Shanghai's 16 administrative districts are selected because they have the highest proportion of the elderly population. It can be seen clearly in Figure 2 that most selected districts are located in the traditional central area of the city, which accords with the analysis of the spatial distribution characteristics of Shanghai's aging population in the existing research [50]. Fifty questionnaires were randomly distributed in each district (total of 400 questionnaires), while 381 questionnaires were collected, with an effective rate of 95.3%. In the second step of the study, four streets with different characteristics in Shanghai were selected as a research sample for the distribution of semantic differential questionnaires. Considering the elderly's habit of going out, the questionnaires were distributed on weekdays and weekends, which were divided into three periods, namely 7–10 am, 10–2 pm, and 2–5 pm. Twenty questionnaires were distributed in each period of a distribution day, totaling 120 questionnaires per street and 480 questionnaires in total for four streets. The validity of the questionnaires was mainly determined by whether the elderly could accurately understand the logic of the SD questionnaire. Finally, 471 valid questionnaires were collected, with an effective rate of 98.1%.

In addition, in order to describe the objective form of street space, this study selects 11 index factors, as shown in Table 2, that might affect the elderly's feelings towards the street space from the aspects of street scale, interface, greenery, rest space, and barrier-free facilities. Street-scale indicators are very important for the elderly to evaluate the safety, convenience, comfort, and belonging of streets. Generally, the indicators used to describe street scale include the street length, total street width, vehicle lanes' width, pedestrian sidewalk width, and ratio of width to height. We select one index of green coverage rate for street greening [51]. The street-facing interface is the vertical interface of street space and also an important part of the street. Its color, scale, continuity, perspective, etc., all affect the elderly's usage and experience, and have an important impact on the vitality and characteristics of the street. Therefore, the continuity and underlying transparency of the street-facing interface are selected as two indicators [52]. Through the pre-research, we know that street parking is essential to the elderly's perceptions of street satisfaction, so we select two indicators, the density of squares along the street and the density of rest facilities, to represent the parking space. As for barrier-free facilities, we use the setting rate of barrier-free facilities to calculate the proportion of the number of barrier-free facilities at various intersections, entrances and exits, crosswalks, and blind roads, so as to reflect the barrier-free popularity of streets.

Table 2. Selection of street space's index factors.

Index Factor	Explanation	Unit
Street length	The length of the selected street part	m
Vehicle lanes' width	Total width of roadway part of street (including central greenery)	m

Table 2. *Cont.*

Index Factor	Explanation	Unit
Total street width	Width distance between road red lines	m
Pedestrian sidewalk width	The sum of the widths of barrier-free walking sections on both sides of the street (excluding occupied areas)	m
The ratio of width to height	The ratio of street width to building height (core lot)	%
Greenery coverage rate	The ratio of green coverage area to the total area within the road red line	%
Interface continuity	The ratio of 'sum of projected width of buildings on both sides of the street' to 'total street length × 2'	%
Underlying interface transparency	The ratio of 'the sum of transparent and accessible interfaces at the bottom of both sides of the street' to 'total street length × 2'	%
Density of squares along the street	Square area along the street in unit length	m^2
Density of rest facilities	Number of seats per 10 m along street	/10 m
Setting rate of barrier-free facilities	The ratio of 'number of barrier-free facilities at various intersections, entrances and exits, crosswalks and blind roads' to 'total number'	%

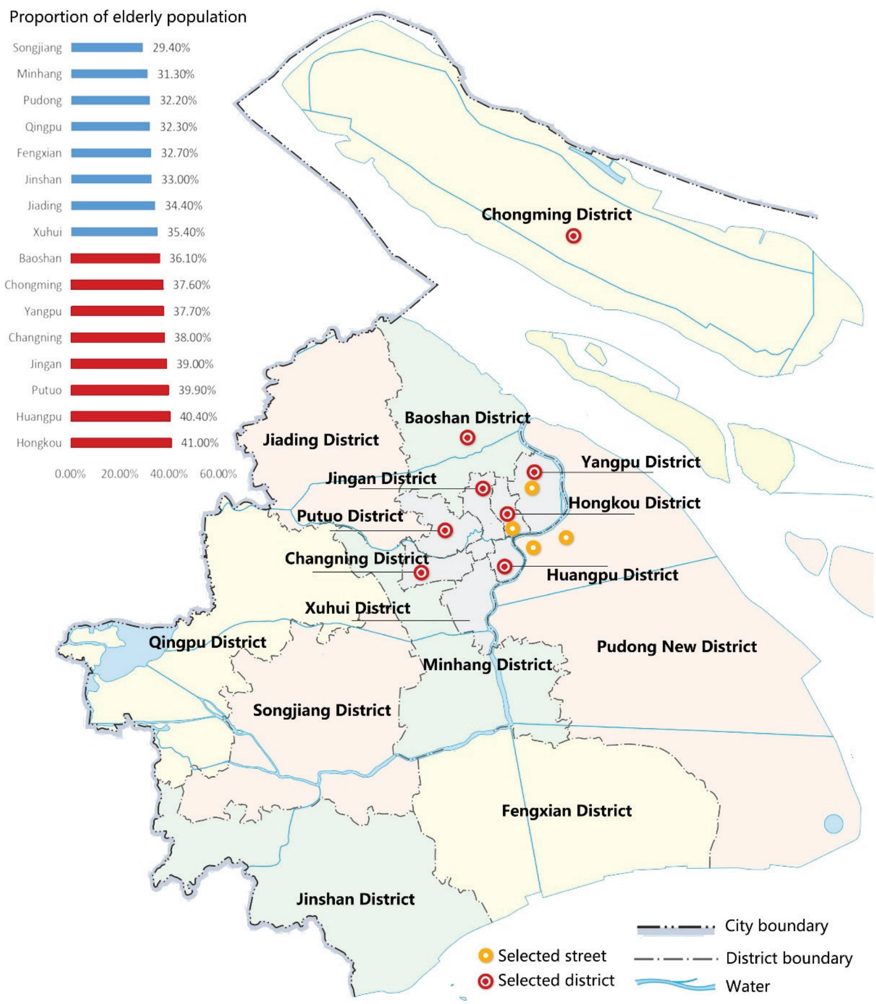


Figure 2. Study area. (Source: The Authors).

4. Street Usage Characteristics of the Aging Group in Eight Districts

4.1. Basic Usage Characteristics of the Aging Group

4.1.1. Usage Frequency and Purpose

The survey results showed that more than 90% of the elderly enjoy walking on streets. On the other hand, a small number of the elderly rarely went out, as they felt inconvenienced and insecure about doing so at their age, and preferred to attend activities within their communities. They said that their communities had senior activity centers and there were plenty of activities organized for them. Compared with the young elderly (60–74 years old), the long-lived elderly (above 90 years old) had much fewer types of activities to enjoy. Most of the activities that the elderly engaged in were wandering, shopping, having medical treatments, and visiting relatives and friends. Although their purposes of travel vary, in general, the frequency of street usage is relatively high, and the streets play a very important role in the elderly's daily lives.

4.1.2. Transportation Mode

The survey results showed that more than 70% of the elderly took walking as their main mode of transportation for going out, because they had sufficient time and exercise through walking. In other words, most of the street usage of the elderly occurred while walking. The second was public transportation. Around 30% of the elderly said that they would take public transportation to go to the hospital or visit relatives and friends, as it is free for them in Shanghai. However, with the increase in the elderly's age, the utilization rate of this mode is gradually decreasing, and wheelchairs or private cars are being chosen instead. There were also 27% of the young elderly choosing to ride bicycles or electric bicycles for travel. In addition, it was found that the elderly ratio using wheelchairs is at a relatively high rate, nearly 30%, and the elderly who had physical impairments or were at an older age often used electric wheelchairs. This is a special mode of transportation and has special requirements for the use of street space.

4.1.3. Usage Experience

The survey results revealed that the majority of the interviewees expressed positive and optimistic feelings towards the use of streets, but a few of them displayed negative emotions (Figure 3). Positive emotions mainly included 'enjoyment, happiness, comfort, safety, and beauty', while negative emotions mainly included 'insecurity, inconvenience, fear, and labyrinth'. In addition, the interviewed elderly also commented on the deficiencies in Shanghai street space design, with keywords such as 'mixed-use pedestrian and vehicle system, speedy vehicles', 'street facilities and bicycles occupied walking space', and 'insufficient barrier-free design'.

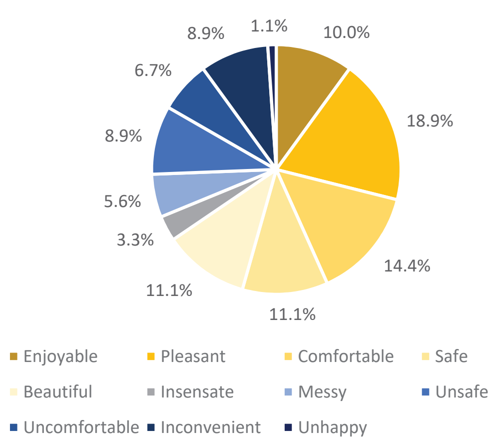


Figure 3. Use experience of interviewed elderly. (Source: The Authors).

4.2. Needs towards Street Space of Aging Population

4.2.1. Aging Population's Hierarchy of Needs

Maslow's needs theory mentioned that an individual's needs display progressiveness, from primary to advanced [53]. They mainly include eight types of needs, namely physiological needs, security needs, belonging and love needs, esteem needs, cognitive needs, aesthetic needs, self-realization needs, self-actualization needs, and transcendence needs. This theory holds that with the relative satisfaction of low-level needs, human needs will gradually develop and evolve from a low level to a high level. Alfonzo points out that when individuals' needs for physical space are met, they will pay attention to their spiritual and psychological needs [54]. Therefore, people's need for a walking environment from low to high includes the needs for accessibility, accessibility, safety, comfort, and pleasure. Mehta expands people's walking needs into seven levels, namely accessibility, accessibility, usability, safety, comfort, pleasure, and sense of belonging [55].

Based on the results of the questionnaire, the elderly's needs for street space are divided into a hierarchy with three overall stages. We compare the average values of the nine first-class need indexes of the interviewed elderly people horizontally, and obtain the general needs of the elderly for street space. The process is to calculate the average score of each first-level need index and compare it with the total average score of all first-level appeal indexes. If the score of a certain first-level appeal index is obviously higher than the total average score, it will be summarized as a first-level need. On the contrary, if the score of a certain first-level need index is obviously lower than the total average score, it will be summarized as a third-level need. The rest of the first-level need indexes that are close to the total average score are summarized as second-level needs.

As shown in Figure 4, the first level includes senses of 'belonging and aesthetics', the second level includes 'safety, convenience, and comfort', and the third level includes 'communicability, entertainment, culture, and inclusiveness'. The needs for spiritual satisfaction, such as entertainment and culture, occupy the top of the pyramid, followed by two social needs, namely inclusiveness and communicability. Spiritual needs and social needs are basic needs, and the importance of comfort, convenience, and safety is increasing in turn. However, it is worth noting that the aesthetic need, which is at a rather high level in Maslow's model, has become a basic need of the elderly for street space. At the same time, the social need of belonging has become more important than safety within the aging group. These findings suggest that in developed cities such as Shanghai, the regeneration goal of elderly-friendly street space may have shifted. The simple construction of infrastructure and facilities cannot meet the primary needs of the elderly. Consequently, we need to pay more attention to the aesthetic preferences of the aging group towards spaces, as well as those street forms with a sense of place.

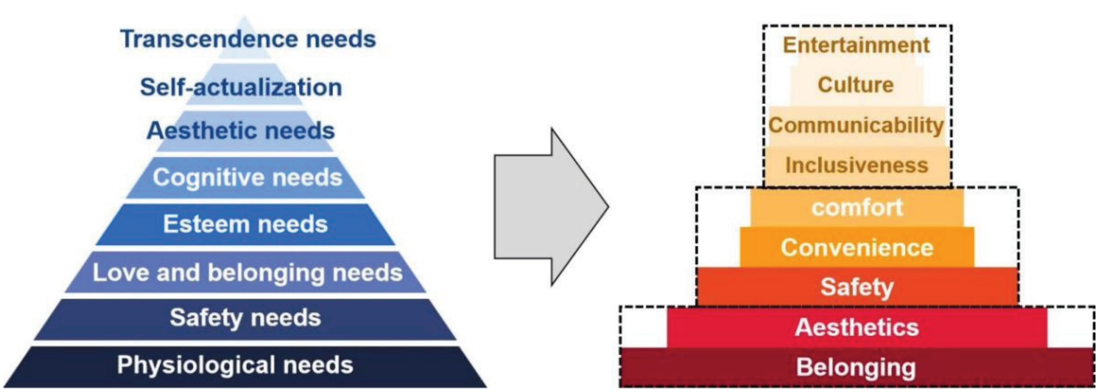


Figure 4. Aging needs model and Maslow's need model. (Source: The Authors).

4.2.2. Needs Analysis of Aging Population with Different Characteristics

The study further analyzed the needs of the elderly with different attributes. We found significant differences in the street needs of the elderly with different social and economic attributes. First, no obvious correlation existed between gender and the needs for street convenience, comfort, communicability, culture, belonging, and inclusiveness. However, the female elderly had higher needs for street safety and beauty, while the male elderly had preferences in street space for a better sense of entertainment. Second, there was no apparent difference in the need for 'comfort, aesthetics, culture, and inclusiveness' among the elderly at different ages. However, the differences in the needs for 'safety, convenience, communicability, entertainment, and belonging' in streets were relatively obvious, indicating that the elderly's needs for 'safety, convenience, and belonging' in streets were positively correlated with age, while their needs for 'communicability and entertainment' in streets were negatively correlated with age. In other words, the older their ages were, the more they needed the safety and convenience of the street and the feeling of home brought about by the street. The younger they were, the more interesting and sociable street spaces they preferred.

Third, no obvious difference in need was found regarding the 'safety, convenience, comfort, aesthetics, and belonging' of the street among the elderly with different education levels. In terms of 'communicability, entertainment, culture, and inclusiveness', the higher the education level, the higher the need. Fourth, the living conditions of the elderly had an influence on their street needs. There were differences and similarities in the overall needs of the elderly with different family structures. The similarities mainly concentrated on the needs of street 'comfort, aesthetics, entertainment, culture, and inclusiveness', while the differences mainly were the needs of 'safety, convenience, communicability, and belonging'. These findings indicate that the elderly living alone were more inclined to prefer streets with high levels of 'safety, convenience, communicability, and belonging', while the elderly living with their children and families or in nursing homes had relatively low needs for such street qualities. To conclude, the needs structure of the elderly with different characteristics is similar, but the degree of attention to different levels of needs is varied. In the street regeneration practice, planners and designers should adjust the emphasis of the scheme according to the population characteristics of the surrounding areas, so as to realize the precise connection between the space supply and the needs of the elderly.

5. The Spatial Form and Perception of Streets

5.1. The Subjective Perception and Overall Satisfaction

In order to explore the relationship between the elderly's overall satisfaction with the streets and various subjective perceptions, this study employs multiple linear stepwise regression to test the influence of the 22 evaluation factors listed in Table 1 on the overall satisfaction of the elderly. The study selected four streets in Shanghai and collected their spatial index factors, listed in Table 2. The samples were Century Avenue, a landscaped street surrounded by modern high-rise commercial buildings; Hailun Street, a historic street surrounded by traditional historic buildings and residential buildings; University Street, a commercial street surrounded by small cultural and creative commercial buildings; and Rushan Street, a residential street surrounded by multi-story old residential buildings. As shown in Figure 5, the results of the SD survey showed that the elderly's subjective perceptions of the four streets differed greatly in the nine types of needs. The scores of University Street and Century Avenue were almost all above 0, and the overall satisfaction with the streets was high. The scores of Hailun Street were mostly below 0, and the overall satisfaction with the street was low. Such results reflect the different characteristics of each street, which is also consistent with the principle and original intention of the initial sample selection.

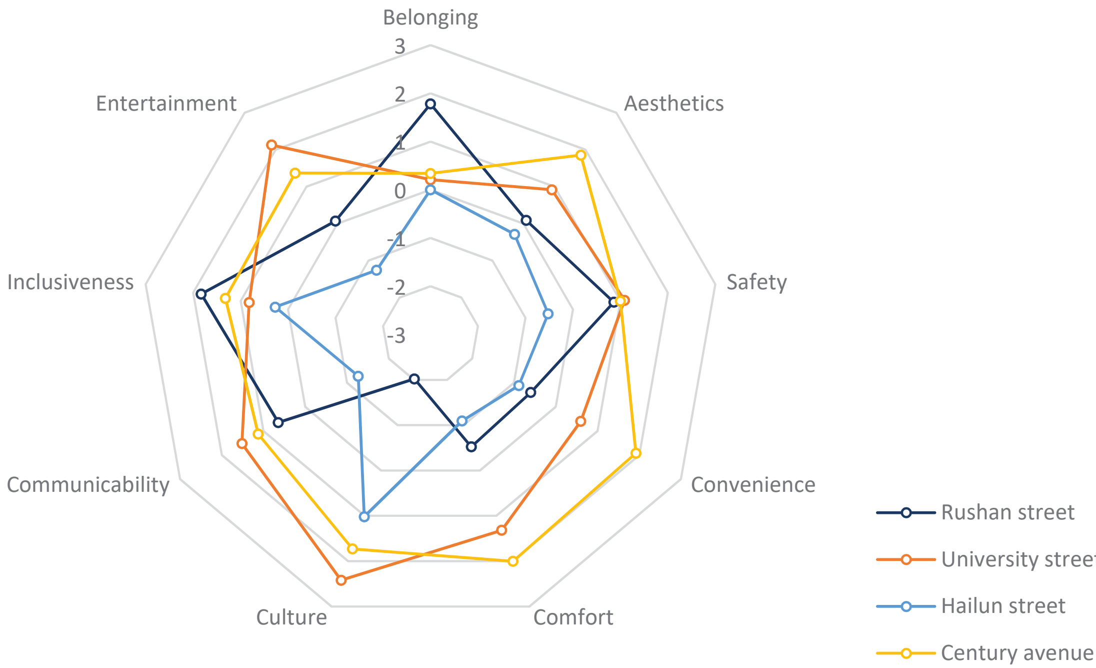


Figure 5. Average score of SD survey in four streets. (Source: The Authors).

In order to avoid the effects of multicollinearity, we conduct the VIF test. The results are shown in Table 3. All values of VIFs are less than 10, and thus the multicollinearity issue is not a challenge for our study. In the multiple linear stepwise regression analysis, five equation models were fitted, and the variables included in the models were as follows: the lighting degree of the street (9. Bright–Dim), the vitality degree (19. Lively–Deserted), the spaciousness of the sidewalk (13. Spacious–Narrow), and the staying ability of the street (18. Willing to stay–Rush by). Hypothesis testing results showed that the F values were 103.713, 67.807, 50.245, 40.001, and 52.744, respectively, and the p values were all less than 0.001, which indicated that the regression model was statistically significant. Compared with the null model, the inclusion of independent variables was helpful to predict the dependent variables. R^2 and adjusted R^2 represent goodness of fit, and they could be used to estimate the fitting degree of the model to the observed values. From the regression analysis, it can be seen in Table 3 that with the increase in the number of variables in models 1, 2, 3, and 4, the R^2 and the adjusted R^2 reflected an increasing trend, while model 5 showed a decreasing trend, and the adjusted R^2 of each fitting model was more than 0.5. Therefore, the explanatory degree of the independent variables to the dependent variables was relatively high. Using the above methods, the research concluded that vitality, spatial scale, and street attraction were not only important influencing factors that affected the overall satisfaction of the elderly, but also the key points that should be considered in relevant planning and construction in Shanghai.

Table 3. Results of the analysis of models.

Variables	Model 1		Model 2		Model 3		Model 4		Model 5	
	B	VIF	B	VIF	B	VIF	B	VIF	B	VIF
Bright–Dim	0.295 *** (10.184)	1.000	0.249 *** (8.398)	1.102	0.113 ** (2.299)	3.085	0.065 (1.256)	3.490		
Lively–Deserted			0.214 *** (5.137)	1.102	0.216 *** (5.261)	1.102	0.155 *** (3.313)	1.444	0.155 *** (3.306)	1.444
Spacious–Narrow					0.186 *** (3.463)	2.967	0.181 *** (3.391)	2.970	0.231 *** (6.441)	1.336
Willing to stay–Rush by							0.150 ** (2.698)	2.054	0.174 *** (3.323)	1.186
R^2	0.471		0.538		0.589		0.631		0.604	

** means $p < 0.05$; *** means $p < 0.01$; t statistic is in brackets.

5.2. *The Subjective Perception and Objective Street Form*

The study adopted Pearson correlation analysis to analyze the relationship between the 22 evaluation factors included in the SD survey in Table 1 and 11 space index factors selected from Table 2. The closer the Pearson correlation coefficient is to 1, the stronger the positive correlation relationship that exists. Aging people's perceptions of street aesthetics and convenience are most influenced by the street space form, while perceptions of street comfort and safety are influenced by the street space form, and perceptions of entertainment, culture, inclusiveness, and communicability are relatively less influenced by street form. Therefore, combined with the research results on the appeal level of the elderly in the third part of this paper, we suggest that the regeneration and transformation of street form can meet the most concerned use needs of the vast majority of the elderly. Furthermore, 27 pairs of factors were significantly correlated, as shown in Table 4, and three main findings were concluded as follows.

First, the interface's transparency is a very important factor that affects the types of perception. The higher the index of the underlying interface's transparency, the greater the spatial perception the elderly for the space. This is due to the magnifying effect of the transparent open interface in the line of sight. At the same time, the higher the index, the more willing the elderly are to stay on the street, which also increases their perception of the interest of the street. This is because street-facing interfaces with high transparency are often equipped with more shop glass, which not only attracts the elderly but also increases the vitality on both sides of the street. The transparent interfaces and door heads of shops are another type of street symbol, which, to a certain extent, deepens the memory of the elderly regarding the street. For this reason, the elderly also believe that a street with high transparency is relatively more memorable and more iconic. In addition, the higher the transparency of the street, the better the greenery level of the street according to the elderly. This is because streets with high transparency are normally related to a higher grade and better spatial quality, with relatively more greening plants. The higher the index of 'continuity of street interface', the more the elderly feel that the space is closed. The elderly prefer a street with less continuity of interface, and the transparent line of sight can appease their uneasy mood.

Second, in terms of the effect of street scale, the higher the index of the pedestrian sidewalk width, the cleaner the elderly perceive the street to be. Moreover, the more unimpeded the streets are, the more convenient they feel to find a place to rest. Wide sidewalks mean fewer people on the street, which makes people feel orderly. On the other hand, to some extent, it also means a higher level of streets. In other words, more rest facilities may be equipped on both sides of the street, which makes it more convenient for the elderly to rest. These have improved the elderly's evaluation of the street staying ability. In addition, the smaller the ratio of height to width, the stronger the perception of safety, unblocked vision, and space openness held by the elderly, because a spacious street makes the elderly feel more secure, and a narrow street is often linked with the mixed traffic of people and vehicles. The width of streets also affects wheelchair use and walking, which may produce more uneasy feelings when inconvenience and a sense of congestion occur.

Table 4. Correlation coefficients of perception evaluation value and space index factors.

Evaluation Factors	A	B	C	D	E	F	G	H	I	J	K
1. Warm–Lonely	0.017	−0.066	0.079	−0.248	−0.424	−0.350	−0.368	−0.138	−0.225	−0.199	0.582
2. Clean–Messy	0.968 *	0.957 *	0.905	0.982 *	−0.795	−0.545	−0.851	0.873	0.955 *	0.965 *	0.701
3. More greenery–Less greenery	0.763	0.726	0.623	0.818	−0.721	−0.120	−0.722	0.985 *	0.741	0.714	0.560
4. Harmonious–Inconsistent	0.110	0.153	0.299	−0.28	0.026	−0.756	−0.059	−0.536	0.088	0.131	0.171
5. Flat–Bumpy	0.707	0.737	0.613	0.861	−0.386	−0.169	−0.449	0.768	0.820	0.796	0.221
6. Safe–Dangerous	0.887	0.824	0.796	0.817	−0.962 *	−0.441	−0.961 *	0.929	0.766	0.755	0.985 *
7. Convenient –Inconvenient (to cross street)	−0.319	−0.439	−0.409	−0.47	−0.259	0.449	−0.113	0.120	−0.543	−0.553	0.267
8. Transparent–Blocked (vision)	0.936	0.884	0.893	0.831	−0.973 *	−0.648	–0.996 *	0.809	0.809	0.809	0.946
9. Bright–Dim (in the night)	0.563	0.464	0.410	0.5	−0.840	0.010	−0.770	0.915	0.404	0.381	0.727
10. Unblocked–Blocked	0.687	0.760	0.671	0.956 *	−0.205	−0.396	−0.319	0.490	0.855	0.846	0.098
11. Clear–Unclear (traffic sign)	0.648	0.604	0.487	0.717	−0.652	0.042	−0.634	0.974 *	0.625	0.594	0.474
12. Convenient–Inconvenient (to rest)	0.962 *	0.985 *	0.946	0.995 *	−0.657	−0.680	−0.751	0.704	1.000 *	0.998 *	0.591
13. Spacious–Narrow (pavement)	0.807	0.787	0.683	0.880	−0.681	−0.197	−0.705	0.954 *	0.816	0.791	0.523
14. Mild–Dazzling (light)	−0.620	−0.681	−0.761	−0.562	0.278	0.956 *	0.409	0.039	−0.659	−0.689	−0.383
15. Continuous–Discontinuous (building and wall)	0.588	0.587	0.444	0.737	−0.411	0.076	−0.428	0.855	0.661	0.629	0.215
16. Open–Closed	0.865	0.795	0.776	0.777	−0.978 *	−0.441	−0.970 *	0.910	0.725	0.716	0.912
17. Distinctive–Featureless	0.186	0.224	0.059	0.422	0.085	0.385	0.064	0.507	0.357	0.321	−0.288
18. Willing to stay–Rush by	0.734	0.705	0.591	0.998 *	−0.657	−0.079	−0.663	0.967 *	0.975 *	0.735	0.485
19. Lively–Deserted	0.365	0.241	0.266	0.188	−0.819	−0.068	−0.723	0.622	0.117	0.109	0.803
20. Familiar–Unfamiliar	−0.576	−0.665	−0.579	−0.754	0.050	0.358	0.172	−0.348	−0.775	−0.768	0.047
21. Inclusive–Exclusive	0.488	0.396	0.500	0.243	−0.818	−0.551	−0.783	0.344	0.242	0.259	0.997 *
22. Interesting–Boring	0.487	0.404	0.308	0.495	−0.693	0.187	−0.625	0.977 *	0.386	0.354	0.534

A—Street length; B—Vehicle lanes' width; C—Total street width; D—Pedestrian sidewalk width; E—Ratio of width to height; F—Greenery coverage rate; G—Interface continuity; H—Underlying interface transparency; I—Density of squares along the street; J—Density of rest facilities; K—Setting rate of barrier-free facilities. * in the table indicates strong correlation, positive value indicates positive correlation, and negative value indicates negative correlation.

Third, as for public space and facilities, the setting rate of barrier-free facilities certainly has positive effects on the elder's perception of safety and inclusiveness, but the density of street squares along the street is also a key factor. Higher density means that older people are more willing to stay on the street, because street squares usually provide older people with more rest and social spaces. It also improves elderly's perceptions of order. In addition, the index of the density of street rest facilities contributes to not only better perceptions of convenience and comfort, but also the perception of the greenery level of the street, which is related to the appearance of rest facilities and greening facilities.

6. Conclusions

The regeneration of street public space is the focus of China's urban government's active aging policy. However, the current spatial planning and design practice generally lack evidence-based support. The project focuses on the safety of streets, but ignores the changing needs of the elderly. In China, cities with serious aging are often economically developed. The elderly in these cities use the street public space more frequently, and their needs are more diverse. Therefore, this paper aims to explore the usage characteristics of the aging population, and to reshape the intrinsic cognition of their structure of needs. Furthermore, we hope that, compared with the existing research, we can further explore which street forms affect the elderly's perceptions of their different needs, and then provide a reference for specific street planning and design.

Our results based on the district-level survey suggest that street space is playing an extremely important role in the elderly's daily lives. They have various travel purposes, and the frequency of street usage is high. Their needs of streets, surprisingly, differ from the common cognition. The need for a sense of belonging has replaced the position of the basic use need. They expect the streets around their communities to feel familiar, instead of rapidly changing under China's rapid urbanization process. In addition, with the aging of the population, the aesthetic needs of the streets are more important than the safety needs. This means that retaining the local memory of the street and emphasizing the local characteristics from a visual point of view may be more important than transforming the physical facilities. In the street-level survey, this study found that aging people's perceptions of their primary needs are highly correlated, meaning that spatial design indeed has the possibility to become an effective way to improve the social welfare of the elderly. We found that higher street vitality, more spacious sidewalks, and more street-staying space had a significant influence on this group's overall satisfaction. Specific physical spatial indexes, such as street length, total width of street, width of walkable sidewalk, density of rest facilities, density of squares along the street, transparency of underlying interface, etc., were more important to the perceptions of convenience and aesthetics among the aging population. The ratios of height to width, interface continuity, and barrier-free setting rate impact the perception of safety and comfort, and the greenery coverage rate was also an important factor affecting comfort. For the communicative perception, the influencing factors included the walking width, the transparency of the underlying interface along the street, and the density of the squares along the street. The above-mentioned spatial characteristics should be important considerations for street space construction in Shanghai's elderly-friendly city development.

Regarding theoretical implications, our results indicate that the specific group's needs for specific types of space have great particularity, and may be against the need hierarchy established by existing research. The sequence of their priority may also reflect a failure to comply with the order of needs from survival to self-actualization. The high-level spiritual need can be the most fundamental need, such as the need for belonging among aging people. This represents the discomfort caused by potential social phenomena such as rapid changes in the surrounding environment and lonely living conditions. Similar conclusions often appear in community-related research, but we find that the street, as a public space frequently used by the elderly, should also respond to these important needs [56–58].

Regarding policy implications, this paper suggests that the construction of an elderly-friendly city, especially the elderly-friendly regeneration of street space, which is the most common public space, should start from the particularity of the needs of the elderly with different geographical backgrounds, and understand the usage characteristics and subjective perceptions of local aging groups based on social investigation, so as to promote the personalization of space design strategies. This paper analyzes the subjective perceptions of the aging population towards street space, as well as the spatial elements and corresponding indicators that can improve their satisfaction, based on interviews and questionnaires. Our study can also provide a reference for similar practices in other cities. In recent years, the Chinese government has advocated for the development of a 'people's city', the core of which is to formulate the development strategy of the city to meet the needs of the vast majority of citizens [59–61]. The related actions taken are started by 'urban physical examination', which mostly consists of big data and social surveys to evaluate the quality of urban construction and development annually, and to guide the formulation and implementation of urban planning. The combination of survey and analysis methods in our study can be integrated with the 'urban physical examination' works that have been carried out in all China's cities by adopting larger-scale and more in-depth data statistics.

The differences between regions can be considered, and therefore further promotes the elderly-friendly city development at a local level. The main limitation of the study lies in the survey object and the size of the survey sample. In this paper, Shanghai, a city with a serious aging trend, is selected as the research object, and its representative streets are selected as the empirical research object. The needs and evaluations of the elderly in other types of cities and streets should be further studied and compared. Further, our social survey was carried out manually, and was not combined with the big data collection method, resulting in a small sample size compared with the huge population of the research object. Future studies can be combined with government-led urban physical examination to compensate for the shortcomings of existing research methods.

Author Contributions: Conceptualization, H.Z. and Y.L.; methodology, Q.J.; software, Q.J. and T.W.; investigation, J.L.; data curation, T.W.; writing and editing, H.Z. and Y.L. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by the National Natural Science Foundation of China, Grant Number 52108035; National Natural Science Foundation of China, Grant Number 51908232.

Institutional Review Board Statement: The study was conducted according to the guidelines of the Declaration of Helsinki, and approved by the Ethics Committee of the Beijing University of Civil Engineering and Architecture (1 January 2021).

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: The data presented in this study are available on request from the corresponding author. The data are not publicly available to protect the privacy of the study's participants.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Fitzgerald, K.G.; Francis, G.C. An overview of age-friendly cities and communities around the world. *J. Aging Soc. Policy* **2014**, *26*, 1–18. [CrossRef]
2. Word Heath Organization. *Global Age-Friendly Cities: A Guide*; WHO: Geneva, Switzerland, 2007.
3. Guo, X.; Li, T.; Yuan, B. The permanent impacts of population aging on Chinese economy and its policy suggestions. *Econ. Theory Bus. Manag.* **2013**, *2*, 43–50.
4. CPC Central Committee. *State Council. Outline of the Healthy China 2030 Plan*; CPC Central Committee: Beijing, China, 2016.
5. State Council. *Opinions of the General Office of the State Council on Implementing Healthy China Action*; State Council: Beijing, China, 2019.
6. State Council. *Implementation and Assessment Plan of Healthy China Action*; State Council: Beijing, China, 2019.
7. Gehl, J. *Cities for People*; Island Press: Washington, DC, USA, 2013.
8. Lynch, K. *Good City Form*; MIT Press: Cambridge, MA, USA, 1984.
9. Southworth, M.; Owens, P.M. The evolving metropolis: Studies of community, neighborhood, and street form at the urban edge. *J. Am. Plan. Assoc.* **1993**, *59*, 271–287. [CrossRef]
10. Lynch, K. *The Image of the City*; MIT Press: Cambridge, MA, USA, 1964.
11. Lawton, M.P. An ecological theory of aging applied to elderly housing. *J. Archit. Educ.* **1997**, *31*, 8–10. [CrossRef]
12. Kahana, E.L.; Lovegreen, B.; Kahana, M.; Kahana, B. Person, Environment, and person-environment fitas influences on residential satisfaction of Elders. *Environ. Behav.* **2003**, *35*, 434–453. [CrossRef]
13. Xie, L. Age-friendly communities and life satisfaction among the elderly in urban China. *Res. Aging* **2018**, *40*, 883–905. [CrossRef] [PubMed]
14. Green, G. Age-friendly cities of Europe. *J. Urban Health* **2013**, *90*, 116–128. [CrossRef]
15. McGarry, P.; Morris, J. A great place to grow older: A case study of how Manchester is developing an age-friendly city. *Work. Older People* **2011**, *15*, 38–46. [CrossRef]
16. Rapoport, A. *Human Aspects of Urban Form: Towards a Man—Environment Approach to Urban Form and Design*; Elsevier: Amsterdam, The Netherlands, 2016.
17. Fincher, R.; Jacobs, J.M. (Eds.) *Cities of Difference*; Guilford Press: New York, NY, USA, 1998.
18. Yoshinobu, A. *The Aesthetic Townscape*; Iwanami Shoten Press: Tokyo, Japan, 1972.
19. Appleyard, D.; Lintell, M. The environmental quality of city streets: The residents' viewpoint. *J. Am. Inst. Plan.* **1972**, *38*, 84–101. [CrossRef]

20. Carp, F.M. A complementary/congruence model of well-being or mental health for the community elderly. *Hum. Behav. Environ. Adv. Theory Res.* **1984**, *7*, 279–336.
21. Ewing, R. *Pedestrian and Transit-Friendly Design: A Primer for Smart Growth*; International City/County Management Association: Washington, DC, USA, 1999.
22. Whyte, W. *The Social Life of Small Urban Spaces*; Project for Public Spaces: New York, NY, USA, 1980.
23. Cao, L.X.; Chai, Y.W. Daily shopping activity space of the elderly in Shanghai city. *Hum. Geogr.* **2006**, *2*, 50–54.
24. Chai, Y.W.; Li, C.X. Spatial characteristics of daily shopping behavior of the elderly in cities in China—Taking Beijing, Shenzhen and Shanghai as examples. *Acta Geogr. Sin.* **2005**, *5*, 401–408.
25. Zhang, C.; Cao, G.Z. On spatial differences of elderly distribution and its influencing factors in Beijing city. *Urban Dev. Stud.* **2007**, *2*, 56–61.
26. Vojnovic, I.; Jackson-Elmoore, C.J.; Holtrop, J.; Bruch, S. The renewed interest in urban form and public health: Promoting increased physical activity in Michigan. *Cities* **2006**, *23*, 1–17. [CrossRef]
27. Purciel, M.; Neckerman, K.M.; Lovasi, G.S. Creating and validating GIS measures of urban design for health research. *J. Environ. Psychol.* **2009**, *29*, 457–466. [CrossRef] [PubMed]
28. Millington, C.; Thompson, C.W.; Rowe, D.; Aspinall, P.; Fitzsimons, C.; Nelson, N.; Mutrie, N. Development of the Scottish Walkability Assessment Tool (SWAT). *Health Place* **2009**, *15*, 474–481. [CrossRef] [PubMed]
29. Tan, Y. Return to the nature of city: Also on the layout of streets in permeable city. *Urban Probl.* **2005**, *5*, 28–32.
30. Shang, X.Q. *Research on the Influence of Permeable Street Pattern to the Vitality of City Community*; Huazhong University of Science and Technology: Huazhong, China, 2006.
31. Ewing, R.; Dumbaugh, E. The built environment and traffic safety a review of empirical evidence. *J. Plan. Lit.* **2009**, *23*, 347–367. [CrossRef]
32. Sugiyama, T.; Thompson, C.W. Associations between characteristics of neighbourhood open space and older people's walking. *Urban For. Urban Green.* **2008**, *7*, 41–51. [CrossRef]
33. Winters, M.; Voss, C.; Ashe, M.C. Where do they go and how do they get there? Older adults' travel behaviour in a highly walkable environment. *Soc. Sci. Med.* **2015**, *133*, 304–312. [CrossRef] [PubMed]
34. Elsawahli, H.A.; ShahAli, F.; Ahmad, K.M. Evaluating potential environmental variables and active aging in older adults for age-friendly neighborhoods in Malaysia. *J. Hous. Elder.* **2017**, *31*, 74–92. [CrossRef]
35. Burton, E.; Mitchell, L.; Stride, C. Bed of roses? The role of garden space in older people's well-being. *Proc. Inst. Civ. Eng. Urban Des. Plan.* **2015**, *168*, 164–173. [CrossRef]
36. Sun, Y.; Ling, J.Q. Walkability and its implications for planning age-friendly cities: Evidence from Hongkong. *Urban Plan. Int.* **2020**, *35*, 47–52.
37. Xu, L.Q.; Shi, J. Walking activity quality and built environment: Take commercial streets in Shanghai as examples. *Shanghai Urban Plan. Rev.* **2010**, *1*, 17–24.
38. Xu, L.Q.; Meng, R.X.; Huang, S.Q.; Chen, Z. Healing Oriented Street Design: Experimental Explorations via Virtual Reality. *Urban Plan. Int.* **2019**, *34*, 38–45. [CrossRef]
39. Han, R.N.; Yang, D.F.; Wei, Y. The impact of street attraction on senior people's capability of activity. *Planner* **2020**, *36*, 67–71.
40. Tan, S.H.; Gao, Y.B.; Li, L.F.; Zhang, Y. Active intervention of community's walking environment in health: A perspective of physical activity. *Urban Plan.* **2020**, *44*, 35–46, 56.
41. Shanghai Municipal Bureau of Statistics. *Statistical Bulletin of Shanghai National Economic and Social Development in 2021*; Shanghai Municipal Bureau of Statistics: Shanghai, China, 2022.
42. Shanghai Municipal Bureau of Statistics. *Shanghai Statistic Yearbook 1981*; Shanghai Municipal Bureau of Statistics: Shanghai, China, 1982. Available online: https://data.cnki.net/Yearbook/Single/N2008050052 (accessed on 13 March 2022).
43. Shanghai Municipal Bureau of Statistics. *Shanghai Statistic Yearbook 2019*; Shanghai Municipal Bureau of Statistics: Shanghai, China, 2020. Available online: http://tjj.sh.gov.cn/tjnj/index.html (accessed on 13 March 2022).
44. National Working Committee on Aging. *Notice of the Office of the National Working Committee on Aging on the Pilot Work of Livable Communities and Friendly Cities for the Elderly (Urban Areas)*; National Working Committee on Aging: Beijing, China, 2009. Available online: http://www.nhc.gov.cn/lljks/new_index.shtml (accessed on 13 March 2022).
45. Shanghai Municipal People's Congress. *The Regulations on the Protection of the Rights and Interests of the Elderly in Shanghai*; Shanghai Municipal People's Congress: Shanghai, China, 2016.
46. Shanghai Municipal Government. *Guidelines for the Construction of Shanghai Elderly Friendly Cities (Trial)*; Shanghai Municipal Government: Shanghai, China, 2013.
47. Finstuen, K. Use of Osgood's semantic differential. *Psychol. Rep.* **1977**, *41*, 1219–1222. [CrossRef]
48. Zhang, J.H. The diagnosis methods in planning and design (16): SD Method. *Chin. Landsc. Archit.* **2004**, *10*, 57–61.
49. Fang, Z.G. *Study on the Urban Design Based on Suitability of Scale at Human*; Tianjin University: Tianjin, China, 2014.
50. Li, T. Spatial distribution of the aged population in Shanghai and influencing factors. *Urban Plan.* **2020**, *44*, 39–46.
51. Sotoma, M.; Miyazaki, H.; Kyakuno, T.; Moriyama, M. Analysis of land use zoning regulations and green coverage ratio. *J. Asian Archit. Build. Eng.* **2003**, *2*, 29–34. [CrossRef]
52. Ewing, R.; Handy, S. Measuring the unmeasurable: Urban design qualities related to walkability. *J. Urban Des.* **2009**, *14*, 65–84. [CrossRef]

53. Lester, D. Measuring Maslow's hierarchy of needs. *Psychol. Rep.* **2013**, *113*, 15–17. [CrossRef]
54. Alfonzo, M.A. To walk or not to walk? The Hierarchy of Walking Needs. *Environ. Behav.* **2005**, *37*, 808–836. [CrossRef]
55. Mehta, V. Walkable streets: Pedestrian behavior, perceptions and attitudes. *J. Urban.* **2008**, *1*, 217–245. [CrossRef]
56. Zhou, Y.M.; Lin, J.Y. Analysis on the development and planning principles of senior living community. *Urban Plan.* **2012**, *36*, 46–51.
57. Sun, Y.J. *The Community Models for Senior Based on the Concept of Full Health Care*; South China University of Technology: Guangzhou, China, 2016.
58. Wang, Y. *Optimized Research of Residential Community Planning Strategy in Cold Region Adapted Aging in Place Mode*; Harbin Institute of Technology: Harbin, China, 2017.
59. Yang, Y.; Li, G.P.; Sun, Y.; Fu, H. Comparative study on urban physical examination and planning implementation evaluation of big cities at home and abroad. *Sci. Geogr. Sin.* **2022**, *42*, 198–207. [CrossRef]
60. He, J.; Zhang, W.Z.; Cao, J.; Zhan, L. Organic integration and application of muti-source data in city health examination: A case of Beijing. *Sci. Geogr. Sin.* **2022**, *42*, 185–197. [CrossRef]
61. Mao, Y. Innovation and practice of physical examination: Old quarter renewal planning of Beijing sub-central district. *Planner* **2022**, *38*, 114–120.

sustainability

MDPI

Article

An Empirical Analysis of the Benefits of Opening a Highway in Terms of Changes in Housing Prices

Wonchul Kim [1] and Sung Hyo Hong [2,*]

[1] Department of Spatial & Environmental Planning, Chungnam Institute, Gongju-si 32589, Korea; iwonchul@cni.re.kr
[2] Economics Department, Kongju National University, Chungnam 32588, Korea
* Correspondence: shong11@kongju.ac.kr

Abstract: This study empirically analyzes the social benefits of opening a highway by assessing the increase in housing prices in two surrounding regions: one defined as the treatment group and the other defined as the control group. Although the two regions are geographically adjacent, they belong to different administrative districts and are physically separated by natural topographical features such as mountain ranges. Both aspects make it so that the interaction or influence between the two regions is limited, which raises the probability that the control group will show a trend similar to that of the treatment group under the influence of economic factors but will not be affected by the opening of the highway. With this in mind, the benefits of accessibility improvement due to the opening of the highway are estimated by using the difference-in-differences framework, i.e., the relative change in housing prices in the treatment group compared to the control group. In addition, the corresponding highway route is analyzed by dividing it into three sections according to their opening times and locations. The findings suggest that the estimated benefits are not fictional but robust. The increase in housing prices due to the opening of a highway is estimated to be, on average, 586 to 3075 dollars per apartment (equivalently, USD 10 to 53 per square meter). These benefits are worthy of being reflected upon, complementary to a traditional cost-benefit analysis.

Keywords: highway; housing prices; accessibility; capitalization; difference-in-differences

Citation: Kim, W.; Hong, S.H. An Empirical Analysis of the Benefits of Opening a Highway in Terms of Changes in Housing Prices. *Sustainability* **2022**, *14*, 5527. https://doi.org/10.3390/su14095527

Academic Editors: Mengqiu Cao, Claire Papaix, Tianren Yang, Benjamin Büttner and Marco Guerrieri

Received: 9 March 2022
Accepted: 29 April 2022
Published: 5 May 2022

1. Introduction

As infrastructure, highways provide benefits such as reducing the physical costs (e.g., fuel costs) and time costs of moving between regions [1]. In addition, if a pre-existing road is more dangerous than the highway that replaces it, another potential benefit is a reduction in the number of traffic accidents. With the increasing economic scale of industries, the amount of traffic between regions seems to be ever-growing in modern society. As social overhead capital, highways reduce logistics costs in production activities, thereby improving the overall price competitiveness of the local industry. Moreover, improved accessibility between regions in terms of living conditions promotes convenience with regard to commuting for work as well as traveling for other purposes (e.g., for leisure or shopping).

Meanwhile, road construction is a typical public investment that involves huge costs, and therefore, the opportunity cost is also considered to be large. For example, it is reported that the cost of constructing a one-lane roadway in the United States ranges between $4.2 million and $15.4 million per mile, with a maintenance cost of $24,000 per year (Transportation for America [2]). Roads often create a geographically chaotic stretch of houses, shops, and jobs. Such urban sprawl limits the achievement of the roads' intended purpose due to the induced demand for people to drive longer distances to more places. According to the analysis results of the dynamic panel model of Hymel [3], the expansion of highway traffic capacity causes a precisely matched increase in vehicular traffic. Accordingly, it was estimated that the derived vehicular traffic will cause the traffic speed to return to the pre-expansion level within approximately five years.

As such, there are conflicting arguments about the effectiveness of highway construction. In particular, while the benefits of highways in relation to production activities such as the reduction of logistics costs are clear, there is controversy about their effectiveness as a settlement-related infrastructure. Therefore, this study estimates the extent to which the opening of a highway leads to benefits in terms of accessibility improvement. Many previous studies have empirically analyzed the effects of highway opening. However, this study controls for the influence of factors other than the opening of the highway by applying a difference-in-differences analysis framework using geographic features. In other words, we empirically analyze the changes in the differences between the prices of housing in areas with improved accessibility due to a highway opening and the prices of housing in areas without it. Since there is no stylized fact about the geographic ranges that show the effects of the accessibility improvement following the opening, the proper definition of the treatment group and the control group is a key factor in minimizing the estimation error in capturing the benefits of accessibility improvement. In this study, although the areas forming these two groups are geographically adjacent, they are distinguished by the borders of administrative districts and natural topographical characteristics such as mountain ranges. Thus, mutual influence or exchanges between the two groups are restricted. As a result, the control group would have a trend in cyclical factors similar to that of the treatment group while not being affected by the opening of the highway. With this in mind, the benefits of accessibility improvement due to the opening of a highway are estimated by the relative changes in housing prices. In addition, analyses of the corresponding highway route by dividing it into three sections according to the opening time and location allow some robustness tests to be done.

The next section discusses the theoretical background and analysis model of this study. Section 3 provides an overview of the data used in the empirical analysis and the basic statistics of the included variables. Section 4 explains the results of the empirical analyses, and the policy implications are discussed in Section 5. The last section summarizes the key results of this study and suggests future tasks.

2. Theoretical Background and Empirical Analysis Model

2.1. Theoretical Background

Road construction affects productivity (Fernald [4]), trade (Duranton et al. [5], Allen and Arkolakis [6]), lane use within cities (Baum-Snow [7], Duranton and Turner [8]), and vehicle externalities (Parry et al. [9]), and it also plays an important role as a fiscal policy for economic stabilization (Leduc and Wilson [10]). However, in order to build a road, huge investments are needed, and if this decision-making is done poorly, the (local) government will face criticism for wasting its budget.

The opening of highways will affect the volume, temporal distribution, spatial distribution, and speed of vehicle traffic (Hymel [3]). This causes an increase in profits and employment by reducing the logistics cost of manufacturers, and at the same time generates the benefit of improved access to the highway for workers or residents. These benefits are often capitalized into increasing housing prices. A rise in housing prices as a benefit of accessibility improvement due to the development of transportation facilities has been reported in many studies (Armstrong and Rodríguez [11], Cheshire and Sheppard [12], Coulson and Engle [13], Franklin and Waddell [14], Henneberry [15], Iacono and Levinson [16], Martínez and Viegas [17]). On the other hand, some studies suggest that there are both positive and negative effects of highway construction that may affect housing preferences (Debrezion et al. [18], Iacono and Levinson [16], Martínez and Viegas [17], Tillema et al. [19]). The negative effects stem from the increase in traffic noise, which decreases the price of housing units located adjacent to the new highway (Kim et al. [20], Nelson [21], Theebe [22], Wilhelmsson [23]).

The economic effects of roads have been analyzed from various points of view. Shrestha [24], as well as Gonzalez-Navarro and Quintana-Domeque [25], show that the improvement in interregional connectivity due to new roads increases property value. In particular, Shrestha [24] indicates that a 1% decrease in the distance to a road raises the market price of an agricultural plot from 0.1% to 0.25%.

According to Ghani et al. [26], highways also contribute to the geographic concentration of manufacturing plants and the increase in their productivity. Similarly, Banerjee et al. [27] provide evidence that proximity to transportation networks has some positive causal effects on per capita GDP. Having roads between cities would lower the intercity transport costs and induce the income of cities to increase. Empirical results reported by Storeygard [28] suggest that a 10% decrease in transport costs leads to a 2.8% increase in a city's economic activity.

In addition to this production side, new roads seem to encourage educational investment in developing countries. In their case study of India, Adukia et al. [29] examine the effects of 115,000 new roads on educational choices. They find that due to these roads, children stay in school longer and perform better on exams. Additionally, a study conducted by Aggarwal [30] in rural India shows that paved roads lowered the prices and increased the availability of non-local goods, i.e., greater market integration.

The impact of the highway analyzed in this study is expected to be greater, as it is directly connected to the Gyeongbu highway, which was built in 1970. This highway plays the most pivotal role in the national transportation of South Korea by connecting Seoul, the capital, and Busan, the second-largest city in the country. However, since the increase in housing prices is affected by various factors, such as changes in the economy, that are not related to the opening of the highway, it is possible to capture the net benefit of the improved accessibility resulting from the opening of the highway only when those other factors are controlled for appropriately.

2.2. Empirical Analysis Model

In order to estimate the benefits of improved access to the Gyeongbu highway, as a result of the opening of the Pyeongtaek-Jecheon highway, in terms of a rise in housing prices in the region, a hedonic model for analyzing housing price determinants is used. It is a toll highway without traffic signals. However, the effects of the highway opening are identified through a difference-in-differences framework as follows:

$$y_{jt} = b_0 + b_1\ treat_j + b_2\ post_t^{\,1} + b_3\ (treat{*}post^1)_{jt} + b_4\ post_t^{\,2} + b_5\ (treat{*}post^2)_{jt} + X_j\ c + u_{jt} \quad (1)$$

Here, y_{jt} is the sale price (in units of ten thousand Korean won per square meter) of apartment j traded at time t. Next, $treat_j$ is whether apartment j is located in Anseong, Gyeonggi province, taking a value of 1 in the case of Anseong and 0 in the case of Jincheon or Eumseong in Chungbuk province. The variable $post_t^{\,k}$ is the time point after the opening of section k. In the case of the Anseong-Namanseong (opened on 31 August 2007) section, k corresponds to 1, and in the case of the Namanseong-Daeso (opened on 11 December 2008) section, k corresponds to 2. Then, X_j is the time-invariant characteristic of apartment j, including its size, year of construction, floor, location, and the name of the complex. Finally, u_{jt} represents a usual error term. As a method to evaluate a policy or an event (i.e., the opening of a new highway in this study), the difference-in-differences framework is one of the popular methods. However, even though the regression Equation (1) controls for the time-invariant characteristics of individual apartments between the treatment and the control group, there would still be unobserved heterogeneity. If there are enough samples in the control group, before estimating Equation (1), we can restrict the samples to those matched to the treatment group in order to lessen the possible bias coming from the dissimilar trends in prices due to the unobserved heterogeneity.

Alternatively, a traditional cost-benefit analysis could be used as an evaluation method. In Korea, the economic feasibility of public investment projects is based on cost-benefit analyses. However, this method restricts the benefits of a new highway to direct ones and excludes indirect ones. Thus, it would not be appropriate for capturing the social benefits of a new highway that may include indirect benefits.

2.3. *Areas of Analysis*

The highway of interest is the Pyeongtaek-Jecheon route, and, as parts of this route, the Anseong-Namanseong section and the Namanseong-Daeso section are analyzed (Figure 1). The route covers a total length of 109.4 km. The construction started with the opening of the Pyeongtaek-Anseong section in 2002, followed by the Anseong-Namanseong section in 2007, the Namanseong-Daeso section in 2008, the Daeso-Chungju section in 2013, and the Chungju-Jecheon section in 2015. In a geographical context, it is important to note that the Anseong-Namanseong section nearly exclusively serves the Anseong area. Moreover, although the nearby areas of Jincheon and Eumseong are geographically adjacent, before the opening of the Namanseong-Daeso section, there were difficulties regarding passage between the two regions due to the mountain range as well as the borders of administrative regions (Gyeonggi and Chungbuk province). Thus, it can be assumed that the opening of the Anseong-Namanseong section mainly affected only the residents of Anseong. Levkovich et al. (2016) pointed out the inadequate definition of the treatment group and the control group as one of the reasons for studies finding different results regarding the effects of a highway opening on the housing market. To address this issue, this study assumes that the treatment group and the control group experience similar cyclical changes in housing prices because they are geographically adjacent, while the effects of the highway opening are limited to the treatment group because they are separated physically and socially due to natural topography and administrative boundaries.

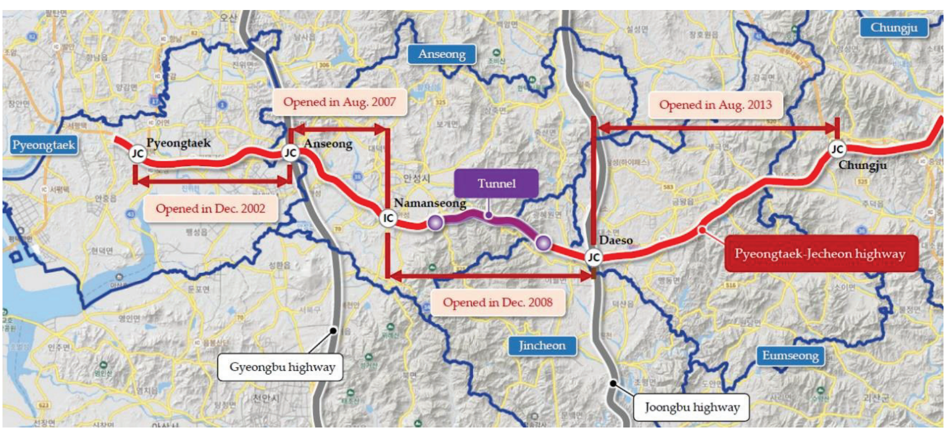


Figure 1. Pyeongtaek-Jecheon Highway Route Map.

In the regression Equation (1), the effects of an increase in neighboring housing prices due to the opening of the Anseong-Namanseong section are estimated and represented by parameter b_3. The benefits of improved accessibility to the Gyeongbu highway due to the opening of this section would be provided to residents in Anseong, and thus, b_3 is supposed to have a positive value. On the other hand, since the treatment group was defined as housing located in Anseong, the opening of the Namanseong-Daeso section would cause an increase in the price of housing located in Jincheon or Eumseong, which form the control group. Thus, parameter b_5 would have a negative value. However, since the Joongbu highway opened in 1987, Jincheon and Eumseong already experienced improved accessibility, and their residents may not experience substantial extra benefits from the opening of the Namanseong-Daeso section in 2007. As such, the estimate is likely to be statistically insignificant or close to zero.

3. Data and Variables

3.1. Data

In this study, the actual transaction price data, obtained through the real transaction price disclosure system of the Ministry of Land, Infrastructure, and Transport (http://rtdown.molit.go.kr/ (accessed on 1 March 2022)), are used for analysis. The transactions recorded in this system are for land, housing (apartment, multiplex housing/townhouse, single/multi-family housing), so-called "officetels" (i.e., a type of studio apartment in a multi-purpose building with residential and commercial units), commercial real estate reported to the local government, and the resale of apartment sales/occupancy rights. In the case of apartments, the disclosure of data includes the address, the name of the complex (the name of the building in the case of a townhouse/multiplex housing), the size of the apartment, the contract date, the transaction amount, the floor, and the year of construction.

The Pyeongtaek-Jecheon highway, the subject of analysis, consists of five sections (Table 1), including the Anseong-Namanseong section opened in 2007 and the Namanseong-Daeso section opened in 2008. Since the current study focuses on the effects of opening these two particular sections, the used dataset concerns all apartments traded in the period from 1 January 2006 to 31 December 2009. However, unlike transactions in general industrial products, real estate transactions are highly unlikely to respond immediately to any event, so transactions around the time of opening—i.e., from two months prior to the opening date to two months after the opening date—are excluded from the analysis. In other words, in the case of the Anseong-Namanseong section opened on 31 August 2007, apartment sales transactions made between 30 June 2007 and 31 October 2007 are not included in the analysis. In total, 18,187 apartment sales transactions were included in the regression analysis for the entire period.

Table 1. Opening times for each section of the Pyeongtaek-Jecheon route.

Section	Length (in Kilo-Meter)	Date of Opening
Pyeongtaek-Anseong	25.7	12 December 2002
Anseong-Namanseong	10.2	31 August 2007
Namanseong-Daeso	22.0	11 December 2008
Daeso-Chungju	27.6	12 August 2013
Chungju-Jecheon	23.9	30 June 2015

3.2. Variables

Table 2 shows the basic statistics of the variables. Regarding the characteristics of the apartments included in the regression analysis, the apartment sizes range from 25.68 square meters to 164.12 square meters, and the average corresponds to 58.57 square meters. The floors on which the apartments are located vary from the (lowest) 1st floor to the (highest) 25th floor, with the average being the 8th floor. The average number of years since construction is 7.49 years. The proportion of apartment sales transactions belonging to the treatment group, which is defined as the area experiencing an impact on housing prices due to the opening of the highway, is 60%. By time point, 42% of the transactions took place before the opening of the Anseong-Namanseong section, 58% took place after its opening, and 17% of the transactions took place after the opening of the Naman-Namanseong section. The average apartment transaction price rose annually from 1.058 million won per square meter in 2006 to 1.376 million won in 2009, representing an average annual growth rate of 9.2%. Considering that the consumer price index rose at an average annual rate of 3.3% during the same period, this implies that the increase in apartment sale prices in the analyzed area exceeded the rate of inflation.

Table 2. Basic Statistics of Variables.

Variable	Average	Std. Dev.	Minimum	Maximum
Size	58.57	17.67	25.68	164.12
Floor	8.00	4.88	1	25
Age	7.49	4.30	0	23
Treat	0.60	0.49	0	1
Post1	0.58	0.49	0	1
Post2	0.17	0.38	0	1
Price in				
2006	105.8	32.7	17.8	241.5
2007	114.6	29.9	27.7	267.5
2008	122.9	41.3	29.4	279.3
2009	137.6	45.1	29.4	288.6

Note. Prices are in units of ten thousand Korean won per square meter.

4. Empirical Results and Discussions

4.1. Baseline

Table 3 presents the empirical analysis results regarding the effects of the opening of the Anseong-Namanseong section and the Namanseong-Daeso section of the Pyeongtaek-Jecheon highway on improved accessibility, as captured in terms of the capitalization into housing prices in the region. Column (1) includes the number of years since the construction of individual apartment complexes and their squares as control variables, while Column (2) includes dummy variables for individual apartment complexes.

Table 3. Results of estimating the effects of the opening of the Pyeongtaek-Jecheon highway on housing prices.

	(1) **Variables for Age and Its Square Are Included**	**(2)** **Dummy Variables for Individual Complexes Are Included**
Treat	38.0492 **	38.9515 **
	(63.11)	(45.34)
Post1	14.6122 **	12.8479 **
	(23.40)	(29.05)
Treat *Post1	6.2580 **	1.2208 *
	(6.90)	(2.03)
Post2	16.0981 **	6.4930 **
	(19.30)	(11.93)
Treat *Post2	0.6620	0.2008
	(0.58)	(0.28)
Characteristics of apartment		
Size	0.4276 **	0.0302 *
	(28.51)	(2.41)
Floor	0.3979 **	0.3483 **
	(10.33)	(15.89)
Age	−9.4144 **	
	(−42.44)	
Squared term of age	0.3600 **	
	(32.14)	
Constant	99.0335 **	41.7062 **
	(62.11)	(9.88)
Fixed effect		
Individual complexes	-	160
Number of observations	18,187	18,187
Adjusted R-squared	0.6146	0.8976

Note. Numbers in parentheses are White-Huber's robust *t*-values. ** and * indicates statistical significance at 1% and 5% level, respectively.

Prior to assessing the effects of opening the highway, it is necessary to examine the difference in apartment prices according to the characteristics of the apartments in order to examine the universal validity of the analysis results. It can be seen that the larger the size of the apartment and the higher the floor it is located on, the higher the apartment price per unit area is, which is consistent with the findings of previous studies. According to the results in Column (1), it can be seen that as more time elapsed after construction, the housing price decreased, albeit at a gradually diminishing rate. In general, it is assumed that apartment prices reach their lowest level after about 26 years, which roughly corresponds to the 30-year life cycle commonly set for apartment reconstruction.

With the opening of the Anseong-Namanseong section, the prices of apartments in Anseong, which is adjacent to Jincheon and Eumseong, Chungbuk province, have increased statistically significantly by about 63,000 won per square meter in Column (1) and 12,000 won per square meter in Column (2). These numbers reflect the effects of the improved accessibility to the Gyeongbu highway for people living in Anseong due to the opening of the Anseong-Namanseong section of the Pyeongtaek-Jecheon highway. Given the average apartment size of 58.57 square meters (Table 2), this benefit corresponds to an average of $586 to $3075 per apartment.

On the other hand, although the opening of the Namanseong-Daeso section improves access to the Gyeongbu highway through the Pyeongtaek-Jecheon highway for residents in Jincheon and Eumseong in Chungbuk province, this increase in transportation convenience appears not to be capitalized into a relative increase in apartment prices in the region. This is because the Joongbu highway, which opened in 1987, already offered Jincheon and Eumseong improved accessibility.

4.2. Robustness

Table 4 shows the analysis results when dividing the entire analysis period in Table 3 into two shorter periods that are centered on the opening times of the two sections. The first column shows the results when the analysis is limited to the period from 1 January 2006 to 11 December 2008, which is the period ending before the opening of the Namanseong-Daeso section. In other words, it shows the impact of the opening of the Anseong-Namanseong section on 31 August 2007, irrespective of the opening of the Namanseong-Daeso section. The results reveal that, with the opening of the Anseong-Namanseong section, the prices of apartments in nearby Anseong increased statistically significantly compared to the prices of apartments in Jincheon and Eumseong, which form the control group. However, this relative increase was 46,000 won per square meter, which is somewhat smaller than the 63,000 won presented in Column (1) of Table 3.

The second column presents the results when the analysis is limited to the period from 1 September 2007 to 31 December 2009, which is the period starting after the opening of the Anseong-Namanseong section. This aims to exclude the effects of the opening of the Anseong-Namanseong section and to exclusively analyze the changes in the prices of neighboring apartments due to the opening of the Namanseong-Daeso section on 11 December 2008. The estimate (0.9453) for the coefficient of the variable representing the effect of the opening of the corresponding section is not statistically significant at all, and it is similar to the result (0.6620) presented in Column (1) of Table 3.

Table 5 corresponds to a kind of placebo test result to show that the analysis result presented in Table 3 is not a spurious result due to simple economic fluctuations. In this test, only housing transactions made in 2006, when the highway sections were not opened yet, are included in the analysis. A dummy variable representing transactions made in the second half of 2006 is created arbitrarily, and it is tested whether or not the relative increase in housing prices in Anseong after the opening of the Anseong-Namanseong section shown in Table 3 is a simple trend through the interaction term between this dummy variable and a dummy variable indicating the housing in Anseong. The results in Table 5 confirm that there were no asymmetric economic fluctuations that caused relatively faster growth in housing prices in Anseong than in Jincheon and Eumseong.

Table 4. Results when the analysis period is divided to estimate the impact per section.

	Opening of the Anseong-Namanseong Section (Data: 1 January 2006–11 December 2008)	**Opening of the Namanseong-Daeso Section (Data: 1 September 2007–31 December 2009)**
treat	39.6687 **	44.6528 **
	(66.78)	(65.85)
post1	15.0467 **	
	(23.89)	
treat *post1	4.5856 **	
	(5.04)	
post2		17.0534 **
		(21.92)
treat *post2		0.9453
		(0.86)
Characteristics of apartment		
Size	0.4529 **	0.3103 **
	(27.49)	(16.90)
Floor	0.3730 **	0.8393 **
	(9.16)	(15.02)
Age	−8.4762 **	−12.5173 **
	(−33.73)	(−47.58)
Squared term of age	0.3494 **	0.4792 **
	(27.28)	(37.28)
Constant	91.0348 **	131.6379 **
	(54.48)	(70.89)
Number of observations	15,047	10,628
Adjusted R-squared	0.5887	0.6362

Note. Numbers in parentheses are White-Huber's robust *t*-values. ** and * indicates statistical significance at 1% and 5% level, respectively.

Table 5. Results for the possibility of different economic trends between groups.

	(1)	**(2)**
treat	46.2521 **	48.2169 **
	(37.85)	(30.55)
from July to December of 2006	1.3375	4.7069 **
	(1.02)	(5.41)
treat * from July to December of 2006	1.3770	−0.2056
	(0.94)	(−0.20)
Characteristics of apartment		
Size	0.5904 **	0.2244 **
	(22.51)	(8.16)
Floor	0.0361	0.2370 **
	(0.59)	(6.52)
Age	−5.2945 **	
	(−14.27)	
Squared term of age	0.2270 **	
	(10.58)	
Constant	63.2398 **	79.8044 **
	(24.88)	(44.98)
Fixed effect		
Individual complexes	-	160
Number of observations	4041	4041
Adjusted R-squared	0.6424	0.9151

Note. Numbers in parentheses are White-Huber's robust *t*-values. ** and * indicates statistical significance at 1% and 5% level, respectively.

5. Discussion

Highways have several positive effects. Fernald [4] suggested, through empirical analysis, that the construction of highways connecting US states before 1973 contributed to the improvement of productivity in vehicle-intensive industries. However, this increase in productivity is not continuous and appears to be limited to one time. Duranton and Turner [8] empirically analyzed the growth of US cities near highways connecting US states. According to them, if a city's initial inventory of highways increases by 10%, employment in the city increases by 1.5% over the next 20 years. On the other hand, according to Allen and Arkolakis [6], trade costs are different due to differences in geographic location, which affect productivity and cause income inequality between regions. They suggested that the construction of a highway increases welfare by 1.1 to 1.4%, which is sufficiently greater than the cost of constructing the highway. Duranton et al. [5] analyzed the effects of highways on transactions between large cities in the United States. Their results showed that a 10% increase in highways in a city increases the city's exports by 5%, as it allows the city to specialize in industries that use highways more intensively.

In contrast, a study by Asher and Novosad [31] found that although India's rural national road construction program caused some workers to shift from agriculture to other industries, it did not cause significant changes in agricultural performance, income, or assets. Noticeably, it was pointed out that the effects are not large enough to slightly increase employment in village firms. One of the many purposes of highway construction is to alleviate traffic congestion in the city. However, as seen in the results of Hymel [3], this effect of road construction appears only for a short period of time. According to the Fundamental Law of Road Congestion (Downs [32]), an increase in roads does not alleviate traffic congestion in the long run because it derives demand for road use on a similar scale. In addition, as seen in the results of Baum-Snow [7], the construction of highways moves the population from the inner city to the suburbs. This causes urban proliferation and wasteful traffic.

Levkovich et al. [33] suggested that the construction of highways improves access and increases housing prices, while noise pollution and the concentration of traffic from highways decrease housing prices. Although these conflicting effects exist, the overall effects of highways on housing prices are generally analyzed to be positive. The negative impacts of traffic noise from highways are often considered to cause a drop in nearby housing prices. For example, Theebe [22]'s empirical analysis showed that, on average, a price drop of 5% occurs.

Overall, it is not easy to draw definite conclusions about the effects of opening a highway. Different results may appear when the evaluation of effectiveness is focused on production activities, such as changes in productivity or employment, improving accessibility or sedentary activities, or taking into account negative aspects such as traffic noise or congestion. Nevertheless, the decision to construct a highway, which requires a huge budget, should be based on the results of a cost-benefit analysis from the perspective of society as a whole. However, the absolute and relative weight of the benefits may vary depending on what the main purpose of the highway is, and benefits from a specific point of view may be emphasized.

From the local government's point of view, the potential impact of a new highway on the population would be regarded as important. Depending on who migrates to the local area, the economic effects would vary. The improved transportation networks due to a new highway would encourage firms to (re)locate near the area. Then, workers would also be attracted to the area. In the larger labor pool, agglomeration economies would be realized, and labor productivity and wages would rise. Then, the overall quality of life in the area would increase.

The method used in this study is worthy of being applied to developing countries or rural areas. In the case of developed countries or urbanized areas, transportation networks would already be well-established; therefore, as Fernald [4] argued, new highways would not lead to remarkable benefits.

6. Conclusions

The opening of highways induces positive effects on production activities and settlement conditions. However, it appears that there is a limit to the alleviation of traffic congestion due to the huge number of resources being invested in the construction and the derived demand for road traffic. In other words, the opportunity cost of highway construction and the possibility of limited effects should be considered. In the end, the benefits of a highway opening should be estimated as accurately as possible, and such insights should form the basis on which the decision to construct a highway is made.

This study empirically analyzes the benefits of opening a highway by applying a difference-in-differences analysis framework to assess the capitalization of these benefits into an increase in neighboring housing prices. More specifically, the study examines two adjacent regions that are physically separated by a mountain range and independent of mutual economic activities. In this way, the effects of simple economic fluctuation factors unrelated to the effects of opening the highway are eliminated. According to the empirical analysis results, the improved accessibility due to a highway opening causes a relative increase in neighboring housing prices, which shows that the benefits of improved settlement conditions are capitalized into housing prices. On the other hand, the analysis reveals that the actual benefits of opening additional routes in areas where access to highways already exists are relatively small. The study results suggest robustness through two complementary analyses in which the benefits are assessed per highway section.

The difference-in-differences analysis framework applied in this study has been used in some earlier studies. In order for this analysis framework to be appropriate as a methodology in the present study, two basic requirements need to be met. First, the benefits of opening a highway should, at least theoretically, appear only in the treatment group and not in the control group. It is assumed that this requirement has been met sufficiently by selecting two regions that are physically separated by a mountain range. Second, assuming there was no highway opening, the treatment group and the control group should show the same trend in time-series changes. This requirement is expected to have been met by having the control group region geographically adjacent to the treatment group region. Nonetheless, the reported study is limited because the analysis period is relatively short, only allowing the estimation of benefits over four years. Highways belonging to infrastructure will, however, cause long-term impacts. Although data on housing prices after 2009 are available, it is not easy to control for other external factors that occur during the period, so follow-up analysis is scheduled as a future task.

Author Contributions: Conceptualization, W.K. and S.H.H.; methodology, W.K. and S.H.H.; software, S.H.H.; validation, W.K. and S.H.H.; resources, W.K.; data curation, W.K.; writing—original draft preparation, W.K. and S.H.H.; writing—review and editing, W.K. and S.H.H. All authors have read and agreed to the published version of the manuscript.

Funding: The corresponding author received financial support from the Korean Expressway Corporation for this research.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: The data presented in this study are available on request from the corresponding author. The data are not publicly available due to privacy.

Acknowledgments: The authors would like to thank the three anonymous reviewers for their valuable comments and suggestions on previous versions of this paper.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Errampalli, M.; Senathipathi, V.; Thamban, D. Effect of congestion on fuel cost and travel time cost on multi-lane highways in india. *Int. J. Traffic Transp. Eng.* **2015**, *5*, 458–472. [CrossRef]
2. Transportation for America. The Congestion Con: It's All a Lie. 2022. Available online: https://t4america.org/maps-tools/congestion-con/ (accessed on 1 March 2022).
3. Hymel, K. If you build it, they will drive: Measuring induced demand for vehicle travel in urban areas. *Transp. Policy* **2019**, *76*, 57–66. [CrossRef]
4. Fernald, J.G. Roads to Prosperity? Assessing the Link Between Public Capital and Productivity. *Am. Econ. Rev.* **1999**, *89*, 619–638. [CrossRef]
5. Duranton, G.; Morrow, P.M.; Turner, M.A. Roads and Trade: Evidence from the US. *Rev. Econ. Stud.* **2013**, *81*, 681–724. [CrossRef]
6. Allen, T.; Arkolakis, C. Trade and the Topography of the Spatial Economy *. *Q. J. Econ.* **2014**, *129*, 1085–1140. [CrossRef]
7. Baum-Snow, N. Did highways cause suburbanization. *Q. J. Econ.* **2007**, *122*, 775–805. [CrossRef]
8. Duranton, G.; Turner, M. Urban growth and transportation. *Rev. Econ. Stud.* **2012**, *79*, 1407–1440. [CrossRef]
9. Parry, I.; Walls, M.; Harrington, W. Automobile Externalities and Policies. *J. Econ. Lit.* **2007**, *45*, 373–399. [CrossRef]
10. Leduc, S.; Wilson, D. Fueling Road Spending with Federal Stimulus. *FRBSF Econ. Lett.* **2014**, 25.
11. Armstrong, R.J.; Rodríguez, D.A. An Evaluation of the Accessibility Benefits of Commuter Rail in Eastern Massachusetts using Spatial Hedonic Price Functions. *Transportation* **2006**, *33*, 21–43. [CrossRef]
12. Cheshire, P.; Sheppard, S. On the Price of Land and the Value of Amenities. *Economica* **1995**, *62*, 247. [CrossRef]
13. Coulson, N.; Engle, R.F. Transportation costs and the rent gradient. *J. Urban Econ.* **1987**, *21*, 287–297. [CrossRef]
14. Franklin, J.; Waddell, P. A hedonic regression of home prices in King County, Washington, using activity-specific accessibility measures. In Proceedings of the Transportation Research Board 82nd Annual Meeting, Washington, DC, USA; 2003.
15. Henneberry, J. Transport investment and house prices. *J. Prop. Valuat. Invest.* **1998**, *16*, 144–158. [CrossRef]
16. Iacono, M.; Levinson, D. Location, regional accessibility, and price effects: Evidence from home sales in Hennepin County, Minnesota. *Transp. Res. Rec. J. Transp. Res. Board* **2011**, *2245*, 87–94. [CrossRef]
17. Martínez, L.; Viegas, J. Effects of transportation accessibility on residential property values. *Transp. Res. Rec. J. Transp. Res. Board* **2009**, *2115*, 127–137. [CrossRef]
18. Debrezion, G.; Pels, E.; Rietveld, P. The Impact of Railway Stations on Residential and Commercial Property Value: A Meta-analysis. *J. Real Estate Financ. Econ.* **2007**, *35*, 161–180. [CrossRef]
19. Tillema, T.; Hamersma, M.; Sussman, J.; Arts, J. Extending the scope of highway planning: Accessibility, negative externalities and the residential context. *Transp. Rev.* **2012**, *32*, 745–759. [CrossRef]
20. Kim, K.; Park, S.; Kweon, Y. Highway traffic noise effects on land price in an urban area. *Transp. Res. D Transp. Environ.* **2007**, *12*, 275–280. [CrossRef]
21. Nelson, J. Highway noise and property values: A survey of recent evidence. *J. Transp. Econ. Policy* **1982**, *16*, 117–138.
22. Theebe, M.A.J. Planes, Trains, and Automobiles: The Impact of Traffic Noise on House Prices. *J. Real Estate Financ. Econ.* **2004**, *28*, 209–234. [CrossRef]
23. Wilhelmsson, M. The Impact of Traffic Noise on the Values of Single-family Houses. *J. Environ. Plan. Manag.* **2000**, *43*, 799–815. [CrossRef]
24. Shrestha, S.A. Roads, Participation in Markets, and Benefits to Agricultural Households: Evidence from the Topography-Based Highway Network in Nepal. *Econ. Dev. Cult. Chang.* **2020**, *68*, 839–864. [CrossRef]
25. Gonzalez-Navarro, M.; Quintana-Domeque, C. Paving Streets for the Poor: Experimental Analysis of Infrastruc-ture Effects. *Rev. Econ. Stat.* **2016**, *98*, 254–267. [CrossRef]
26. Ghani, E.; Goswami, A.; Kerr, W. Highway to Success: The Impact of the Golden Quadrilateral Project for the Location and Performance of Indian Manufacturing. *Econ. J.* **2016**, *126*, 317–357. [CrossRef]
27. Banerjee, A.; Duflo, E.; Qian, N. On the road: Access to transportation infrastructure and economic growth in China. *J. Develop. Econ.* **2020**, *145*, 102442. [CrossRef]
28. Storeygard, A. Farther on down the Road: Transport Costs, Trade and Urban Growth in Sub-Saharan Africa. *Rev. Econ. Stud.* **2016**, *83*, 1263–1295. [CrossRef]
29. Adukia, A.; Asher, S.; Novosad, P. Educational Investment Responses to Economic Opportunity: Evidence from Indian Road Construction. *Am. Econ. J. Appl. Econ.* **2020**, *12*, 348–376. [CrossRef]
30. Aggarwal, S. Do rural roads create pathways out of poverty? Evidence from India. *J. Dev. Econ.* **2018**, *133*, 375–395. [CrossRef]
31. Asher, S.; Novosad, P. Rural Roads and Local Economic Development. *Am. Econ. Rev.* **2020**, *110*, 797–823. [CrossRef]
32. Downs, A. The law of peak-hour expressway congestion. *Traffic Q.* **1962**, *16*, 393–409.
33. Levkovich, O.; Rouwendal, J.; Van Marwijk, R. The effects of highway development on housing prices. *Transportation* **2016**, *43*, 379–405. [CrossRef]

sustainability

MDPI

Article

Does High Spatial Density Imply High Population Density? Spatial Mechanism of Population Density Distribution Based on Population–Space Imbalance

Dian Shao [1,*] and Weiting Xiong [2]

1 School of Architecture, Southeast University, Nanjing 210096, China
2 School of Landscape Architecture, Nanjing Forestry University, Nanjing 210037, China; xwt@njfu.edu.cn
* Correspondence: 230198412@seu.edu.cn; Tel.: +86-156-5166-3507

Abstract: Numerous studies have suggested a positive correlation between spatial and population densities. However, few have systematically conducted quantitative analysis and deciphered the detailed correlation in block scale. Here, we construct a population–space correlation algorithm to quantify and compare the correlation between mobile phone signalling data and vector spatial data and identify blocks with uneven population density. We analyse the influences of various urban spatial characteristics on population density and the distribution characteristics of the identified city blocks. Changzhou City, China, was selected as the study case. The results indicate that (1) population density distribution is unbalanced only when spatial density exceeds a critical value, reflecting the level and sphere of influence of blocks with varying spatial densities; (2) low population density distribution is concentrated in the zonal space, along the boundary between primary and secondary urban centres; (3) spatial characteristics affecting population density distribution vary with the type of block, and the green landscape's attractiveness is reduced. Our study provides a novel perspective on quantifying the link between urban form and population distribution. It can help decision-makers and planners in accurately recommending urban intervention in population density distribution by adjusting the spatial morphology and promoting rational use of urban public resources.

Keywords: population–space imbalance; population density distribution; spatial characteristics; spatial density; spatial mechanism

Citation: Shao, D.; Xiong, W. Does High Spatial Density Imply High Population Density? Spatial Mechanism of Population Density Distribution Based on Population–Space Imbalance. *Sustainability* **2022**, *14*, 5776. https://doi.org/10.3390/su14105776

Academic Editors: Mengqiu Cao, Claire Papaix, Benjamin Büttner and Tianren Yang

Received: 13 April 2022
Accepted: 9 May 2022
Published: 10 May 2022

1. Introduction

Population density is universally regarded as a yardstick for the urban planning level and an important evaluation criterion for urban development and spatial balance [1]; therefore, governments and society regard population density as a matter of concern. Since construction land is becoming increasingly scarce, many governments have adopted a high-density spatial development model to address population density's rapid growth [2,3], and there is growing evidence of a significant positive correlation between spatial density and cities' population density [4,5]. In this study, 'population density' refers to the population density in the activity space of an urban block; 'activity space' refers to the main space for population activities in a city, including indoor space and outdoor public space [6]. In addition, the population density also reflects the urban vitality to a certain extent. Urban vitality here refers to the change in frequency of population flow in the block and the attraction of the block to the population [7]. Therefore, research on population density can play a reference role in improving urban vitality.

Follow-up surveys of population density reveal a population–space imbalance in cities. In most cases, population density in blocks with the same function is directly proportional to spatial density, slightly fluctuating around the average [8,9]; however, there are also blocks with population density significantly above or below average. These are particularly common in high-density urban areas [10] (see Figure 1). The 'block' mentioned in this paper refers to the closed space surrounded by roads. It is the basic unit of urban space and is usually considered the smallest unit of a census in population flow research [11].

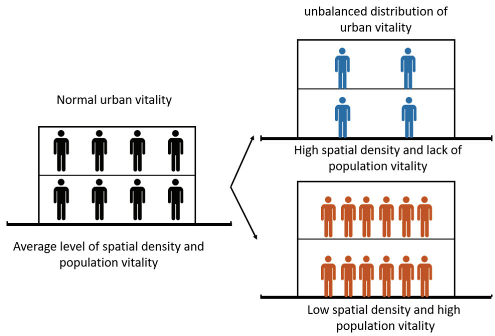


Figure 1. Phenomenon of unbalanced distribution of population density.

This study posits that high spatial density in blocks is universally beneficial to increasing population density, but differences in spatial characteristics (e.g., location, accessibility, and landscape) and their impact on population behaviours (e.g., living, education, and work) affect population density distribution, resulting in a significant population–space imbalance in some blocks [12]. When government decision makers and planners plan the distribution and quantity of facilities in the block, their judgment is based on the daily population density in that block, and the population density is calculated according to the spatial density [13]. Population–Space imbalance will cause their judgment to deviate based on the population density in the block; thus, they are unable to accurately judge the demand quantity of public service facilities and the distribution of the traffic network system according to the construction density of space [14,15]. This may lead to social problems (e.g., aggravated supply–demand imbalance of public facilities, local traffic congestion, and insufficient support services), thus restricting urban sustainability [16,17].

To effectively address unbalanced population density distribution, it is necessary to identify the factors that affect it and how it is affected. Many previous studies adopted a macroeconomic, social, or environmental perspective on a regional or urban scale; existing studies focus on how population density distribution is affected and propose effective measures to regulate population density distribution based on the concept of sustainability [18–20]. However, few studies have employed a spatial perspective, particularly a micro perspective of blocks. Block-scale space is the basic arena for population activities and urban development and constrains the development of urban elements (e.g., roads, locations, landscape, and functions), thereby affecting population density distribution [21].

Given existing studies' deficiencies, this study examines how population density distribution is affected by urban spatial characteristics from a meso or micro perspective. The study investigates the following questions: (1) What are the characteristics of blocks with unbalanced population density distribution, and how can these blocks be identified through big data and algorithms? (2) In addition to the influence of location, traffic, and other factors, how are the blocks with unbalanced population density distributed in space? Can we find the spatial distribution law of this imbalance? (3) What spatial characteristics in the city will affect the distribution of population density? How do these characteristics interact and affect the flow of people?

China is a densely populated country, where each city's central urban areas are high-density. Using smartphone signalling data and spatial vector data, we conducted data coupling and empirical analysis to further examine how urban spatial characteristics affect population density distribution, aiming to provide methodological suggestions for intervention in and regulation of urban population density distribution from a spatial perspective, thus promoting rational use of urban resources.

The rest of this paper is divided into five sections. In Section 2, we introduce the main factors that affect population density distribution and the composition of urban spatial characteristics. In Section 3, we discuss the chosen case study as well as the data and research methods used. In Section 4, we discover the inherent correlation and principles of urban spatial characteristics and population density distribution. In Section 5, on the basis of our findings, we explore how urban spatial characteristics affect population density distribution and the policy implications of this study. In Section 6, we summarise the key findings and contributions of this study.

2. Literature Review and Working Hypotheses

2.1. The Examination of Unbalanced Population Density Distribution

The focus and progress of studies on unbalanced population density distribution vary by country. In North America, related studies focus on the unbalanced distribution of socially disadvantaged groups. For example, Ariste [22] and Masuda et al. [23] analysed the impact of environmental health problems on the distribution of disadvantaged groups and their social causes (e.g., public facilities). Canales and Frank analysed US population distribution and found that an ageing population unbalances the urban working population distribution; they argued that the working population distribution could be balanced through an appropriate immigration policy.

Compared with North America, South American countries show more concern for the unbalanced distribution of the immigrant population. For example, Vinuela investigated cross-regional movement (e.g., across urban agglomerations or neighbouring countries) and the unbalanced distribution of the Spanish immigrant population [20]. Bauer analysed agglomeration and dispersion characteristics of the Mexican immigrant population and summarised the influence of social externalities on the unbalanced population density distribution [24]. In addition, unbalanced population density distribution related to slow population growth is an issue of common concern in studies of South American countries. Highly targeted policies are implemented to improve socio-economic development [25,26].

Similarly, studies of European countries also focus on immigrant populations. For example, unbalanced population density distribution is related to European countries' wage and unemployment standards [27], Bulgaria's migration and population policies [28], and Spanish urban economies' structural changes [29].

By contrast, studies of Asian countries focus more on unbalanced population density distribution in the process of urbanisation, as well as consequent urban and social problems. For example, Diwakar found that the unbalanced distribution of population density in India is caused by an urban development gap in the urbanisation process [30]. By analysing the movement of Chinese populations since 1978, Duan found that unbalanced population density distribution exists in China's urbanisation process, which will further widen the economic development gap between eastern and western China [31]. Based on a horizontal comparison of cities with different development levels, Lee found that the economic and land development gap between South Korean cities results in an unbalanced distribution of population density [4].

The focus on unbalanced population density distribution varies across cities in different regions worldwide, depending on their actual condition and needs. Overall, academia has provided due attention to the imbalance in population movement between cities and unbalanced regional distributions of population density (e.g., in urban agglomerations or neighbouring countries) but has scarcely studied unbalanced population density distribution inside cities [32]. Hence, it is necessary to further examine by what factors and how population density distribution is affected.

2.2. Main Influencing Factors of Population Density Distribution and Related Study Trends

In the era of big data, the quantitative distribution of population density has become a hot topic in urban sustainability and planning [33]. A review of existing studies shows that regional differences in economic level, social development, and ecological environment can primarily account for unbalanced population density distribution. Economic factors include economic development, employment level, regional wages, and hedonic price of labour [31,34,35]. The impact of social development factors on population density distribution is more complex; in addition to government interventions (e.g., social demographic policy and national immigration policy) [25,28], population density distribution is also affected by major social events, cultural backgrounds, political stability, and social fairness [18,29,36,37]. Ecological factors (e.g., ecological vulnerability or sensitivity, hydrological condition, and geological condition) can also affect a population's spatial selection [38,39]. At the same time, location is also an important factor affecting the distribution of population density. Relevant research on location theory shows that the location and maximum migration length of important facilities such as commerce, entertainment, and sports will influence the distribution of population density [40,41]. Moreover, for residential and community blocks, the difference in location and surrounding land use distribution will also lead to the deviation of population density distribution [42].

A few studies focused on the impact of urban space on population density distribution. Wu and Meijers examined the correlation between population density distribution and the overall urban layout of central systems [43,44]; Li analysed problems arising from unbalanced Taiwanese population density distribution and proposed a design approach to urban hierarchy [45]; in analysing urban public resources' spatial structure and spatial distribution, Zhu proposed a spatial 'rebalancing' strategy to address the growth and unbalanced distribution of population density [46]; Chi analysed the impact of urban structure and time on population distribution and proposed a complex and practical procedure to address unbalanced population density distribution [47]. Existing studies of urban space focus on urban structures on a relatively large scale and from a regional perspective, sharing a similar entry point with related studies conducted from macro-regional perspectives (e.g., economic, social, and environmental perspectives). The characteristic differences in various factors (e.g., urban structure, economic, and social factors) are more significant on a relatively large scale, thus helping to identify the factors that account for the unbalanced distribution of population density.

However, urban structure and urban spatial characteristics are not equivalent. Internal elements of urban space (e.g., spatial density, morphological scale, business function, and location) also reflect urban spatial characteristics, or rather, refined spatial characteristics on a smaller scale (i.e., block scale). In the last five years, researchers have investigated the impact of these spatial characteristics on population density distribution. Lee and Xia demonstrated both a significant positive autocorrelation and local mismatch between spatial density and population density, where the local mismatch is related to the type of land use, urban location, and time period [4,5]. Zhang demonstrated that the agglomeration scale and educational spatial morphology intensity affect population density distribution [48]. Zhao analysed population distribution characteristics in Shenyang and found an unbalanced distribution of population density in cities and further found that it was closely related to the distribution of infrastructure and functional diversity around the neighbourhoods [49].

2.3. Composition and Indicators of Spatial Characteristics

Urban spatial characteristics have different connotations and constituent elements depending on perspective. For example, regional spatial characteristics usually include the distribution pattern of cities and urban spatial networks within a region [24,29], and spatial characteristics from the macro-scale perspective of cities usually include the structure, overall layout, and central system of the city [40,41]. This study analyses the influence of spatial characteristics on population density distribution at the more accurate research scale of city blocks, thus requiring us to determine the elements of spatial characteristics from the perspective of blocks.

From this perspective, the spatial characteristics are those of the external and internal environments of the blocks [50]. The spatial characteristics of the external environment of blocks refer to the spatial relationships between a block and its surrounding environments, such as location, transport, and other networks [51,52]. Among recent studies, Jan et al. discussed the impact of block-level public centres and their degree of centrality in urban population activity [53]. Zhang et al. found that transport network accessibility and types of public services can affect population flows [54]. Mao et al. demonstrated that road network accessibility has a significant positive correlation with population density within blocks [55]. As a result, this study selected three indicators that are strongly correlated with population density, namely location centrality, functional diversity, and accessibility, to conduct further research. Similarly, the spatial characteristics of the internal environment of blocks include factors such as form, facilities, and boundaries [56]. In recent literature, Mousavi et al. found using a crowd prediction model that the density and compactness of blocks can affect population distribution [57]. Ratti et al. found using location-based services data that the quality of a landscape can affect the activity and behaviour of crowds [58]. Zhang et al. demonstrated that block-scale intensification affects population density distribution [48]. Wang et al. discovered that a compact spatial form is more likely to lead to a concentrated population distribution [59]. Therefore, this study selected three indicators that are closely correlated to population distribution, namely scale intensiveness, morphological compactness, and landscape quality, to conduct further research.

For the current study, we selected six indicators (locational centrality, functional diversity, accessibility, scale intensiveness, morphological compactness, and landscape quality) on two layers (external environmental conditions and internal spatial characteristics). See Table 1.

Table 1. Relevant indicators of spatial characteristics.

Characteristic Indicator	Calculation
Locational centrality	$CLI_n = \sum \frac{\sqrt{S_k G_k}}{D_{nk}{}^2}$, where K denotes the number of city-level central areas in the measured city; G_k denotes the total floor area of public facilities within the scope of city-level central areas; S_k denotes the total area of blocks in the central area k; D_{nk} denotes the straight-line distance between the spatial unit n and city-level central area k.
Functional diversity	$LDI_n = -\sum_{u=1}^{U}\left(\frac{p_u}{\sum_{u=1}^{U} p_u} \times ln(\frac{p_u}{\sum_{u=1}^{U} p_u})\right)$, where p_u denotes the block area of type u in the block n; U denotes the total number of block types within a block range.
Accessibility	$RAI_n = \frac{L}{S}$, where L denotes the total length of road axes within a spatial unit; S denotes the total block area within a spatial unit.
Scale intensiveness	$BDI_n = \frac{M}{S}$, where M denotes the total base area of all buildings within a spatial unit; S denotes the area of a spatial unit.
Morphological compactness	$PSI_n = \frac{\sqrt{\pi S}}{V}$, where S denotes the total block area within a spatial unit; V denotes the perimeter of all planar shapes within a spatial unit.
Landscape quality	$GCI_n = \frac{E_{500m}}{S_{500m}}$, E denotes the green area in the buffer zone within a distance of 500 m from a spatial unit; S denotes the area of the buffer zone within a distance of 500 m from a spatial unit.

2.4. Existing Characteristics and Shortcomings of Research

Existing studies of unbalanced population density distribution focused on the imbalance across different countries, regions, or cities and identified the main factors affecting population density distribution, which include the regional perspective economic level, social development, and ecological environment.

Few studies have investigated the impact of spatial characteristics (particularly urban structure) within a city on population density distribution. However, urban structure is also a macro-level influencing factor and cannot fully represent the specific spatial characteristics within a city. From a block perspective (a higher analytical prevision), spatial characteristics within a city are also reflected by locational centrality, functional diversity, accessibility, scale intensiveness, morphological compactness, and landscape quality. These characteristics are the basic spatial carriers of people's daily behaviours, have a direct influence on those behaviours and on population density distribution, and can be directly and effectively managed and adjusted by the authorities concerned [60]. By using a city's spatial characteristics as an entry point, this study examines how they affect population density distribution. The study findings are significant for developing interventions for population density distribution in each city and employing rational use of urban resources.

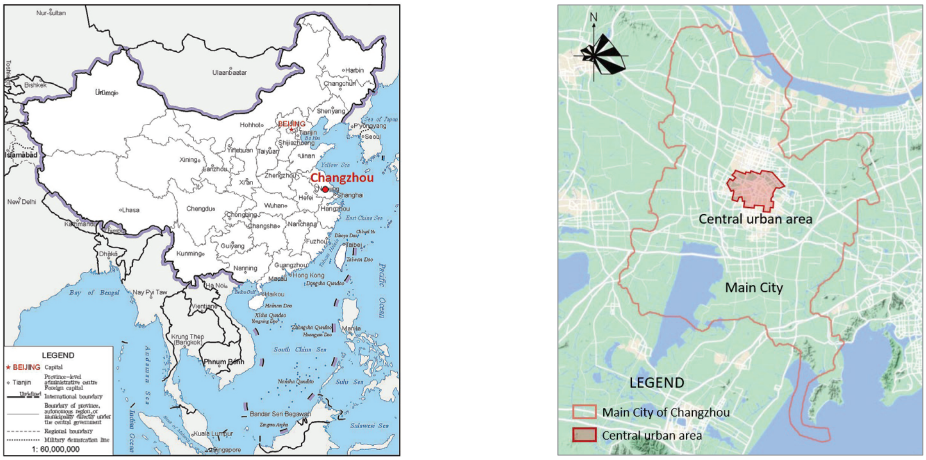
3. Materials and Methods

3.1. Study Area and Data Acquisition

3.1.1. Study Area

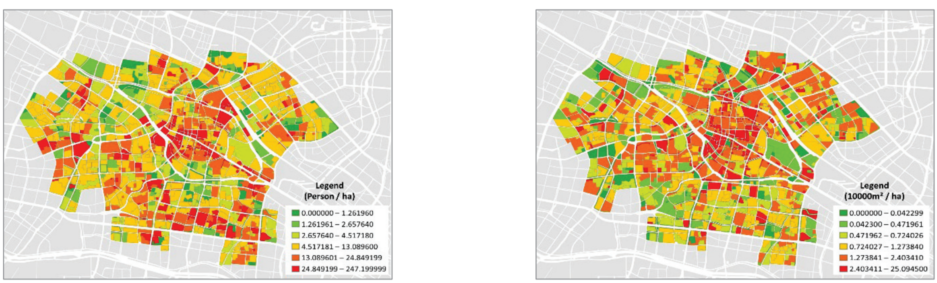
China has a high population density and some of the highest density cities and regions in the world. The central urban area of Changzhou is located in the plain area along the east coast of China (Figures 2 and 3). It has a subtropical climate and is the densest area of high-density cities in China. Similar to most high-density cities in China, Changzhou is influenced by Chinese Taoism and Confucian culture; thus, it is representative of culture, climate, and terrain. Additionally, similar to the development process in other high-density areas, the influences of location, economy, and population migration, among others, led to a gradual increase in the centralisation and density of Changzhou, causing the building coverage ratio to exceed 50% and population density to exceed 10,000 people/km^2. This is typical of high-density areas in China [61]. During this process, however, as the population concentrated in the centre and land space became increasingly sparse, a population–space imbalance appeared in the centre of Changzhou, which led to social problems such as imbalanced public service facilities and traffic congestion. This is a common scenario experienced by most high-density areas in China during the course of urbanisation [31]. It is also typical of high-density areas around the world, such as Birmingham in the United States, Seoul and Busan in South Korea, and Goa and Tamil Nadu in India. All of them are developing into high-density spaces and are suffering from population–space imbalances due to population loss, locational differences, and other factors [4,62,63]. The development processes and problems of these cities or regions have similarities with the central urban area of Changzhou, which is why Changzhou was chosen as a case study.

Calculate the population density and spatial density of each block, in which the unit of population density is 'person/hectare' and the unit of spatial density is '10,000 m^2/hectare' (see Figure 3). The kernel density superposition between population density and spatial density reveals that the degree of coupling between population density and spatial density is relatively high in the centre but declines in peripheral areas, indicating an emerging unbalanced distribution of population density (Figure 4).



(**a**) (**b**)

Figure 2. Location of Changzhou and central urban area. Note: (**a**) Location of Changzhou; (**b**) Urban central area.



(**a**) (**b**)

Figure 3. Population density and spatial density of each block. Note: (**a**) Population density; (**b**) Spatial density.

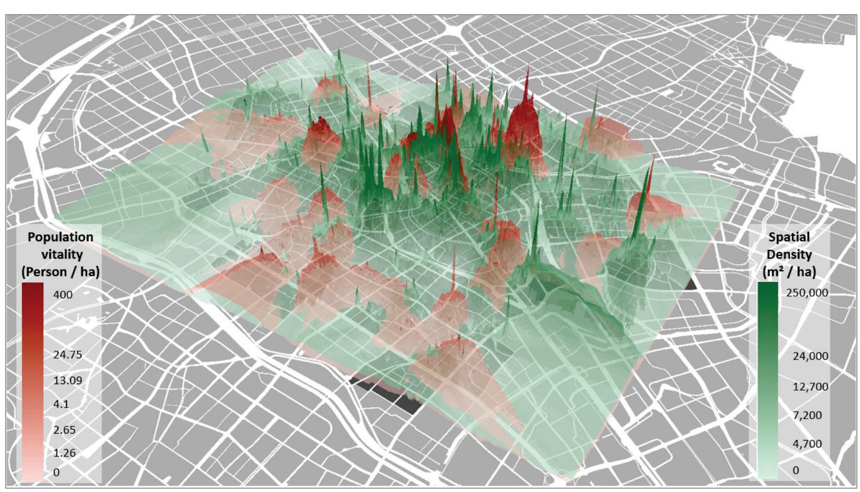


Figure 4. Comparison between population density and spatial density.

3.1.2. Data Sources and Preprocessing

The study's population density data comprise data from mobile phone subscribers of China's largest telecommunications operator across all of Changzhou, which represents an approximate 70% share of Changzhou's entire mobile phone market. The remaining 30% of the data come from other operators; however, there is no difference in age, income, culture, and location. Nevertheless, there are coordinate differences between data from different operators. If all data are included in the study, there will be a discrepancy in population positioning, which will affect the accuracy of the study. Therefore, the remaining 30% of data will not be used.

The data set contains personal signalling data (e.g., encrypted mobile terminal identity, time of signalling, code of base station connected to the mobile phone at the time of signalling, and latitude-longitude coordinates of the mobile phone), and mobile base station data (e.g., base station code and latitude-longitude coordinates). In order to prevent effects from a subscriber being within multiple base stations' service areas during the same period, the base station with the longest cumulative period of stay per hour was used as the primary serving base station during the period, and the statistical data were measured on an hourly basis (see Table 2). The data set covers 24 days in 2017, including 15 typical working days (Wednesday or Thursday), six typical weekends (Saturday or Sunday), and three typical holiday or festival days. These samples cover 12 months of the year, including different weather and temperature characteristics, and the 24 samples are relatively balanced in time intervals. Therefore, they will not be selected as samples for two consecutive days for representativeness. The data were provided by 15,800 mobile base stations and involved 3,450,000 mobile phone subscribers.

Table 2. Example of base station data sample.

Station	Longitude	Latitude	0:00	1:00	2:00	3:00	4:00	5:00
2,079,730,131	120.09251	31.51191	184	182	184	172	182	169
6:00	7:00	8:00	9:00	10:00	11:00	12:00	13:00	14:00
190	203	240	269	309	277	297	274	273
15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00
277	288	242	260	254	241	223	213	210

Note: The time in the table corresponds to the number of mobile phones connected to the current base station per day.

The study's urban space data came from vector topographic maps, which were calibrated, corrected, and updated by the investigators after a field survey. The vector topographic maps contain 10,664 blocks in Changzhou, the functional type of each block, 120,591 buildings, road axes at different levels, and the natural boundary environment (see Table 3).

Table 3. Urban spatial data content.

Database	Data Layer	Content
Data of urban space	Block layer	This layer contains block boundaries and block area.
	Functional type layer	This layer contains the functional type and code of each block.
	Building layer	This layer contains the base area of buildings, building stories, and building functions.
	Road traffic layer	This layer contains road axes and stops or stations of urban public traffic.
	National boundary environment	This layer contains rivers, river systems and mountains.

3.2. Methodology

We first determined appropriate calculation methods according to the conceptual characteristics of population density and spatial density; conducted correlation analysis to identify the functional types of blocks with a strong correlation between population density and spatial density; created an equation to calculate the population–space correlation; identified specific blocks with unbalanced population density among the blocks of the above functional types; analysed the degree of coupling between such blocks and spatial density, spatial indicators, and spatial distribution; and finally, discussed the spatial mechanism of population density distribution (see Figure 5). Through high-precision population positioning data and building data to accurately calculate the population density and spatial density of each block, Shi has proven the effectiveness of this method, especially the accuracy of population density calculation results, which has been greater than 80% [16]. At the same time, Edwards and Xu also adopted similar methods to screen the research objects through the correlation coefficient and constructed the algorithm model to study the population distribution [64,65].

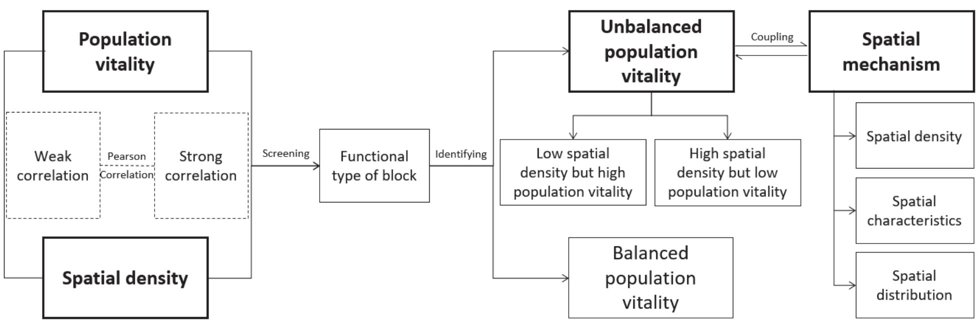


Figure 5. Framework diagram.

3.2.1. Population Density and Spatial Density Indicators

For mobile signalling data, the number of mobile subscribers was calculated on a base station basis. The radiation scope of a base station is universally larger than the area of a block. Therefore, the conventional method for cleaning mobile signalling data by gridding and spatial interpolation [58,66,67] will cause a certain imbalance in the study results. We used the space transformation method for meso- and micro-scale mobile signalling data to calculate the population density according to the area of activity space [18], thus improving the calculation accuracy of population density in each block. The equation for population density is:

$$\rho_{c_i} = \frac{1}{A'_{c_i}} \cdot \frac{A_{(c_i \cap v_j)} D_{v_j}}{A_{v_j}} \quad (1)$$

where, c_i denotes the block numbered i; v_j denotes the mobile signalling cell numbered j (A signalling cell is a faceted service area around the centre of a base station in a mobile communications network.); ρ_{c_i} denotes the population density of the activity space of c_i (unit: persons/ha); A'_{c_i} denotes the area of c_i; D_{v_j} denotes the average number of mobile subscribers within v_j (As the number of mobile subscribers within a signalling cell is constantly changing during one day, we measured the number of mobile subscribers per hour within each block, calculating the average number of mobile subscribers within each block during each of the 24 hours in a day.) (equal to population in this study); A_{v_j} denotes the area of the activity space of v_j; $A_{(c_i \cap v_j)}$ denotes the area of activity space within the overlapping area between c_i and v_j.

In this study, spatial density refers to the total floor area of buildings per unit area within a block and reflects the intensity of spatial development. The equation for spatial density is:

$$\rho'_{c_i} = \frac{1}{A'_{c_i}} \cdot \sum S_{b_k} F_{b_k} \tag{2}$$

where, c_i denotes the block numbered i; b_k denotes the building numbered k within c_i; ρ'_{c_i} denotes the spatial density of c_i (unit: 10,000 m^2/ha); A'_{c_i} denotes the area of c_i; S_{b_k} denotes the projected area of b_k; F_{b_k} denotes the number of storeys of b_k.

3.2.2. Classification Based on the Correlation between Population Density and Spatial Density

We used Pearson correlation coefficients to identify the types of blocks with a strong correlation between population density and spatial density; we used these types of blocks in the analyses and excluded the types of blocks with a weak correlation between them (e.g., industrial blocks and medical and health blocks). The population density difference between these types of blocks depends on the scale and grade of public facilities and types of services, and they are influenced by urban surroundings. Hence, these types of blocks were excluded. The Pearson correlation coefficient is calculated as follows:

$$r_{xy} = \frac{\sum_{i=1}^{n}(x_i - \overline{x})(y_i - \overline{y})}{\sqrt{\sum_{i=1}^{n}(x_i - \overline{x})^2 (y_i - \overline{y})^2}} \tag{3}$$

where, $\overline{x} = \frac{1}{n}\sum_{i=1}^{n} x_i$ and $\overline{y} = \frac{1}{n}\sum_{i=1}^{n} y_i$. The value range of the coefficient r_{xy} is from −1 to 1. If variables are positively correlated, the sign of the correlation coefficient is positive; if variables are negatively correlated, the sign of the correlation coefficient is negative.

As described in Table 4, the degree of correlation between population density and spatial density varies significantly across different types of land use. Educational research, commercial, business, general residential, and residential shanty blocks collectively account for more than 75% of total blocks and present a strong correlation between population density and spatial density. Other types of blocks are of no referential significance because they had low correlation coefficients or small quantities, so showing a significant correlation between population density and spatial density across them was not possible.

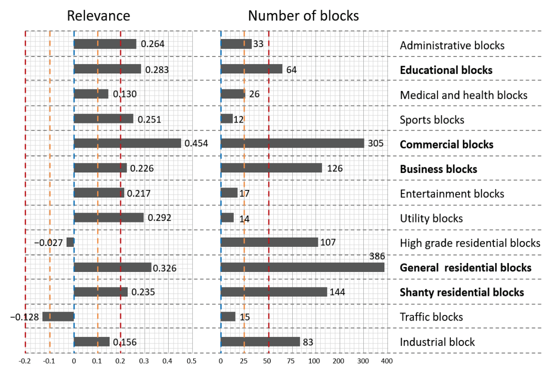
3.2.3. Identifying the Blocks with Unbalanced Population Density

After identifying different types of blocks, we further identified the types of blocks with unbalanced population density. We construct a population–space correlation algorithm to quantify the dispersion degree of population density within a certain spatial density range (spatial density ranges were separated at an interval of 0.2). Through the fluctuation curve of the population–space correlation, we determined the critical value of spatial density. Blocks with a spatial density above their critical value had unbalanced population density. The degree of population–space correlation was calculated as follows:

$$\mathrm{D} = \frac{1}{\overline{\rho_c}} \sqrt{\frac{1}{N} \sum_{1}^{N} (\rho_{c_i} - \overline{\rho_c})^2} \tag{4}$$

where D is the correlation between population density and spatial density with a certain spatial density range; c_i denotes the block numbered i within the spatial density range; N denotes the number of blocks within the spatial density range; $\overline{\rho_c}$ denotes the average population density of all blocks within the spatial density range; ρ_{c_i} denotes the population density of c_i.

Table 4. Analysis of correlation between population density and spatial density.

Functional Type of Block	Coefficient of Correlation between Population Density and Spatial Density	Block Quantity	Bar Chart of Data
Administrative block	0.264 *	33	
Educational block	**0.283 ***	**64**	
Medical and health block	0.130	26	
Sports block	0.251	12	
Commercial block	**0.454 ****	**305**	
Business block	**0.226 ***	**126**	
Entertainment block	0.217 *	17	
Utility block	0.292 **	14	
High-grade residential block	−0.027	107	
General residential block	**0.326 ****	**386**	
Shanty residential block	**0.235 ****	**144**	
Traffic block	−0.128 **	15	
Industrial block	0.156	83	

Note: ** denotes the significant correlation at 1% level (two-tailed test), and * denotes the significant correlation at 5% level.

4. Empirical Results

4.1. Correlation between Spatial Density and Population Density

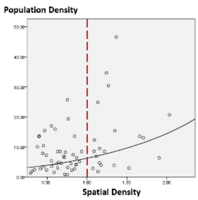
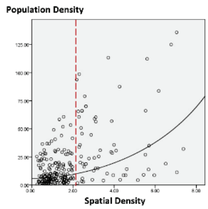
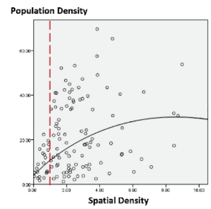
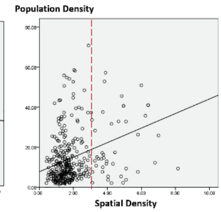
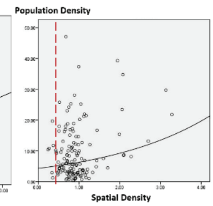
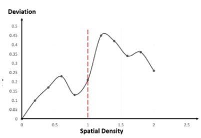
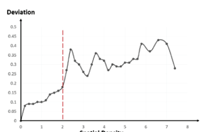
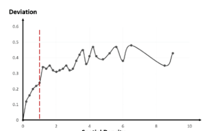
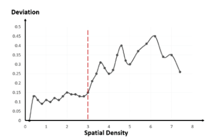
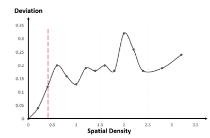
The data clustering results showed a linear or exponential correlation between population density and spatial density among different types of blocks; the calculation results of the population–space correlation show that the unbalanced distribution of population density was more significant with increased spatial density (see Table 5). Moreover, when spatial density was greater than a certain critical value (the red line in Table 5), the unbalanced distribution of population density significantly increased.

This phenomenon was evident in commercial and general residential blocks. When the spatial density of commercial blocks was lower than 22,000 m^2/ha or the spatial density of general residential blocks was lower than 30,000 m^2/ha, population density overall was exponentially correlated with spatial density without any significant unbalanced population density distribution. When spatial density was above a critical value, unbalanced population density distribution significantly increased. Moreover, the critical value of spatial density varied across different types of blocks.

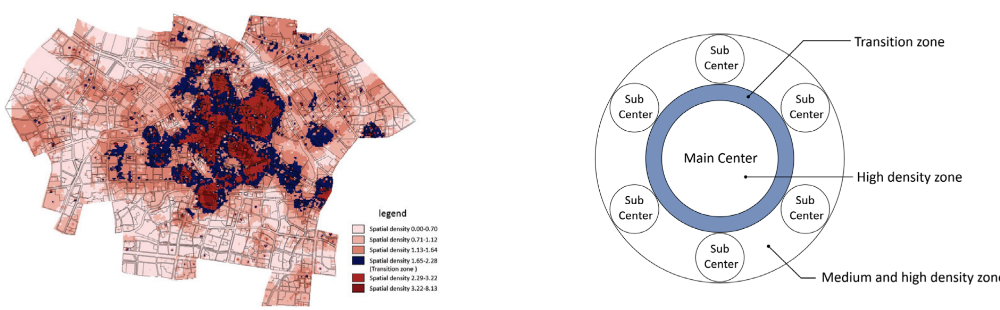
4.2. Distribution Principles of City Blocks with Uneven Population Density

We calculated the spatial density of high-density areas by kriging interpolation, converted the block surface elements into point elements, estimated the unknown points on the plane by the weighted average of known samples, and described the spatial distribution characteristics and discrete characteristics of block density. We found that spatial density was highest in the centre and decreased towards the peripheral zones to the medium- and high-density (see Figure 6a). Between the centre and peripheral zones, there was a transition zone of spatial density, which was located along the boundary between the urban primary and secondary centres, and presents a long and continuous morphology (see Figure 6b).

Table 5. Population density distribution, spatial density, and degree of population–space correlation in different types of blocks.

	Educational Block	Commercial Block	Business Block	General Residential Block	Shanty Residential Block
Distribution of population density and spatial density					
Degree of population–space correlation	 When spatial density is higher than 10,000 m^2/ha, unbalanced distribution of population density is obvious.	 When spatial density is higher than 22,000 m^2/ha, unbalanced distribution of population density is very obvious.	 When spatial density is higher than 10,000 m^2/ha, unbalanced distribution of population density is obvious.	 When spatial density is higher than 30,000 m^2/ha, unbalanced distribution of population density is obvious.	 When spatial density is higher than 4000 m^2/ha, unbalanced distribution of population density is obvious.

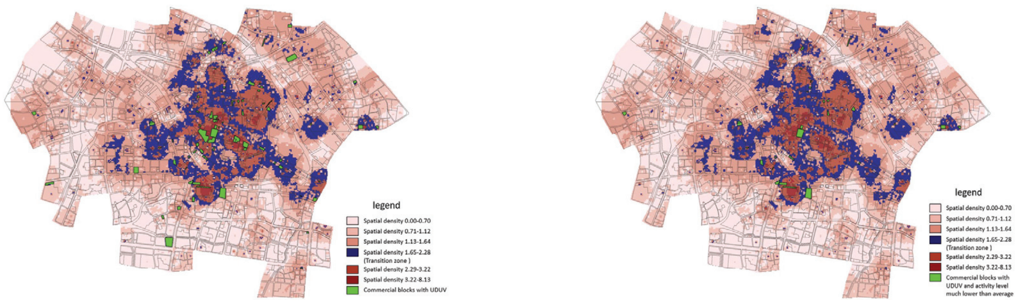
Note: – – – denotes the critical value of unbalanced distribution of population density.



(**a**) (**b**)

Figure 6. Spatial density in high-density zones. Note: (**a**) Krigin interpolation calculation for spatial density distribution and transition zone ditribution; (**b**) Types of zones by spatial density.

For example, commercial blocks with unbalanced population density were superimposed on spatial density, and the blocks were relatively scattered, showing no obvious regularity (see Figure 7a). Then, commercial blocks with significantly below-average population density were identified and superimposed on spatial density. More than 70% of such blocks were distributed within the transition zone (see Figures 7b and 8), whereas only 25% and 3.57% of such blocks, respectively, were distributed in the high-density zone and medium- and high-density zone. Likewise, several other types of blocks were verified, and the above phenomenon was also present in business and general residential blocks with unbalanced population density. Among them, the population density in business blocks is significantly lower than the average, and 64% of the blocks are distributed in the transition zone. Generally, the vitality of residential block groups is significantly lower than the average level; 83% of the blocks are distributed in the transition zone and concentrated in the south of the city (see Figures 9 and 10). By contrast, this phenomenon was not present in educational and shanty residential blocks because they are distributed in peripheral areas.



(**a**) (**b**)

Figure 7. Spatial distribution of commercial blocks with unbalanced population density and commercial blocks with medium and low population density. Note: (**a**) Spatial distribution of commercial blocks with unbalanced population density; (**b**) Spatial distribution of commercial blocks with unbalanced medium and low population density.

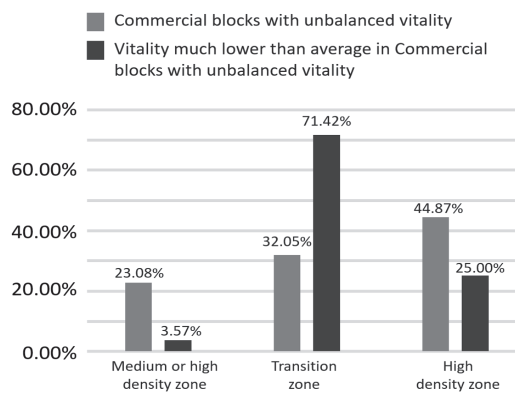


Figure 8. Quantitative distribution of commercial blocks with unbalanced medium and low population density in three types of spatial zones.

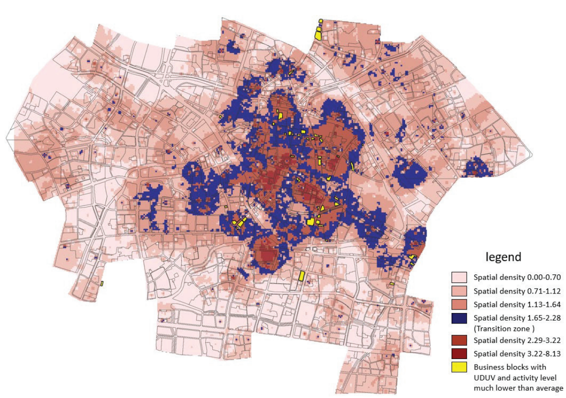


Figure 9. Spatial distribution of business blocks with unbalanced medium and low population density.

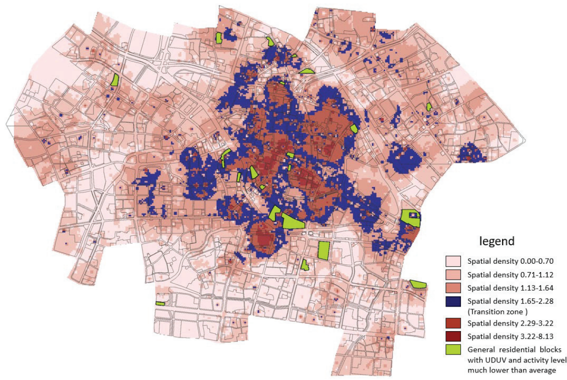


Figure 10. Spatial distribution of general residential blocks with unbalanced medium and low population density.

In summary, at the edge of urban areas with the highest intensity of urban construction (i.e., along the boundary between primary and secondary urban centres), there is zonal space with low population density, where commercial, business and general residential blocks have high spatial density but low population density, in sharp contrast with surrounding areas. This finding is consistent with the description of the distribution of population density in the urban shadow zone theory proposed by Zhang and Hu et al. [68,69].

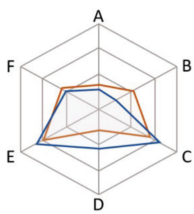
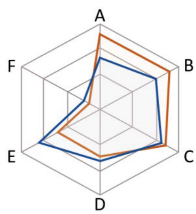
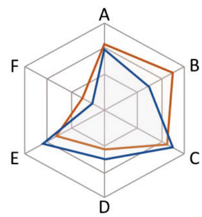
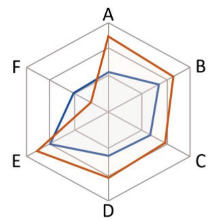
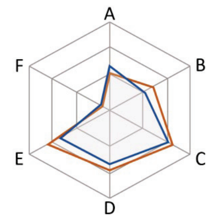
4.3. Spatial Characteristics Affecting Population Density Distribution

We identified blocks with an unbalanced population density, selected from the blocks with significantly above-average and below-average population density, and calculated and compared their spatial characteristics (including locational centrality, functional diversity, accessibility, scale intensiveness, morphological compactness, and landscape). See Table 6.

We found that functional diversity and locational centrality are the main spatial characteristics accounting for unbalanced population density distribution in high-density urban areas. The effect of functional diversity was particularly significant; the more diverse the functional types within a block, the higher the population density within that block. This indicates that high functional diversity attracts more population but also reflects the unbalanced distribution of functions in high-density areas and types of businesses in blocks. Moreover, the main spatial characteristics varied with the type of block. Locational centrality was the dominant characteristic for commercial and residential blocks; functional diversity was the dominant characteristic for educational and business blocks. This reflects the difference in the sphere of influence and locational needs between different types of blocks.

In addition, in our traditional concept, residential blocks with location conditions such as waterfront and green space will be more inclined to such living space because of a better environment and landscape quality; thus, the population density of these blocks will be higher. In high-density urban areas, however, landscape quality advantages do not necessarily attract more population, and in residential blocks, the population density was negatively correlated with landscape quality.

Table 6. Spatial distribution and characteristics of blocks with unbalanced population density.

	Educational Blocks with Unbalanced Population Density	Commercial Blocks with Unbalanced Population Density	Business Blocks with Unbalanced Population Density	General Residential Blocks with Unbalanced Population Density	Shanty Residential Blocks with Unbalanced Population Density
Distribution of blocks					
Spatial characteristics of blocks					

Note: ☐ denotes the spatial characteristics of the top 20 blocks in terms of the ratio of population density to spatial density; ☐ denotes the spatial characteristics of the bottom 20 blocks in terms of the ratio of population density to spatial density; A denotes the locational centrality of a block, B denotes the functional diversity of a block, C denotes the accessibility of a block, D denotes the scale intensiveness of a block, E denotes the morphological compactness of a block, and F denotes the landscape quality of a block.

5. Discussion

This study summarises the characteristics of unbalanced population density distribution and identifies how a city's spatial features affect population density distribution (see Figure 11). We identified the types of blocks highly correlated with population density and spatial density and analysed the population behaviours in these types of blocks. The demand and selection preference for spatial characteristics vary among different population behaviours. When the spatial characteristics of a block meet certain conditions, population behaviours are differentiated, resulting in a deviation in population density in some blocks.

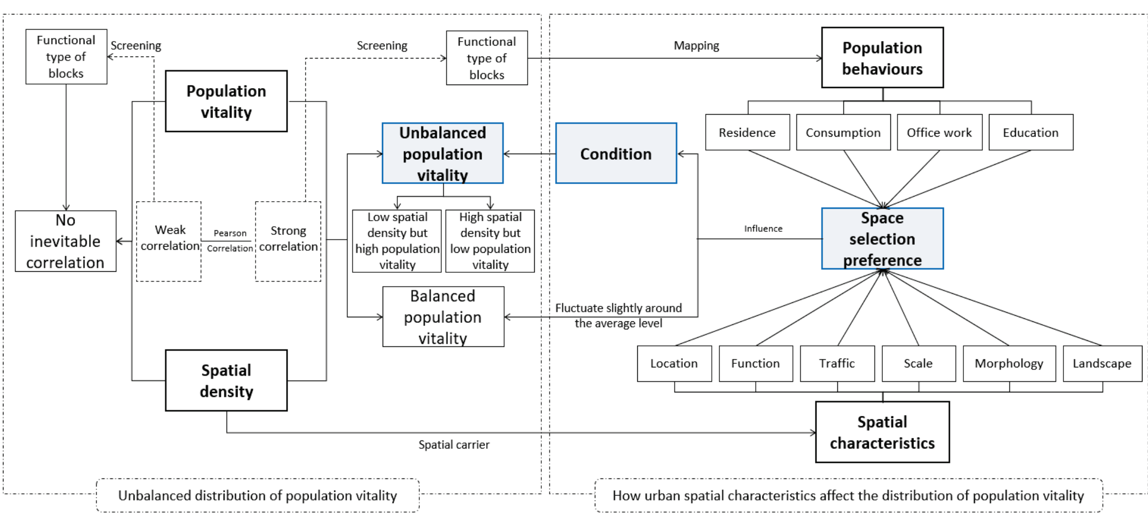


Figure 11. How spatial characteristics affect population density distribution.

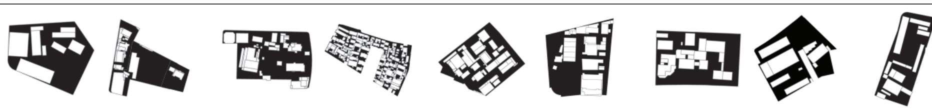
Hence, it is necessary to focus on the following three questions: (1) unbalanced population density is conditional; why is population density distribution unbalanced when the spatial density exceeds a critical value? (2) Why are urban areas with low population density distributed zonally? The solutions to the three questions will offer policy suggestions. (3) The influence of different spatial characteristics on population density is differentiated; what do people prefer in space selection?

5.1. Influence of Spatial Density on Population Density Distribution

As mentioned in Section 4.1, unbalanced population density is particularly significant among commercial and residential blocks when their spatial density exceeds a critical value. As demonstrated by the two types of blocks, this study analysed how spatial density affects population density distribution.

Of 305 commercial blocks, we selected typical commercial blocks for analysis (see Table 7). The critical value of spatial density (22,000 m^2/ha) provides a demarcation line for building size and morphology. When spatial density is higher than the critical value, commercial complexes are dominant within these blocks, and building morphology is quite regular. When spatial density is lower than the critical value, small-sized pedestrian streets or scattered commercial clusters are dominant within these blocks.

Table 7. Typical morphology of commercial block when spatial density is above or below the critical value.

Spatial density ≥ Critical value	
Spatial density < Critical value	

However, the difference in urban morphology results from differences in the types of business and the effectiveness of public facilities between different blocks [70]. Commercial blocks with a spatial density above their critical value are usually large- and medium-sized commercial complexes or wholesale markets, which have diverse types of business and high service levels, serving the whole city or whole urban districts. Because of the difference in their functions, the business diversity significantly varies between them, resulting in a significant difference in their target customers [71]. For example, Galaxy Bay Computer Town and Changzhou Shopping Centre have similar locations and similar traffic and scale conditions. However, Galaxy Bay Computer Town serves only computer users, dealing in electronic products with low turnover and high returns; the Changzhou Shopping Centre serves more diverse customers, relying on diverse types of business and brand effects to attract the population [72]. However, commercial blocks with a spatial density below their critical value usually serve the nearby blocks around them and are characterised by an agglomeration of small shops and functional diversity, resulting in a similar type and quantity of target customers; therefore, unbalanced population density is not obvious.

The same is true for residential blocks. Most residential blocks with a spatial density above 30,000 m^2/ha comprise high-rise buildings with at least 12 stories. If such residential blocks are scattered and surrounded by other types of blocks, their population density is higher. If they are clustered and constitute large residential clusters, insufficient supporting facilities (especially educational and commercial facilities) result in higher housing vacancy rates [73], thus reducing the overall population density. Most residential blocks with a spatial density below 30,000 m^2/ha comprise old residential buildings with six or fewer stories. Such residential blocks were built early enough to have escaped the influence of certain government policies implemented later (e.g., low-rise commercial buildings are restricted on the street-facing side) [74], so commercial and residential buildings are mixed. Therefore, the population density differences between such blocks are small.

Critical spatial density values reflect the importance of blocks with varying spatial density in a city, the scope of their influence, and the diversity of their surroundings. When the spatial density of a block exceeds a certain critical value, its importance and scope of influence also increase, thus exacerbating unbalanced population density distribution. This finding corroborates Pawe's survey results on population density in the Guwahati metropolitan area of India [75].

5.2. Formation of Zonal Space with Low Population Density

This study argues that zonal space with low population density is formed for three reasons. First, such space provides a vacuum space for citizens' sense of identity. An urban primary centre within the zonal space is characterised by large size and high build-up rate and has an obviously higher primacy ratio and identifiability than other urban centres. These characteristics combine with internal landmark buildings (e.g., railway station, shopping mall, and municipal government buildings) so that the urban primary centre easily arouses citizens' strong sense of identity, making it extremely attractive to consumer activities and public facilities [76]. The sub-centres (i.e., primary centres) outside the zonal space can also arouse citizens' sense of identity because they can feel the change in population density, landscape, and functional structure in the sub-centres [77]. This also explains the reason for zonal distribution along the boundary between urban primary and secondary centres; in addition, this finding corroborates Zhao's argument that the unbalanced distribution of population density is characterised by a circular layered structure [49].

Zonal space with low population density is also affected by both a diffusion and an agglomeration effect. An urban primary centre's diffusion effect allows the peripheral areas to absorb the population density spillover from the urban primary centre; the agglomeration effect on peripheral areas allows population density to gather at growth points of the peripheral areas [76]. In high-density urban areas, each block is subject to the superimposed result of the positive and negative diffusion and agglomeration effects, resulting in a spillover effect [69]. Peripheral sub-centres are subject to a positive diffusion combined with a positive agglomeration effect. Zonal space is subject to a negative agglomeration effect combined with a negative diffusion effect, resulting in a negative spatial spillover effect [68,78] and a consequent insufficient population density.

Moreover, the formation of zonal space with low population density is also related to a service mode of public facilities, and each large public facility must be backed by logistical space that provides distribution services. These logistical services are agglomerated in zonal space, resulting in insufficient population density. This corroborates Hu's hypothesis regarding the influence of urban service facilities' spatial distribution on population density [69].

5.3. Population–Space Selection Preference in Different Types of Blocks

The influence of spatial characteristics on population density is similar between educational blocks and business blocks (see Table 6), indicating that people share a similar value orientation in choosing educational space and business space. There are two reasons for this: (1) the functions of educational and business blocks are relatively complete and independent and are similar in their sphere of influence [79]; (2) work and schooling are rigid demands, so these two types of blocks are usually people's daily destinations on work days; in addition, they have similar functional orientations [80]. In China's central urban areas' development process, educational and business blocks are prone to develop into small-scale community-level living centres if spatial clusters with diverse types of business are formed around them [81], which makes them more attractive to the population. This explains why people prefer to select educational and business blocks with high functional diversity. Moreover, the morphological scale has a certain influence on people's space selection preference; the larger the agglomeration scale, the weaker the ability to attract population and promote the development of surrounding functional facilities. This corroborates Zhang's argument that educational blocks' morphological agglomeration scale affects population density distribution, with this study finding that they are negatively correlated [48].

People first consider locational centrality when they choose commercial and residential blocks. This corroborates Xia's argument that unbalanced population density distribution is related to the type, location, and functional diversity of blocks. In addition, this study further confirms that location has a more significant influence than functionality [5]. However, Xia's study did not discuss the influence of landscape quality on people's selection preferences. This study found that, contrary to the traditional concept, the landscape quality advantages in high-density areas are not sufficient to attract more population. This does not imply that people no longer prefer areas with high landscape quality when choosing residential and commercial space, but it reveals that landscape quality is no longer people's primary concern for choosing space. People prefer to choose centrally located urban spaces with more diverse functions rather than urban spaces with more green land and higher landscape quality [82]. There are a few large parks and green zones with good landscape resources in the central area of Changzhou, but their accessibility is low owing to the poor layout of the road network. Instead, many accessible green zones are fragmented (e.g., street-side green land, green waterfront land, and residential green land) with an average size of less than one hectare and outdated facilities. This reflects a universal problem in high-density urban areas. When a high-density urban construction model is adopted, urban managers usually provide importance in constructing a large green space to promote ecological harmony [83]. Under the constraint of diverse factors (e.g., road width and cost of street-side renovation), fragmented green space is not sufficiently improved, thus reducing the attractiveness to people over time [84].

5.4. Policy Influence

This study's findings provide a reference for urban development and regulating population density, along with high-quality development and renewal in high-density urban areas. The findings reveal how urban spatial characteristics affect population density distribution and have important implications for addressing the problems faced by rapidly developing cities. Although Chinese authorities have realised that the unbalanced distribution of population density results from multiple effects of diverse factors [15,43], economic measures (e.g., investment promotion, control of housing prices, and creating jobs) are still the most important methods for regulating population density distribution through urban planning and management [5,85]. High-density commercial complexes and office buildings, large scale comprehensive service facilities, and residential building clusters have sprung up around high-density areas. New urban or community centres have been built to encourage the population to work and live nearby rather than concentrating in urban centres. However, this decentralised and spatially-homogenised development model cannot prevent the unbalanced distribution of population density; unplanned and decentralised urban development under real urban conditions may cause social and environmental problems. The complex status of high-density urban areas suggests an urgent need to balance the attractiveness of different urban spaces to attract people from multiple perspectives (e.g., economic, social, environmental, and spatial perspectives) while rationally controlling the scale of urban development and the pattern of urban centres. This study's findings provide a reference for spatial renewal in high-density areas and a basis for intervening in and regulating population density aspects (e.g., spatial density, function, road, morphology, and landscape) from the perspective of urban space.

5.5. Limitations

Population density is a real-time and dynamic process, which significantly varies in certain types of blocks across different periods. This study measured the average population density in a block over 24 h, so the results may contain certain errors, and some findings may be attributable to characteristics reflected by specific data. Moreover, the population data used in this study were cited from the signalling data provided by China's largest mobile telecommunications operator, but such population data cannot reflect the density of all populations in the study region (e.g., people who do not use mobile phones, such as children and the elderly). In addition, some people have multiple mobile phones, which could affect the population density measures. Signalling positioning data are acquired from base stations, and it is not possible to accurately identify each mobile subscriber. Although we used the Thiessen polygon and interpolation methods to improve positioning accuracy [18], a certain degree of positioning error remains. In subsequent studies, we will employ a combination of mobile signalling data and high-accuracy positioning data of mobile APPs to calibrate the positioning data and improve positioning accuracy, further testing this study's results.

6. Conclusions

In order to address the universal unbalanced distribution of population density in high-density urban areas, this study analysed mobile signalling data and spatial vector data to examine how a city's spatial characteristics affect population density distribution. The key finding is that population density distribution is unbalanced only when spatial density exceeds a critical value, which reflects the importance of blocks with varying spatial density in a city, the scope of their influence, and the diversity of their surroundings. Further, a vacuum space for citizens' sense of identity and public facilities and services is formed by the diffusion and agglomeration effects of urban centres at different levels. Consequently, a zonal space with low population density is formed along the boundary between primary and secondary urban centres. From a spatial perspective, the unbalanced distribution of population density is essentially a result of people's space selection preferences. Functional diversity and locational centrality are the main spatial factors that account for the difference in population density in high-density urban areas. In addition, the attractiveness of the green landscape is diminishing for various reasons (e.g., insufficient road width and high cost of street-side renovation). The findings provide a novel perspective on quantifying the link between urban form and population distribution in high-density areas and a reference for intervening in and adjusting for population density distribution in different aspects (e.g., spatial density, function, and morphology) from the perspective of urban space, thus promoting rational use of urban public resources and urban sustainability.

Author Contributions: Conceptualisation, D.S. and W.X.; methodology, D.S.; software, W.X.; data curation, D.S.; validation, W.X.; formal analysis, D.S. and W.X.; investigation, D.S. and W.X.; writing-original draft preparation, D.S.; writing-review and editing, W.X.; visualisation, D.S.; supervision, W.X.; project administration, W.X.; funding acquisition, W.X. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by The General Project of Philosophy and Social Science Research in Colleges and Universities in Jiangsu Province (Grant No. 2021SJA0143).

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: The data presented in this study are available from China Mobile.

Acknowledgments: The authors are grateful to the three reviewers for their helpful comments.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Yue, W.Z.; Chen, Y.; Thy, P.T.M.; Fan, P.L.; Liu, Y.; Zhang, W. Identifying urban vitality in metropolitan areas of developing countries from a comparative perspective: Ho Chi Minh City versus Shanghai. *Sustain. Cities Soc.* **2021**, *65*, 102609. [CrossRef]
2. Small, K.A.; Song, S. Population and employment densities: Structure and change. *J. Urban Econ.* **1994**, *36*, 292–313. [CrossRef] [PubMed]
3. Lessmann, C. Spatial inequality and development-Is there an inverted-U relationship? *J. Dev. Econ.* **2014**, *106*, 35–51. [CrossRef]
4. Lee, H.; Kim, U.Y.; Lee, J. The impact of density of land use and spatial structure on urban vitality: Focused on comparing two new town; Bundang and Ilsan in metropolitan area of Korea. *SH Urban Res. Insight* **2014**, *4*, 47–56. [CrossRef]
5. Xia, C.; Yeh, A.G.O.; Zhang, A. Analysing spatial relationships between urban land use intensity and urban vitality at street block level: A case study of five Chinese megacities. *Landsc. Urban Plan* **2020**, *193*, 103669. [CrossRef]
6. Shi, Y.; Yang, J.Y. The Study of Spatiotemporal Behaviour density algorithm based on mobile phone signalling data. *Chin. Landsc. Archit.* **2019**, *5*, 102–106.
7. Lan, F.; Gong, X.Y.; Da, H.L.; Wen, H.Z. How do population inflow and social infrastructure affect urban vitality? Evidence from 35 large- and medium-sized cities in China. *Cities* **2020**, *100*, 102454. [CrossRef]
8. Clark, C. Urban population densities. *J. R. Stat. Soc.* **1951**, *114*, 490–496. [CrossRef]
9. Wang, L.M. Research on configuration theory and method of man earth relationship system for PRED problem. *Geogr. Res.* **2002**, *2*, 38–44.
10. Brennan, E.M.; Richardson, H.W. Asian megacity characteristics, problems, and policies. *Int. Reg. Sci. Rev.* **1989**, *12*, 117–129. [CrossRef]
11. Jae-won, J.; Na, J.S. Comprehensive renewal plan of low-rise residential area using appropriate blocks for the implementation of urban block renewal project–Focusing on the case of Incheon Metropolitan City. *J. Urban Des. Insitute Korea* **2022**, *23*, 53–68.
12. Luthi, A. Ecological limits to population growth. *Schweiz. Z. Fur Volkswirtsch. Und Stat.* **1989**, *125*, 461–472.
13. Hu, W.X. Study on spatial agglomeration and diffusion in coastal urban dense areas. *City Plann. Rev.* **1998**, *6*, 22–29.
14. Shi, Y.; Yang, J.Y.; Shen, P.Y. Revealing the correlation between population density and the spatial distribution of urban public service facilities with mobile phone data. *ISPRS Int. J. Geo-Inf.* **2020**, *9*, 38. [CrossRef]
15. Liu, Y.S.; Zhao, P.J.; Liang, J.S. Study on urban vitality based on LBS data: A case of Beijing within 6th Ring Road. *Areal Res. Dev.* **2018**, *37*, 64–87.
16. Chang, F.; Wang, L.; Ma, Y.; Yan, C.; Liu, H. Do urban public service facilities match population demand? Assessment based on community life circle. *Prog. Geogr.* **2021**, *40*, 607–619. [CrossRef]
17. Szele, A.; Kisgyorgy, L. The vitality of traffic directions in road networks with recurrent congestion and its effect on road traffic design. In Proceedings of the Third International Conference on Traffic and Transport Engineering (CTTE), Tangier, Morocco, 27–28 May 2016; pp. 1012–1018.
18. Gao, Y.P.; Xu, X.F.; Wei, Y. Analysis on the imbalance of population flow network during the Spring Festival travel rush in China in 2015. *PLoS ONE* **2021**, *16*, e0249520. [CrossRef]
19. Zhang, F. Man-land relationship: Crisis, feature and thought on harmonisation. *China Popul. Res. Environ* **1993**, *1*, 9–14.
20. Vinuela, A.; Posada, D.G.; Morollon, F.R. Determinants of immigrants' concentration at local level in Spain: Why size and position still matter. *Popul. Space Place* **2019**, *25*, e2247. [CrossRef]
21. Nie, X.J.; Zhang, Y.C.; Zhou, W.; Su, H.; Yang, T.T.; Li, X.H.; Lan, S.R. Research status and trend of urban space vitality comparative analysis of Chinese and English literature. *J. Southwest Univ. Nat. Sci. Ed.* **2021**, *43*, 147–155.
22. Ariste, R. Availability of health workforce in urban and rural areas in relation to Canadian seniors. *Int. J. Health Plann. Manag.* **2019**, *34*, 510–520. [CrossRef] [PubMed]
23. Masuda, J.R.; Zupancic, T.; Poland, B.; Cole, D.C. Environmental health and vulnerable populations in Canada: Mapping an integrated equity-focused research agenda. *Can. Geogr.-Geogr. Can.* **2008**, *52*, 427–450. [CrossRef]
24. Bauer, T.; Epstein, G.; Gang, I.N. Herd effects or migration networks? The location choice of Mexican immigrants in the US. *IZA Discuss. Pap.* **2002**, *551*, 1–44.
25. Bonaparte, H.M. Toward a population policy. *Cuad. De Econ. Soc.* **1982**, *4*, 77–95.
26. Reboratti, C.A. Some considerations on population policy in Argentina. *Cuad. Econ. Soc.* **1982**, *4*, 45–55.
27. Alogoskoufis, G.; Manning, A. Wage setting and unemployment persistence in Europe, Japan and the USA. *Eur. Econ. Rev.* **1998**, *32*, 698–706. [CrossRef]
28. Geshev, G.; Tsekova, E.; Kalchev, I.; Spiridonova, I. The impact of migration on regional demography. *Naselenie* **1992**, *5*, 29–39.
29. Alcala, C.M.; Moral-Pajares, E. Unbalanced distribution of the foreign population among the Spanish provinces: Determining factors. *Rev. Estud. Reg.* **2015**, *103*, 109–130.
30. Diwakar, A. Processes and factors of metropolitanisation in India. *Popul. Geogr.* **1993**, *15*, 41–60.
31. Duan, P.Z. Influence of China's population flow in the change of regional disparity since 1978. *China Popul. Res. Environ.* **2008**, *18*, 27–33.
32. Liu, Y.W.; Yan, Q.W.; Huang, S.; Jiang, C.L.; Jiang, L. Analysis on spatio-temporal dynamics of population distribution in Jiangsu. *Sci. Survey. Mapp.* **2015**, *40*, 30–35. [CrossRef]
33. Liu, S.J.; Zhang, L.; Long, Y. Urban vitality area identification and pattern analysis from the perspective of time and space fusion. *Sustainability* **2019**, *11*, 4032. [CrossRef]

34. Evans, A.W. The assumption of equilibrium in the analysis of migration and interregional differences—A review of some recent research. *J. Reg. Sci.* **1993**, *30*, 515–531. [CrossRef] [PubMed]
35. Harrigan, F.J.; McGregor, P.G. Equilibrium and disequilibrium perspectives on regional labour migration. *J. Reg. Sci.* **1993**, *33*, 49–67. [CrossRef]
36. Casado, M.; Molina, L.; Oyarzun, J. El analisis economico de los movimientos migratorios internacionales: Determinantes empiricos y nuevas propuestas de regulacion, Facultad de Ciencias Economicas y Empresariales de la UCM. *Work. Pap.* **2003**, *7*, 180–210.
37. Mar, C. Los determinantes de los flujos migratorios internacionales: El caso espanol, 1995–2007. *Princ. Estud. Econ. Politica* **2009**, *14*, 49–68.
38. Liu, J.S.; Chen, Y.G. GIS-based cellular automata models and researches on spatial complexity of man-land relationship. *Geogr. Res.* **2002**, *21*, 155–162.
39. Li, X.J.; Wen, Y.Z.; Li, Y.Z.; Yang, H.M. High-quality development of the Yellow River Basin from a perspective of economic geography: Man-land and spatial coordination. *Econ. Geogr.* **2020**, *40*, 190–199.
40. Minagawa, K.; Sumiyoshi, K. Studies on the optimal location of commerce-basic laws considering the distribution of population. *Int. J. Prod. Econ.* **1999**, *60–61*, 295–300. [CrossRef]
41. Dorozhovets, M. Forward and inverse problems of Type A uncertainty evaluation. *Measurement* **2020**, *165*, 108072. [CrossRef]
42. Yucong, H.; Haiwei, C.; Jian, O.; Lianhua, P.; Fengming, L. Land-Use Spatial Distribution Simulation and Traffic Demand Forecasting in New Town. *J. South China Univ. Technol. Nat. Sci. Ed.* **2014**, *42*, 27–34.
43. Wu, Q.B.; Chen, Q.H. Population spatial change and urban spatial restructuring in Hangzhou from 2000 to 2010. *City Plann. Rev.* **2015**, *39*, 30–38.
44. Meijers, E.J.; Burger, M. Spatial structure and productivity in US metropolitan areas. *Environ. Plan A* **2010**, *42*, 1383–1402. [CrossRef]
45. Li, K.T. Population distribution and quality of life in the Taiwan area. *Zi You Zhongguo Zhi Gong Ye* **1983**, *60*, 17–31.
46. Zhu, J.; He, B.J. Rebalance strategies for metropolitan area in the context of urban growth: Implications from Greater Sydney strategic planning 2056. *Shanghai Urban Plan. Rev.* **2017**, *5*, 83–89.
47. Chi, G.Q.; Ventura, S.J. An integrated framework of population change: Influential factors, spatial dynamics, and temporal variation. *Growth Change* **2011**, *42*, 549–570. [CrossRef]
48. Zhang, Z.C.; Luan, W.X.; Tian, C.; Su, M.; Li, Z.Y. Spatial distribution equilibrium and relationship between construction land expansion and basic education schools in Shanghai based on POI Data. *Land* **2021**, *10*, 1059. [CrossRef]
49. Zhao, D.; Li, J.Y.; Yan, H.W.; Yin, H.Y.; Fu, Y.D.; Li, J.X. Spatial distribution characteristics of urban potential population in Shenyang City based on GIS and RS. *Chin. J. Appl. Ecol.* **2017**, *28*, 2697–2704.
50. Lee, S.G.; Cho, I.S.; OHSEGYU. A Study on the planning characteristics of void spaces revealed in the external appearance of collective housings -focusing on the cases of collective housings in the architects working around the Netherlands. *J. Archit. Inst. Korea* **2014**, *16*, 11–20.
51. Ma, B.; Jiang, J.; Xue, D.Q.; Li, M.; Cai, L. Spatial characteristics of historical and cultural block in the perspective of integration of subject and object:a case study of Xi'an Shuyuanmen. *J. Shaanxi Normal Univ.* **2018**, *46*, 102–109.
52. Lee, J.H. A study on typology and property of the method of spatial composition in the block of street. *J. Archit. Inst. Korea Plan Des.* **2005**, *21*, 177–186.
53. Jan, G.; Gemzoe, L. *New City Spaces*; Danish Architectural Press: Copenhagen, Denmark, 2000; ISBN 8774072552.
54. Zhang, Z.B.; Pan, J.; Da, F.W. Population spatial structure evolution pattern and regulating pathway in Lanzhou City. *Geogr. Res.* **2012**, *31*, 2055–2068.
55. Mao, Z.R.; Chen, X.K.; Xiang, Z.H.; Chen, Y.R. Research on the measurement and influencing factors of street vigour in historic districts: A case study of Wenming Street historic district in Kunming. *SPE J.* **2021**, *4*, 54–61.
56. Jiang, C.J.; Gab-Geun, Y. Research on the design methods of historical and cultural blocks and public facilities -take Harbin Central Street for example. *J. Humaniti. Soc. Sci.* **2021**, *12*, 15–28.
57. Mousavi, A.; Bunker, J.; Lee, J. Exploring socio-demographic and urban form indices in demand forecasting models to reflect spatial variations: Case study of childcare centres in Hobart, Australia. *Buildings* **2021**, *11*, 493. [CrossRef]
58. Ratti, C.; Williams, S.; Frenchman, D.; Pulselli, R.M. Mobile landscapes: Using location data from cell phones for urban analysis. *Environ. Plann. B Plann. Des.* **2006**, *33*, 727. [CrossRef]
59. Wang, H.J.; Li, X.Y.; Zhang, Z.L.; He, X.Y.; Chen, W.; Chen, Y.B.; Hu, J.B. Analysis on urban spatial expansion process in Shenyang City in 1979–2006. *J. Appl. Ecol.* **2008**, *19*, 2673–2679.
60. Liu, L.B.; Peng, Z.H.; Wu, H.; Jiao, H.Z.; Yu, Y. Exploring urban spatial feature with dasymetric mapping based on mobile phone data and LUR-2SFCAe method. *Sustainability* **2018**, *10*, 2432. [CrossRef]
61. Tian, G.J.; Jiang, J.; Yang, Z.F.; Zhang, Y.Q. The urban growth, size distribution and spatio-temporal dynamic pattern of the Yangtze River Delta megalopolitan region, China. *Ecol. Modell.* **2011**, *222*, 865–878. [CrossRef]
62. Banerjee, A.; Saha, J. Population environment interface in urban India: A geographical analysis. *Landsc. Ecol. Water Manag.* **2014**, *1*, 147–163.
63. Lafrombois, M.E.H.; Park, Y. The uneven shrinking city: Neighborhood demographic change and creative class planning in Birmingham, Alabama. *Urban Geogr.* **2021**, *10*, 4788. [CrossRef]

64. Edwardes, M. Kendall Tau is Equal to the Correlation-Coefficient for the Be Distribution. *J. South China Univ. Technol. Nat. Sci. Ed. Stat. Probab. Lett.* **1993**, *17*, 415–419.
65. Xu, W.C.; Ma, R.B.; Zhou, Y.Z.; Peng, S.G.; Hou, Y.H. Asymptotic properties of Pearson's rank-variate correlation coefficient in bivariate normal model. *Signal Process.* **2015**, *119*, 190–202. [CrossRef]
66. Pulselli, R.; Ramono, P.; Ratti, C.; Tiezzi, E. Computing urban mobile landscapes through monitoring population density based on cellphone chatting. *Int. J. Des. Nat. Ecodyn.* **2008**, *3*, 121–134.
67. Louail, T.; Lenormand, M.; Ros, O.G.C.; Picornell, M.; Herranz, R.; Frias-Martinez, E.; Ramasco, J.J.; Barthelemy, M. From mobile phone data to the spatial structure of cities. *Sci. Rep.* **2014**, *4*, 5276. [CrossRef]
68. Hu, X.Y.; Yang, J.Y. Spatial characteristics and boundary defining of shadow areas in public centre districts of megacities. *J. Southeast Univ. Nat. Sci. Ed.* **2014**, *44*, 1093–1098.
69. Zhang, J.X.; Zhuang, L.D. Study on the evolution mechanism and countermeasures of metropolitan shadow area. *J. Nanjing Univ. (Nat. Sci.)* **2000**, *6*, 687–692.
70. Frank, L.; Bradley, M.; Kavage, S.; Chapman, J.; Lawton, T.K. Urban form, travel time, and cost relationships with tour complexity and mode choice. *Transportation* **2008**, *35*, 37–54. [CrossRef]
71. Ye, Y.; Li, D.; Liu, X.J. How block density and typology affect urban vitality: An exploratory analysis in Shenzhen, China. *Urban Geogr.* **2018**, *39*, 631–652. [CrossRef]
72. Yi, Y.M.; Gim, T.H.T. What makes an old market sustainable? An empirical analysis on the economic and leisure performances of traditional retail markets in Seoul. *Sustainability* **2018**, *10*, 1779. [CrossRef]
73. Gabriel, S.A.; Nothaft, F.E. Rental housing markets, the incidence and duration of vacancy, and the natural vacancy rate. *J. Urban Econ.* **2001**, *49*, 121–149. [CrossRef]
74. Law of the People's Republic of China on the Prevention and Control of Atmospheric Pollution. Available online: https://heinonline.org/HOL/LandingPage?handle=hein.journals/chinelgo37&div=39&id=&page= (accessed on 1 May 2014).
75. Pawe, C.K.; Saikia, A. Decumbent development: Urban sprawl in the Guwahati Metropolitan Area, India. *Singap. J. Trop. Geogr.* **2020**, *41*, 226–247. [CrossRef]
76. Yang, J.Y.; Hu, X.Y. Study on shadow area of city centres in circle-core structure mode. *City Plann. Rev.* **2012**, *36*, 26–33.
77. Ou, G.L.; Zhou, M.; Zeng, Z.P.; He, Q.S.; Yin, C.H. Is there an equality in the spatial distribution of urban vitality: A case study of Wuhan in China. *Open Geosci.* **2021**, *13*, 469–481. [CrossRef]
78. Ghaempanah, N.; Rahnamaei, M.T. Analysis success factors of the new cities establishment (case study: Pardisan town). *Nexo Rev. Cient.* **2021**, *34*, 1231–1242. [CrossRef]
79. Kuang, W.H.; Du, G.M. Analysing urban population spatial distribution in Beijing Proper. *J. Geo-Info Sci.* **2011**, *13*, 506–512.
80. Yigitcanlar, T.; Sarimin, M. Contributions of knowledge-based foundations of universities in knowledge city formation: A Malaysian case study. In Proceedings of the 2011 6th International Forum on Knowledge Asset Dynamics (IFKAD2011), Tampere, Finland, 15–17 June 2011; pp. 13–37.
81. Xue, B.; Li, J.Z.; Xiao, X.; Xie, X.; Lu, C.P.; Ren, W.X.; Jiang, L. Overview of man-land relationship research based on POI data: Theory, method and application. *Geogr. Geo-Info Sci.* **2019**, *35*, 51–60.
82. Rupasinghe, H.T.; Halwatura, R.U. Benefits of implementing vertical greening in tropical climates. *Urban For. Urban Green.* **2020**, *53*, 126708. [CrossRef]
83. Yu, S.J.; Yuan, S.Q. Study on the spatial pattern of urban public green space based on GridsA case study of the main urban area of Fuzhou. *J. Fujian Norm. Univ. Nat. Sci.* **2011**, *27*, 88–94.
84. Mu, B.; Liu, C.; Mu, T.; Xu, X.N.; Tian, G.H.; Zhang, Y.L.; Kim, G.W. Spatiotemporal fluctuations in urban park spatial vitality determined by on-site observation and behaviour mapping: A case study of three parks in Zhengzhou City, China. *Urban For. Urban Green.* **2021**, *64*, 127246. [CrossRef]
85. Noh, S.C.; Park, J.H. Cafe and restaurant under my home: Predicting urban commercialisation through machine learning. *Sustainability* **2021**, *13*, 5699. [CrossRef]

sustainability

MDPI

Article

Multiple Smart Cities: The Case of the Eco Delta City in South Korea

Dongho Han [1] and Ji Hyun Kim [2,*]

[1] Bartlett School of Planning, University College London, London WC1H 0NN, UK; dongho.han@ucl.ac.uk
[2] Department of Urban Planning & Engineering, Pusan National University, Busan 46241, Korea
* Correspondence: jikim@pusan.ac.kr

Abstract: This paper follows the urban development process of the Eco Delta City (EDC) in South Korea, a new waterfront development demonstrating the concept of a smart city. The investigation focuses on the mobilisation process under the framework of assemblage thinking: the way in which the smart city concept was applied to the project and the relational moments that delayed and stopped the process. This qualitative research with the case study and ethnographical tradition of analysis was conducted with data from diverse archival sources and interviews. By dissecting the network of EDC development, the analysis finds that the smart city mobilisation emerged from the complex actor-relations rather than from the top-down policy, and the initially brought smartness framed by the government was not accepted intactly but was contested, affiliated and compounded by the actor-relations. This study also verifies that the assemblage approach is a suitable tool in managing and evaluating policy mobilisation because it is affected by the local context and actor-relations rather than just imitation and direct application.

Keywords: smart city; policy mobility; assemblage thinking; actors; eco delta city

Citation: Han, D.; Kim, J.H. Multiple Smart Cities: The Case of the Eco Delta City in South Korea. *Sustainability* **2022**, *14*, 6243. https://doi.org/10.3390/su14106243

Academic Editors: Tianren Yang, Mengqiu Cao, Claire Papaix and Benjamin Büttner

Received: 28 March 2022
Accepted: 17 May 2022
Published: 20 May 2022

1. Introduction

The concept of the 'smart city' has followed in the footsteps of sustainability discourses and has also become a major ubiquitous leitmotif on urban development [1]. The extent of its meaning has been expanding for the last decade and the frequency of searches for 'smart city' has been increasing since 2010 [2]. Discussions are taking place across broad areas such as urban development, urban regeneration, climate change, and participation [3]. Currently, the concept seems to have become the final solution for urban problems and has become a window through which to view the cities of the future. However, there is also growing recognition that we lack a comprehensive understanding of how we are utilising and managing the smart city concept in the real-world urban space, specifically in the contexts of diverse societies. Joss et al. [1] argued that the smart city can be considered a 'global discourse network' and a collective of locally contextualised yet globally interconnected discourses. The smart city idea is important but understanding the local application of 'smartness' is critical for its utilisation in urban development and management. Recent analyses have found that policy-making processes involve complex adaptation and reproduction, rather than the simple repetition or imitation of an idea [4,5]. For example, the industrial structure [6] or the institutional fabric [7] of a society could bring the unique application pattern of policy, idea, and development models. This paper tries to reveal a lesson from a smartness mobility case in the South Korean urban development context.

The South Korean government, following the success of Songdo and several other smart city developments, is attempting to increase its urban development/managing ability with the smart city concept and 4th industrial technologies. Since the 1990s, the South Korean government has integrated 'ubiquitous city (U-City)' development with internet communication technology (ICT) and has undertaken active legislative action to uphold the U-City development. In 2017, the U-City Act was changed into a new smart city act, an 'Act on the Promotion of the Smart City Development and Industry'. Based on legal and administrative support, diverse parts of urban development and comprehensive urban planning have been established under the smart city concept. The South Korean government aspires to create a verified smart city development package and to export knowledge and technologies to other countries wishing to develop smart cities [8,9]. This paper follows the urban development process of the smart city district of the Eco Delta City (EDC) in South Korea, a new waterfront development led by the government's goal but with the various aspirations of multiple actors.

The smart city mobilisation of EDC has specificities and significant meanings for a single case research in the sense that this is a government-led top-down project with diverse aspirations of the actors involved, which results in a fuzzy and blurred concept of the smart city. An investigation into an in-depth understanding of the process of fuzziness of the worldwide and imposed smart city concept can provide a significant insight into the mobilisation process. In terms of this, this research treats the EDC case as 'a potential exemplar of some general law or principle that applies across time and space [10]' and tries to extract significant ideas and implications.

An assemblage perspective as a main analysis framework was applied in this paper to highlight these complex relations in the process between the involved actors, and to see the influences of the government-led and developmentalism context of a society on smart city mobility. The assemblage perspective is sensitive to the non-linear and changing association, which is ideally suited to revealing the characteristics of social and material relations and their productions. To rectify the lack of understanding how this globally integrated discourse is applied in a particular local system and to understand what a particular practice offers in terms of paradigm mobility, this article investigates the whole process of smart city development. The advantage of an assemblage perspective—how a certain entity is produced out of heterogeneous relations—is applied to track the transformation of a broad, unsettled idea (smart city) into a specific local context. This research focuses on the application process in the planning system and follows the different aspirations of actors that are interrelated with each other during the smart city urban development.

The analysis is based on the results of nine semi-structured interviews with key participants in the project and the archival data. Face-to-face interviews were conducted between 2018–2019, which aimed at producing the contextual understanding and the actor relations that enabled and shaped the application of the smart city concept. Three questions are addressed in this research:

- How is the smart city paradigm (smart city) empowered by the local (political/economic) actor's aspirations?
- How do different conceptualisations of smart cities affect the process of smart city mobility?
- How did South Korea's government-led developmentalism characteristics [6,11] affect the smart city adaptation process?

This investigation of EDC indicates how to utilise the globally debated smart city concept within specific types (government-led) of development systems and gauges. By dissecting the intertwined network of development processes and by examining the interrelations between the inside actors, a detailed understanding of how a broad idea is stabilised (and transformed) in a particular condition can provide implications for managing urban development processes.

2. Smart Cities of South Korea

2.1. Discourses of Smart City

The smart city concept is thought to have originated from the term 'smart growth' [12], referring to the need to make cities more compact with less ground waste, an idea which was influenced by 1980s US New Urbanism [7]. The term 'smart' was adopted by ICT infrastructure and innovation for managing cities, particularly with the 'intelligent city' debates [13]; thus, ICT industries such as Cisco [14], IBM [15], and Siemens [16] have adopted the phrase for integrating urban infrastructure and complex information services. The smart city, led by large corporation technologies, is particularly noticeable in the US. However, in most European countries, the human-centric perspective of ICT-driven urban innovation and development, and the balanced combination of human, social, cultural, environmental, economic and technological aspects, are emphasised [17].

There are various types of smart city literature across the world. Numerous scholars have focused on articulating the meaning of 'smart city' by connecting the concept with its practice [7,18–20]. Through the smart technologies surrounding urban areas, Batty et al. [21] argued that 'cities can only be smart if there are intelligence functions that are able to integrate and synthesise these data to some purpose.' By creating technology-based innovation in the planning and development stages, cities become not just attractive but intelligent. Intelligent cities enable urban data to be measured, analysed, and integrated and utilise the outcomes of such data in policy- and decision-making processes. Komninos [13] defined this aspect of intelligent and smart cities as 'a metaphor of the city', which enables us to understand the physical city through its virtual representation. For instance, to improve services, management, and governance within a city, the smart co-operative framework, which uses information technology in an individual professional field, was suggested. This ultimately sought to achieve a sustainable development approach [22].

The idea of sustainability is one of the main themes in smart city discourses. Diverse applications by using Information and Communication Technologies (ICT) and Internet of Things (IoT) in smart city case studies are explored and thoroughly investigated [23].

Regarding social sustainability, Chang et al. [11] discuss the reshaping of power dynamics in urban governance made by smart urbanism. Irvine et al. [24] suggested a future smart city case study by providing design visualizations of alternatives and emphasised the importance of integrating community familiarity. Moreover, real-time data management (based on data-driven smart applications) in the smart city will become a much more important method for public participation, focusing on human and social capital in the future [25].

Harrison et al. [26] focused on the economic sustainability of the smart city in competition with countries, cities and even neighbours, focusing on the conservation of resources and local identities. The idea of the smart city also encourages 'creative classes [27]' to support environmental sustainability. Dubuque, Iowa, in the US, is a successful example of this [28]. In terms of Asian case studies, by comparing smart city development characteristics, such developing renewable energy systems, efficient energy use, and citizen participation policy, such as in Japan and China, Su et al. [29] argue the significance of Asian countries' sustainable applications and practices.

To achieve a sustainable smart city, research into smart city management has had attention paid to it. A bottom-up approach was emphasised for the robustness of the framework in smart sustainable development. This was particularly proved by the evaluation of sustainability outcomes in Shenzhen, China and Greater Manchester, UK [30]. As a type of management approach, measuring the level of sustainability in smart cities is a theme in which scholars have been interested. A standardised framework from the public's perspective was introduced [31]. This research highlights that the infrastructure of a smart city can be regarded as a new commodity for a city, as well as a means of improving the quality of citizens' lives. However, the assessment should be tailored to be sophisticatedly dependant on the cities' particular visions and on their priorities for achieving their objectives [32].

2.2. Applications in South Korea

Smart city adoption in South Korea has followed two tendencies: a developmentalism tradition and a government-led policy-making character [33,34]. In South Korea, the term 'smart city' came to be used as a substitute catchphrase for 'ubiquitous city', which had been used for the mainframe of new urban development. It was first mentioned during the development of Centum City in 2003 under the name of U-City (Ubiquitous City). The concept of a U-City was defined as an urban space of the future where ubiquitous technology was embedded into space to build urban functions more efficiently and to improve citizens' quality of life [35].

> *"Actually, it [the idea of the smart city] began by my suggestion under the name of U-City. Due to the successful delivery of Centum City, I believed that the city of Busan should prepare for the new urbanism era. However, since it required a great amount of funds, the city government could not support the project"*
>
> *(Interview with a former officer of Centum City Development Department of Busan Metropolitan City, 2018)*

In 2017, the South Korean government established the Smart City Special Committee as a sub-institution of the Presidential Committee of the 4th Industrial Revolution (PCFIR); the term 'U-City' was substituted for 'smart city' in official government documents. A smart city is typically defined as 'a city—particularly urban infrastructures—which provides citizens with effective and efficient urban services by using IoT and ICT technology [9]'. This shows South Korea's technology-based, corporate smart city model [17], which was initiated and driven mainly by the central government.

However, the South Korean government asserts that the U-City and smart cities share characteristics, but that there are two significant differences between them [9,35]: The U-City is a government-led urban regeneration idea, while a smart city project is implemented and managed by multiple actors. The government suggests that smart cities can resolve not only the country's traditional urban problems, but can also prevent unexpected future issues (e.g., an ageing society, shrinking city, etc.) It also criticises the construction-led U-City, which has not been as productive as the national government expected.

Furthermore, in Korean smart cities, Jo et al. [36] argue that the emerging smart industries, such as smart buildings and smart vehicles, should become anchor industries, which create value chains of new industries for the sustainable development of other industries.

3. The Mobilisation of the Smart City from the Assemblage Perspective

3.1. Policy Mobility

Many circuits of knowledge and policy frameworks have been investigated to date. Although the circulation process has become a common activity in the current era, it has been interpreted using diverse approaches. For instance, lesson-drawing defines the actors, knowledge and space where the process occurs and where the mechanism of the circulation is processed. Policy convergence and policy transfers categorise a few mechanisms of the circuits of knowledge and policies. In policy transfer scholarships, policies are regarded as 'fully formed, off-the-shelf policies' [37], which are completely delivered from one context to another by understanding the transfer in abstract terms, as a 'dissocialized movement' [38]. The world, however, consists of complicated networks and relationships surrounded by vague boundaries and changeable contexts. The complex nature of the knowledge and policy circulation process cannot be reflected accurately through the lens of traditional theories. Furthermore, a complete transfer without any loss or conflict cannot exist in the real world. Since policymaking is often complex, the detailed content of the policy and the idea of the circulation processed in the conventional concept are under-emphasised [39].

This has led to a reconceptualisation of circuits of knowledge and policy, not as static (with linear causality), but as constituted through relations and interactions [40], particularly in the fields of social science and human geography [41,42]. Such relational thinking results in urban scholars considering cities as the sites of multiple flows of people, commodities, information and networks that are constantly interacting [43]. Healey [44] extended this by suggesting that post-modern society is recognised as a dynamic complexity with diverse contingencies in urban conditions. Under neoliberalism, contemporary urban areas can be (re)produced by a network of histories, socio-political structures, social relationships, movements of labour and capital, and communications with cross-scale governance, rather than a conventional place containing a set of boundaries with categorised actors.

Consequently, a relational thinking approach leads geographers to investigate urban issues concerning flows and networks, the dynamic over the static, and interactions over objects.

In contrast to the common conceptualisation of knowledge and policy circulation, which only focuses on territorially, politically, and socially bounded states, the policy mobilities approach emphasises various scales of unbounded entities (as crucial circulatory infrastructures such as states or state actors). This brings about a greater analyses of the knowledge and policy circulation process concerning the trans-national and trans-local constitution of institutional relations, governmental hierarchies and policy networks. Such inter-scalar conditioning of governance, through which knowledge and policy models move and in which they mutate, results in an assemblage of policy models—bundles of knowledge and techniques purposefully gathered together for particular reasons—and expertise drawn out of circulation and gathered in the local context. As policies circulate, they usually not only change and mutate over time and through interactions but also become coherent fixed entities through a process of assembling, disassembling, and reassembling [45].

The rise of neo-liberalism has translated into a series of reforms and initiatives aimed at minimising government intervention in the delivery of urban planning and development [46]. On the other hand, the role of private investors has increased. For instance, the Global Intelligence Corps (GIC) plays a fundamental role in the global circulation of ideas regarding urban planning and design, because of the growing demands for their services across the world [47]. There is also a lack of investigation, which focuses on external stakeholders. Stakeholders do not have equal rights and powers within the governance system of urban planning [48]. Although the external stakeholders do not impact on the urban planning project directly, the analysis of their indirect implications on the project helps to address the delivery of it and to understand its outcomes more deeply [49].

3.2. Assemblage Perspective

The assemblage perspective, along with its cousin actor-network theory (ANT), views everything around us as continual inter-relations between texts and readers. Society, culture, community, built environment, and space are enacted into multiple meanings throughout discursive and non-linear relations. In approaching the subject, there are no pre-defined terms or pre-defined knowledge; the assemblage approach simply pursues and draws what the network relations are producing. An ANT initiator, Latour [50], noted that, if we must examine the controversial knowledge or a proposition that appears to be stabilised, then we must go upstream and examine their complex internal relations. Learning how actors are 'translated' to produce or act as something, how these actor relations emerge and through which processes the relations produce regular outputs (stabilisation) bring insights on to a given subject.

One of the advantages of assemblage thinking applied in planning studies is a framework that enables us to follow the process of a certain policy, planning intention and design with their element associations. By revealing actors and the way they affect each other in a certain direction, assemblage thinking advances our understanding of how an intention has changed and evolved and sometimes illuminates the material actors that are small yet significant in the process.

In the mobilisation of policy, actors are not isolated but are group members of an assemblage. Within it, they attempt to adapt new policies and schemes into local context by '(un)consciously (re)shaping existing and/or new institutional arrangements, norms, and power relations [51]'. Prince [5] explained that assemblage thinking can be applied in two different ways through policy mobility studies: one concerns how the city stretches beyond its territorial boundaries through urban policies as an empirical object and the other is a methodological adaptation of how a policy is constructed, used, adapted, and rejected out of the various objects. Hence, the assemblage approach is good for transforming abstract social influences into material realm entities and it can distinguish between the different network bodies that are central to the discussion of the different enactments of the network.

3.3. Research Gap

Since policy mobility is a comparatively comprehensive approach, it helps to look at how things happen and emerge carefully. Moreover, with the network relations between actors and the multiple enactments of networks, assemblage thinking describes the whole subject as it emerges from its complex parts. On this background, a plethora of research has reviewed diverse types of cases by exploring various levels of governance, as well as actors and their relations within a state's broader policy process and policy priorities. For instance, the mobilisation of policies and programmes—such as urban regeneration [52–54], Eco-cities [55], Smart cities [7,17] and Business Improvement Districts [56–58]—are analysed and thoroughly discussed.

Policy mobility literature's importance lies in specific details that pinpoint what enables policy mobility, such as inter-relationships. For example, as far as a wider range of actors are considered in the policy mobility, the delivery of urban planning—under the concept of 'smart city' in this research—is understood and addressed in a much more sophisticated way. In the conventional knowledge and policy circulation literature, the idea of power is something embedded in specific people, places or institutions, such as mayors, politicians, and departmental representatives. In this circumstance, only a few specific actors who played a certain role in policy mobility were analysed. Through the lens of policy mobility, however, it is believed that power could be extended outwards through networks across a flat surface. In this way, it is far more dispersed and diffused [59]. This requires the investigation of a wide range of actors surrounding the mobilisation of ideas and knowledge.

In relation to this, the research focuses on the moment when the actor-relations bend the smart city development process. It will examine what actors are involved and how they affect one another to produce a certain type of space. Indeed, both complex partial relations and overall processes are empirically examined and described.

4. Research Method

The objective of analysis is an in-depth understanding of the case that is a government-led development project with a clearly defined smart city concept, which becomes multiple and floated during the process. The analysis process is based on the qualitative approach and with the case's unique setting, the top-down smart city framework and its dissolution, it is an intrinsic type of qualitative case study [60]. However, in terms of the means of analysing data and presenting the case, it is also in the conventional mode of the ethnographical tradition (Figure 1) [60,61].

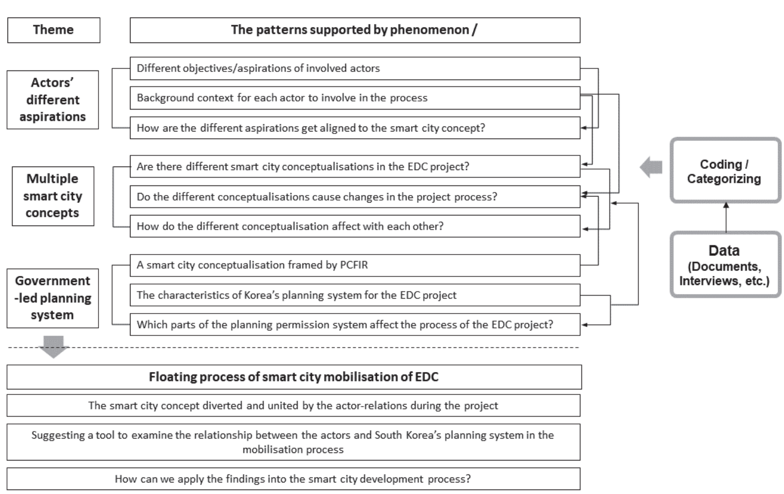


Figure 1. Analysis framework (source: author's own).

This study examines actors (humans, organisations, bureaus, etc.) and their mutual influences on the smart city district of the EDC development. The central government of South Korea performs a multileveled decision-making process on the implementation of large-scale urban development, with the EDC and pilot smart city development in the same category. The assemblage approach analyses the strategic policy-making process regarding urban development and its relation to the adaptation of global policy and how it is projected, transformed and equipped in the physical strategies of the development scheme, in line with South Korea's planning system.

This analysis is based on the results of nine semi-structured elite interviews with key participants in the process. The interviewees were categorised into two groups: the interviewees involved with national and regional-level relations and those concerned only with EDC (Table 1). The former group explored the mobilisation process of urban policy regarding urban regeneration in the local area, while the latter group addressed individual efforts concerning urban regeneration projects. The interviews were conducted face-to-face between 2018 and 2019. The documents used for the analysis included official publications by Busan Metropolitan City Council (BMCC), Busan Development Institute, Busan Port Authority and the Korea Water Resources Corporation. Local newspapers, news magazines, newsletters, and websites were also used (Table 2).

Table 1. Interviewees.

Category	Description	The Number of Interviewees
Central government	Presidential Committee on the Fourth Industrial Revolution (PCFIR)	1
Local government	Busan Metropolitan City Council (BMCC)	1
Government-led research Institute	Busan Development Institute (BDI)	1
Public Corporation	Korea Water Resources Co. (K-Water) Busan Metropolitan Corporation (BMC)	1 2
Educational institute	Public/Private universities	3
Total		9

Table 2. Archival data for the EDC project.

Type	Name	Author
Archives	Busan Metropolitan City's supplementary planning guidance on planning practice	Busan Metropolitan City
	Environmental Policy in South Korea—Problems and Perspectives	Konrad A. S.
	Busan Smart City Visions & Strategies	Busan Metropolitan City
	Administrative Audit and Inspection	BMC
	Busan Eco-delta City Construction Technology Masterplan Guides for Special District	K-Water
	Smart City Strategies	PCFIR
	The 3rd Smart City Master Plan 2019–2023 (National)	Ministry of Land, Infrastructure and Transport (MOLIT)
Newspapers (local)	Busan Ilbo	-
	The Kookje Daily News	-

Table 2. *Cont.*

Type	Name	Author
Newsletters and Websites	www.busan.go.kr (accessed on 1 May 2018)	Busan Metropolitan City
	www.bdi.re.kr (accessed on 1 May 2018)	Busan Development Institute
	www.busanpa.com (accessed on 1 May 2018)	Busan Port Authority
	www.kwater.or.kr (accessed on 1 May 2018)	Korea Water Resource Co.
News magazines	Dynamic Busan	Busan Metropolitan City

5. Actor Network: Why Do They Need a Smart City?

5.1. Eco-Delta City (EDC)

EDC is located in Gangseo-gu, on the west side of Busan, South Korea (Figure 2). Gangseo-gu was an underdeveloped area of Busan which was not properly developed until 2010, as both the building height restriction for Gimhae International Airport and the green belt obstructed the urban development process. This issue was resolved by the Ministry of Land, Infrastructure and Transport (MOLIT) through the Nakdong River maintenance programme. In 2010, the urban regeneration project near the waterfront area was planned and named the 'Eco Delta City' (Table 3). Two years later, BMCC, BMC (Busan Metropolitan Corporation is the local government agency for supplying housing and land and developing urban areas within Busan Metropolitan City), and K-Water (also called the Korea Water Resources Corporation is a national government agency for comprehensive water resource development and provides both public and industrial water in South Korea) agreed to act as the main developers through the implementation of the EDC project. During the planning stages, BMCC applied to the central government bureau, MoLIT, for the national pilot smart city project; the central part of the EDC was finally designated as one of two national pilot projects by the national government. Site construction began in 2019, aiming to create 2.2 km^2 of smart city for 3380 households with 8500 residents as a national pilot smart city project (Table 4).

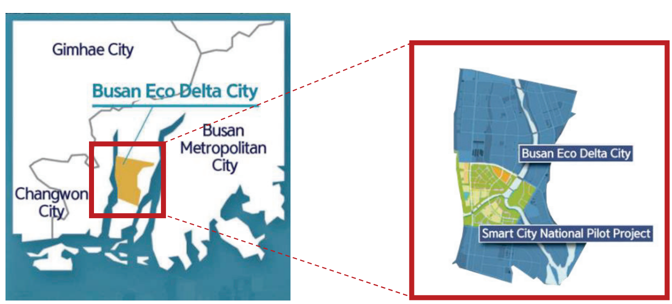


Figure 2. The location of EDC (source: K-Water).

The key advantages of the site are that it can utilise water and the water-scape, it has good accessibility (Gimhae International Airport, Busan Port and Busan Railway Station), and it is surrounded by traditional industrial clusters within the area of Busan Metropolitan City. Such circumstances create a synergetic effect by accelerating cooperation between private firms and young knowledge workers in the fields of IoT, ICT, and computer science to settle in EDC. Urban planners expected so that the agglomeration of diverse industries would prevent the pattern of the ever-decreasing population by gathering various types of labor from outside Busan Metropolitan City [62].

Table 3. Summary of EDC.

EDC		Smart City: National Pilot Project	
Location	Gangseo-gu, on the west side of Busan, South Korea		
Area	11.77 km^2	Area	2.2 km^2
Period	2012–2023		
Population (aim)	75,100 (30,000 households)	Population (aim)	8500 (3380 households)
Land usage	Residence, Commercial, Research and Development, Logistics	Facilities	Waterfront area, Convention centre, Shopping centre, Marina
Total	K-Water, BMC, Busan Metropolitan City		

Table 4. Key stages of EDC's development.

Date	Planning Process
Feb. 2012.	Agreement made for development by K-Water and BMC
Dec. 2012.	Revision of urban management plan—release green belt area by MoLIT
Dec. 2012.	Designation of the waterfront area
Sep. 2013.	Beginning of land compensation in Myeongji-dong
Sep. 2014.	Change of designated waterfront area and issue for construction document
Oct. 2014.	Beginning of land compensation in Guangdong-dong
Jul. 2015.	Beginning of land construction for areas 1–4 (Myeongji-dong)
Jun. 2016.	Beginning of land compensation in Daejeon-2-dong
Nov. 2016.	Beginning of land construction for 2–2 areas (Guangdong-dong)
Jun. 2017.	Change of designated waterfront area and change of construction document
Jan. 2018.	Designation of National Pilot Smart City
Jul. 218.	Establishment of master plan draft for Smart City
Nov. 2018.	Business information session held for areas 2–4 (Guangdong-dong)
Dec. 2018.	Establishment of the master plan (final) for Smart City
Aug. 2019.	Issue for construction document (2nd revised)
Dec. 2019.	Beginning of land construction for area 3 (Daejeon-2-dong)
Dec. 2023.	Completion stage

5.2. Different Aspirations between Actors

5.2.1. K-Water

There were three developers involved in the EDC project: K-Water, BMC, and BMCC. However, there were two different aspirations in the group: K-Water had a financial aspiration and the other developers had a long-term goal to revitalise the area. K-Water has been in financial loss for a long time. Both the enactment of the 'Special Act on the Utilization of Waterfronts', which enabled K-Water to be the only authorised developer of the waterfront area, and the central government's financial support, caused the organisation to initiate the EDC project.

> *"Under the Myung-bak Lee administration (particularly in 2012), there was additional budget, 800 billion Korean won, which has to be consumed under the administration. So, the administration gave the budget to the K-water since it suffered from its financial problems. When the K-Water recovered its enterprise soundness, it determined to invest a property-led urban development under its authorization. It is the very start of Eco Delta City project. Anyway, whatever the concept of the urban development is, the government-led corporation will spend the budget for the site and urban infrastructure construction"*
>
> *(Interview with former external master planner, 2019).*

5.2.2. BMCC/BMC

For BMCC, the development of the Gangseo-gu area was a great opportunity. Since 1996, the population of Busan has been decreasing, transforming it into an 'ageing society' in 2002, with the lowest level of fertility among the cities of South Korea; the city will become a super-aged society by 2022. There is also concern regarding the decreasing number of the working-age population and the loss of many knowledge workers. Additionally, economic growth has slowed (Figure 3). Due to the diminution of Busan's global competitiveness, small- and middle-sized local enterprises face global challenges, which has impacted the unemployment rate. Thus, located in the western periphery of South Korea and with the high potential area of Busan having always been under developmental pressure, BMCC and BMC were motivated to develop the area. Thus, there was no reason to reject the pilot project, which would help establish an innovative industrial ecosystem, thereby attracting young knowledge workers.

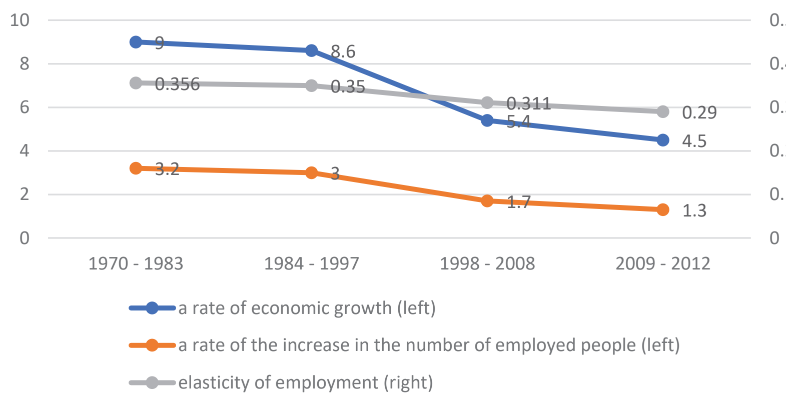


Figure 3. Unemployment rate in Busan.

5.2.3. PCFIR

PCFIR was founded based on the Presidential Decree on the Creation and Management of the PCFIR, promulgated in 2017 [63]. The organisation mainly aims to create national master plans and strategies regarding the fourth industrial revolution [64]. In this context, the PCFIR and central government wanted to use EDC as an experimental project to produce a standard for smart city development. PCFIR promoted a relationship with international partners during the implementation of the EDC project, an essential prerequisite for the successful mobilisation of knowledge and policy. Based on the PCFIR's efforts to create a global standard for smart cities, both the central and local governments intended to commercialise EDC as a Korean smart city model to export to other countries and cities [65] (please see Table 5).

Table 5. Actors in the EDC project.

Actors	Visions for the EDC Project
K-Water	Financial benefit from the project
BMCC/BMC	Revitalisation of the local area through industrial input
MoLIT, PCFIR	Representative case of smart city development
Ministry of Environment (MoE)	Priority of water quality and supply rather than waterfront development

5.2.4. Authority: MoLIT and MoE

For the legally authorised bureaus, their particular aspiration for EDC was simply an implementation of the whole urban development. Under Korea's planning system, MoLIT was the legal authority granting permission for EDC's development under 'the Special Act on the Utilization of Waterfronts' until 2018. Thus, EDC urban development processes and the pilot smart city area plans were authorised by MoLIT. K-Water, as a primary developer, was controlled by MoLIT throughout the development process.

In May 2018, while the EDC planning process was still ongoing, there was an announcement from the central government that the control by K-Water had been transferred from MoLIT to the Ministry of Environment (MoE), whose main interest was to preserve water-related resources and water quality, rather than development. However, MoLIT retained some influence on the project and operated as one of the governmental actors in the EDC's smart city development. For example, in 2019, after changing the primary jurisdiction bureau, MoLIT announced a competition for 'an activation project for the national pilot city regulation defer system' in connection with the two national pilot smart cities.

6. Precarious Network: Multiple Conceptualisation of Smartness

The EDC's development process was delayed and not implemented as planned initially. From the interviews and document reviews, this paper finds that one of the main reasons for those changes is because BMCC, K-Water, and the external master planner had different definitions of smart cities. The misaligned aspirations made the project network precarious. For BMCC, the idea of the smart city was a developed version of U-City, a concept they had previously pursued. In 2005, the Busan Metropolitan City was introduced by the Financial Times as the first city in the world where the U-City masterplan had been officially established. In the U-City project, BMCC usually focused on creating ICT-centered urban services and governance. From this experience, BMCC believed the idea of the smart city to be equal to the U-City concept that is also found in the definition of 'smart city' in the 'Smart City Act'.

> *'Smart City Act' defines 'smart city' as a sustainable city that provides a variety of city services through urban infrastructure constructed with the convergence of ICT and land development technology to improve the competitiveness of the city and the quality of life* [66].

Although the actual developer of EDC was K-Water, this project was led by the national smart city master planners from the PCFIR. There were two master planners: internal and external. The internal master planner engaged with K-Water, while the external master planner was hired by the PCFIR. Master planners have a unique position (a central point) in the organogram of the EDC project (Figure 4) and thus have authority throughout the implementation of a project. Both the master planners and the main developers are decision-makers. The main developers concentrate on establishing contracts with private firms for constructing the new urban space based on specific technologies, creating the next generation of industrial clusters. Developers build a relationship with domestic and global firms through the master planner's (mainly the external master planner's) recommendation. In this vein, the master planners are another means of 'smart city' mobilisation in the EDC project. Simultaneously, the master planners cooperate and share ideas (solid arrow). Under the smart city guideline publicised by the central government, they communicate with several branches of the national government (for regulations and restrictions), academia and research institutes (for cutting-edge technology and theories) through several consultations (empty arrow). Thus, master planners usually play roles as facilitators who can support the main developers' implementation of a project.

The main developers aimed to concentrate on establishing and maintaining a technical perspective of urban infrastructure rather than managing the city. As a member of the main developer (K-Water), the internal master planner also preferred to find visible outcomes (for instance, new buildings, roads, and visitors).

> *Eco-delta City will be the first smart city which uses highly developed several technologies within the urban area: a city performance evaluation and certification tool. In particular, three main areas—planning (innovation in process), construction (innovation in technol-*

ogy) and management (innovation in public participation)—will be critically examined within the development of Asian KPIs

(Interview with former internal master planner, 2018).

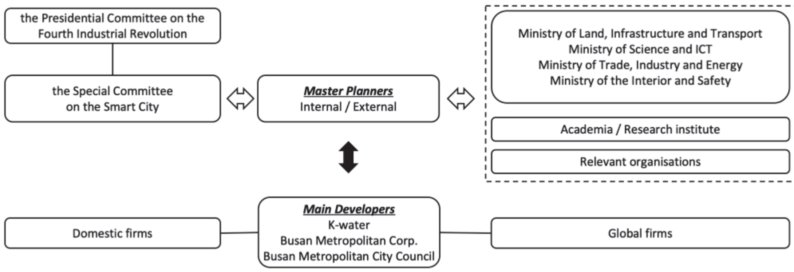


Figure 4. Organogram in the EDC project (source: author's own).

On this background, one of the global programmes and ideas which main developers and the internal master planners attempted to adapt in the Eco-delta City is the Key Performance Indicators (KPIs) for smart cities. Not only the main developers (K-Water and BMC) but also the central government focused on the global standardisation of the smart city model. There were no global guidelines or ultimate indicators that could assess the level of a smart city, even though some organisations developed their individual KPIs. Hence, civil servants in the South Korean government sought to create standards for assessment regarding a smart city. Through the development of KPIs, they also hoped that such a developed Korean standard for smart cities would later become a global standard in the long term. They believed that if the Korean standard for a smart city is able to achieve a global reputation, the Korean smart city model (Eco-delta City) could be exported globally.

The internal master planner particularly paid attention to KPIs for smart cities from European Nations (EU) and the International Telecommunication Union (ITU). Both organisations already developed and suggested KPIs as a measurement of the city's progress towards their smart city goals.

In 2017, the Act on the Promotion of Smart City Development and Industry was partly revised, and it provided significant support for KPIs for a smart city [67]. Under the revised Act, the national pilot smart city had to set up KPIs as well as the aims of its business, and had to announce its performance level to improve the efficiency and effectiveness of the smart city project. The Key Performance Indicators (Figure 5) are divided into core and advanced indicators. There are three basic agendas of measurement: People, Technology, and Nature. Each agenda has a couple of aims such as '5 years longer healthy life' and 'work & life balance' in people; '28,000 jobs' and '124 h saved' in technology; and 'energy plus 20%' and 'recycle 100%' in nature. Under the aims, four or five core indicators are established. For instance, in terms of people, there are five core indicators: natural disaster, social disaster, health, living environment, and workplace environment. Another five core indicators are handled in nature: transportation, renewable energy, construction, water, and waste. In the field of technology, four core indicators were developed: innovative industrial ecosystem, construction, transportation, and life-related services. Advanced indicators provide more in-depth perspectives of smart cities, such as the progress of detailed initiatives [68]. The developers created 35 advanced indicators.

At the initial stage of the development of the national pilot project, the two master planners set a vision of the Eco-delta City as a 'global innovative growing future city in combination with human, nature, and technology'. Based on this vision, three aims were created: a city where work and rest coexist; a city where humans and nature coexist and an innovative city which contributes to the achievement of sustainable development. However, the two master planners (internal and external) showed different detailed views on the project and on the concept of a smart city.

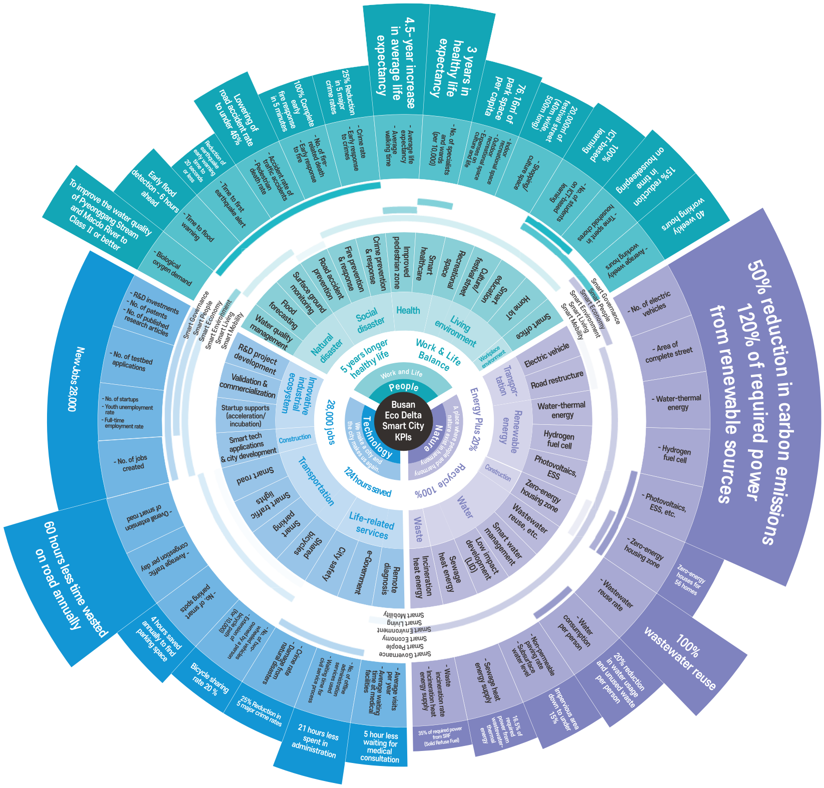


Figure 5. Key Performance Indicators in the EDC project (source: K-Water)).

For instance, the external master planner ran a business incubator firm in London as a British accelerator supporting Fintech and smart city technology companies. He had many years of experience in training start-ups, particularly in Singapore, Hong Kong, and London. Rather than creating several visible outcomes, the external master planner considered smart cities to be tools to prepare the next generation of industries by creating a business-friendly environment. His comment following his resignation as the external master planner describes his thoughts:

> *"There was not a smart city in Busan. There is not a smart city in Busan. Eventually, there will not be a smart city in Busan, even in South Korea as well. They [the main developers] were still focusing on property-led development, which was a very general and popular approach for urban development in the 1990s and 2000s. Yet, it would not work for now. It's almost the 2020s. In my opinion, without the next generation of industry, the city should disappear, and this will impact on South Korea simultaneously. They [the main developers] had no idea how to invite innovative start-ups and how to create a new generation of industry in Busan. South Korea government should also consider this issue urgently".*
>
> *(Interview with the former external master planner, 2019)*

Interestingly, the South Korean government were aware of this different view on the concept of a smart city prior to recruiting him. The committee intended to use his experience and knowledge of smart cities because he was familiar with several of the programmes, policies, and challenges for private firms (start-ups) involved in smart city industries. This means that the South Korean government might believe that learning from a developed country's ideas and policies regarding smart cities would be useful and could be adopted in South Korea:

> *"I cannot say this is what they [the main developers] thought precisely. This is my opinion. However, I believe that they gave me tacit approval for my approach focusing on the establishment of new industry (not on the short-term and visual outcomes) even though the internal master planner did not have the very same approach".*
>
> *(Interview with the former external master planner, 2019)*

However, different conceptualisations have impacted on the aims and objectives of the EDC project. This has brought about a delay in the delivery of the project and a restructuring of the governance system of the decision-making process within the project. Fundamentally, the main reason for the precariousness and stop–start progression of the network is the different perspectives of the master planners and developers, as well as the loosened relationship and failure to make objectives of the two parts—master planners and the developers—that are aligned as the same, is critical one. As a result, the master planners resigned and initiatives suggested by the master planners were partly implemented with a delay of the project for a certain period of time.

7. The Process of Government-Led Urban Development

In the South Korean context, the bureaucratic procedures complicated the policy mobility process. The main developers asserted that the South Korean government's regulations should have been considered [69]. The unique governance system and the protocol of urban development also affected the adoption of the smart city concept in South Korea.

> *"In the United Kingdom, there is no government agency which prohibits and regulates the private firms' suggestions before creating their outcomes. This type of simple and light governance system encourages private firms to develop their idea and to secure autonomy (and flexibility) during the development process"*
>
> *(Interview with academia in the field of smart city, 2019).*

Conversely, regarding EDC, every programme was managed by either local (BMCC and BMC) or national government (K-Water). In other words, if private firms wished to develop a programme within the EDC platform, they needed to adhere to government restrictions and regulations, which would require additional time and effort.

> *"Developers claimed that they will create a regulatory sandbox, especially for motivating private firms to develop their ideas and programmes without restrictions and regulations. However, it did not work because they didn't know to what extent they eased the restrictions and regulations. Furthermore, a certain number of private firms were chosen as a member who can achieve specific resources (e.g., economic support, technical advice, etc.) by the national government. This means that such firms have to be supervised by the government even though they deliver their project within the regulatory sandbox".*
>
> *(Interview with the former external master planner, 2019)*

Although the external master planner suggested that this type of governance system and process should be modified for the implementation of the EDC project, his suggestion was indirectly denied. Similar to a previous large-scale urban development project—Centum City—the EDC project was implemented and funded by both national and local governments. Thus, civil servants (in the group of developers) argued that they had to manage the whole process. This caused different outcomes for the smart city project, regardless of policy mobility processes, which could be interpreted as a failure of policy mobility.

8. Conclusions

This article has explored the urban development process of EDC in South Korea under the smart city paradigm. This research verifies the value of focusing on actor relations to understand how the smart city paradigm (universal paradigm) operates and can be applied to local/practical urban development processes. This study did not assess the success or failure of EDC's urban development. The key focus of this discussion was to follow the controversial moment when the broad, global idea of the smart city met a specific society's planning system and the power relations between the actors. It has identified the importance of actor-relations in the development process and how these contribute to planning and design results and elaborate policy mobility.

Discussions of the three research questions which make up the main research question are given below.

- *How Is the Smart City Paradigm Empowered as a Development Concept by Local Political and Economic Actors' Aspirations?*

In the case of EDC, the smart city mobilisation emerged from the actor-relations rather than from the objectively defined consensus of the society. The smart city development was initiated from the interrelations of different and multiple purposes; K-Water, a key player, transferred BMCC to the development project and moved the central government bureaus, MoLIT and PCFIR. K-Water needed financially successful urban development by promoting the smart city concept and BMCC needed a growth engine for the relatively underdeveloped area of its boundary; the central bureaus were searching for a testbed for standardised smart city urban development. All the different aspirations could be aligned, under K-Water's and BMCC's network relations, under the mobilisation of the smart city concept.

- *How Do Different Conceptualisations of the Smart City Affect the Process of Smart City Mobility?*

There is no single case of a successful smartness mobilisation but there are multiple. The multiple ways of mobilisation competed and challenged each other within the local context. The actors involved in the process of development, including the master planners, had different conceptualisations of the smart city. Unlike the different objectives between the actors, the varying conceptions of the smart city hindered the process, damaging the network. After the initial network was changed, the development process could progress slowly. Whatever type of smart city idea is adopted, the critical point that this case study indicates is the importance of a unified idea between actors.

- *How Did South Korea's Government-Led Development Affect the Smart City Adaptation Process?*

South Korea has a long history of government-led urban development, which has a complicated multilevel bureaucratic process. There were two main obstacles in the EDC process caused by this planning system. Firstly, the system has a narrow scope in which to hold the newly introduced technologies that have never been applied in the city. In this hierarchical planning system, the government's permission process also prevents bottom-up and lower-level actors' creative suggestions from being processed. Secondly, multiple bureaus can affect development schemes and can be a burden to the application of new ideas. In the case of EDC, the bureaus involved held different ideas about smart cities, making the whole development network precarious.

In the government-led development system, the bureau's authority and the developer's aspirations must be carefully examined before the project begins. Maintaining an aligned and unified conception of what is being developed is critical. Therefore, there must be a careful investigation into the formal process and into the actors; the mobilisation of the smart city must be presented before the urban development process is established. This paper recognises no archetype of urban smartness, as there exist different and controversial examples of this [7]. There is no single successful 'smart city package' that can be exported to and planted in diverse societies with different urban and economic contexts.

From the analysis, in the case of EDC, the smart city concept is not a ready-made frame that is waiting to be applied in the real world. Rather than this, the case of EDC shows that smartness is a generic and floating entity that is continually changing by the actor-relations throughout the process. As Crivello [11] argues, there is no single case of a successful smart city to imitate and there are very different and controversial examples. The analysis of this study verifies that the initially brought smartness framed by the government was not accepted intactly but was contested, affiliated, and compounded by the actor relations. In other words, a smart city is made not by a single mind but by the actual local actors' unique means of relations—institutions, individuals, bureaus, and others. In addition, this study also verifies that the assemblage approach is one of the most suitable tools in proceeding and evaluating smart city development which can provide an in-depth understanding of the actual operations of the project's network. However, the detailed means of using the assemblage tool in the smart city project, or any other policy mobilisation case, needs to be further studied in greater depth. Furthermore, future research will compare diverse smart city case studies in South Korea and will investigate whether such cases will be generalised under the answers discussed above.

Author Contributions: Conceptualization, D.H.; methodology, D.H., J.H.K.; formal analysis, D.H., J.H.K.; investigation, D.H.; resources, D.H.; data curation, D.H., J.H.K.; writing—original draft preparation, D.H., J.H.K.; writing—review and editing, J.H.K., D.H.; visualization, D.H.; supervision, J.H.K.; project administration, J.H.K., D.H.; funding acquisition, J.H.K. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by Pusan National University, a 2-Year Research Grant (ref: 202014110002).

Institutional Review Board Statement: The study was approved by UCL Research Ethics Committee (Approval Code: 12281/001 Approval Date: 24 November 2017).

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: Not Applicable.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Joss, S.; Sengers, F.; Schraven, D.; Caprotti, F.; Dayot, Y. The smart city as global discourse: Storylines and critical junctures across 27 cities. *J. Urban Technol.* **2019**, *26*, 3–34. [CrossRef]
2. Moir, E.; Moonen, T.; Clark, G. *What Are Future Cities? Origins, Meanings and Uses*, 1st ed.; Catapult: London, UK, 2014.
3. Luque, A.; McFarlane, C.; Marvin, S. Smart urbanism: Cities, grids and alternatives? In *After Sustainable Cities?* 1st ed.; Hodson, M., Marvin, S., Eds.; Routledge: London, UK, 2014; pp. 86–102.
4. Peck, J.; Theodore, N. Mobilizing policy: Models, methods, and mutations. *Geoforum* **2010**, *41*, 169–174. [CrossRef]
5. Prince, R. Local or global policy? Thinking about policy mobility with assemblage and topology. *Area* **2017**, *49*, 335–341. [CrossRef]
6. Fuchs, C. Industry 4.0: The digital German ideology. *Triplec. Commun. Capital. Crit.* **2018**, *16*, 280–289. [CrossRef]
7. Crivello, S. Urban policy mobilities: The case of Turin as a smart city. *Eur. Plan. Stud.* **2015**, *23*, 909–921. [CrossRef]
8. Ministry Of Land Infrastructure and Transport (South Korea). *Smart City Master Plan*, 3rd ed.; Ministry of Land Infrastructure and Transport: Sejong City, Korea, 2019.
9. TTA (Telecommunications Technology Association). *The Concept of Smart City and Its Standardisation: Standardisation Issue*; Tecommunications Technology Association: Seongnam, Korea, 2018.
10. Burawoy, M. Reconstructing Social Theories. In *Ethnography Unbound: Power and Resistance in the Modern Metropolis*; Burawoy, M., Burton, A., Ferguson, A., Fox, K., Gamson, J., Hurst, L., Julius, N., Kurzman, C., Salzinger, L., Schiffman, J., et al., Eds.; University of California Press: Berkeley, CA, USA, 1991; pp. 8–27.
11. Chang, I.; Jou, S.; Chung, M. Provincialising smart urbanism in Taipei: The smart city as a strategy for urban regime transition. *Urban Stud.* **2020**, *58*, 559–580. [CrossRef]
12. Bollier, D. *How Smart Growth Can Stop Sprawl: A Fledgling Citizen Movement Expands*, 1st ed.; Essential Books: Washington, DC, USA, 1998.
13. Komninos, N. *Intelligent Cities: Innovation, Knowledge Systems and Digital Spaces*, 1st ed.; Routledge: London, UK, 2002; pp. 1–320.
14. Dubai: The Smart City. Available online: http://www.cisco.com/web/learning/le21/le34/downloads/689/nobel/2005/docs/Abdulhakim_Malik.pdf (accessed on 11 December 2021).
15. Smarter Cities: New York 2009. Available online: http://www.ibm.com/smarterplanet/us/en/smarter_cities/article/newyork2009.html (accessed on 11 December 2021).
16. Stadt der Zukunft? Available online: http://www.siemens.com/innovation/de/publikationen/zeitschriften_pictures_of_the_future/PoF_Fruehjahr_2004/SmartCity.htm (accessed on 11 December 2021).

17. Mora, L.; Bolici, R.; Deakin, M. The first two decades of smart-city research: A bibliometric analysis. *J. Urban Technol.* **2017**, *24*, 3–27. [CrossRef]
18. WIIG, A. IBM's smart city as techno-utopian policy mobility. *City* **2015**, *19*, 192–207. [CrossRef]
19. Correia, D.; Teixeira, L.; Marques, J.L. Reviewing the State-of-the-Art of Smart Cities in Portugal: Evidence Based on Content Analysis of a Portuguese Magazine. *Publications* **2021**, *9*, 49. [CrossRef]
20. Huang, K.; Luo, W.; Zhang, W.; Li, J. Characteristics and Problems of Smart City Development in China. *Smart Cities* **2021**, *4*, 74. [CrossRef]
21. Batty, M.; Axhausen, K.W.; Giannotti, F.; Pozdnoukhov, A.; Bazzani, A.; Wachowicz, M.; Portugali, Y. Smart cities of the future. *Eur. Phys. J. Spec. Top.* **2012**, *214*, 481–518. [CrossRef]
22. Chawviang, A.; Kiattisin, S. Sustainable Development: Smart Co-Operative Management Framework. *Sustainability* **2022**, *14*, 3641. [CrossRef]
23. Anthopoulos, L.; Janssen, M.; Weerakkody, V. Smart service portfolios: Do the cities follow standards? In Proceedings of the 25th International Conference Companion on World Wide Web, Geneva, Switzerland, 11–15 April 2016.
24. Irvine, K.N.; Suwanarit, A.; Likitswat, F.; Srilertchaipanij, H.; Ingegno, M.; Kaewlai, P.; Boonkam, P.; Tontisirin, N.; Sahavacharin, A.; Wongwatcharapaiboon, J. Smart City Thailand: Visioning and Design to Enhance Sustainability, Resiliency, and Community Wellbeing. *Urban Sci.* **2022**, *6*, 7. [CrossRef]
25. Kaluarachchi, Y. Implementing Data-Driven Smart City Applications for Future Cities. *Smart Cities* **2022**, *5*, 25. [CrossRef]
26. Harrison, C.; Eckman, B.; Hamilton, R.; Hartswick, P.; Kalagnanam, J.; Paraszczak, J.; Williams, P. Foundations for Smarter Cities. *J. Res. Dev.* **2010**, *54*, 350–365. [CrossRef]
27. Florida, R. Cities and the Creative Class. *City Community* **2003**, *2*, 3–19. [CrossRef]
28. US Conference of Mayors Announce 2008 City Liveability Award Winners. Available online: http://www.usmayors.org/pressreleases/uploads/cityliveng.pdf (accessed on 11 December 2021).
29. Su, Y.; Miao, Z.; Wang, C. The Experience and Enlightenment of Asian Smart City Development—A Comparative Study of China and Japan. *Sustainability* **2022**, *14*, 3543. [CrossRef]
30. Ng, M.K.; Koksal, C.; Wong, C.; Tang, Y. Smart and Sustainable Development from a Spatial Planning Perspective: The Case of Shenzhen and Greater Manchester. *Sustainability* **2022**, *14*, 3509. [CrossRef]
31. Oh, J.; Seo, M. Measuring Citizens-Centric Smart City: Development and Validation of Ex-Post Evaluation Framework. *Sustainability* **2021**, *13*, 11497. [CrossRef]
32. Alcaide Muñoz, L.; Rodríguez Bolívar, M.P. Different Levels of Smart and Sustainable Cities Construction Using e-Participation Tools in European and Central Asian Countries. *Sustainability* **2021**, *13*, 3561. [CrossRef]
33. Park, B. Re-reading smart city discourses through the Lefebvrian concept of urban revolution. *Space Soc.* **2020**, *30*, 141–171. [CrossRef]
34. Shin, D. *Smart City*; Korea Research Institute for Human Settlements: Anyang, Korea, 2013.
35. Lee, S.H.; Han, J.H.; Leem, Y.T.; Yigitcanlar, T. Towards ubiquitous city: Concept, planning, and experiences in the Republic of Korea. In *Knowledge-Based Urban Development: Planning and Applications in the Information Era*, 1st ed.; Yigitcanlar, T., Velibeyoglu, K., Baum, S., Eds.; Information Science Reference: London, UK, 2008; Chapter 9; pp. 148–170.
36. Jo, S.-S.; Han, H.; Leem, Y.; Lee, S.-H. Sustainable Smart Cities and Industrial Ecosystem: Structural and Relational Changes of the Smart City Industries in Korea. *Sustainability* **2021**, *13*, 9917. [CrossRef]
37. Peck, J.; Theodore, N. Exporting workfare/importing welfare-to-work: Exploring the politics of Third Way policy transfer. *Political Geogr.* **2001**, *20*, 427–460. [CrossRef]
38. Mccann, E.J. Urban Policy Mobilities and Global Circuits of Knowledge: Toward a Research Agenda. *Ann. Assoc. Am. Geogr.* **2011**, *101*, 107–130. [CrossRef]
39. Dolowitz, D.P.; Marsh, D. Who Learns What from Whom: A Review of the Policy Transfer Literature. *Political Stud.* **1996**, *44*, 343–357. [CrossRef]
40. Massey, D. Geographies of responsibility. *Geogr. Ann. Ser. Hum. Geogr.* **2004**, *86*, 5–18. [CrossRef]
41. Sheller, M.; Urry, J. The New Mobilities Paradigm. *Environ. Plan. A* **2006**, *38*, 207–226. [CrossRef]
42. Cresswell, T. Towards a politics of mobility. *Environ. Plan. D Soc. Space* **2010**, *28*, 17–31. [CrossRef]
43. Raco, M.; Street, E.; Freire-trigo, S. The New Localism, Anti-Political Development Machines, and the Role of Planning Consultants: Lessons from London's South Bank. *Territ. Politics Gov.* **2016**, *4*, 216–240. [CrossRef]
44. Healey, P. *Urban Complexity and Spatial Strategies: Towards a Relational Planning for Our Times*, 1st ed.; Routledge: Oxon, UK, 2007.
45. McFarlane, C. Translocal assemblages: Space, power and social movements. *Geoforum* **2009**, *40*, 561–567. [CrossRef]
46. McGuirk, P.M. Producing the Capacity to Govern in Global Sydney: A Multiscaled Account. *J. Urban Aff.* **2003**, *25*, 201–223. [CrossRef]
47. Raco, M. Private Consultants, Planning Reform and the Marketisation of Local Government Finance. In *Planning Practice: Critical Perspectives from the UK*, 1st ed.; Ferm, J., Tomaney, J., Eds.; Routledge: New York, NY, USA, 2018.
48. Williams, K.; Dair, C. A framework for assessing the sustainability of brownfield developments. *J. Environ. Plan. Manag.* **2007**, *50*, 23–40. [CrossRef]
49. Jung, T.H.; Lee, J.; Yap, M.H.T.; Ineson, E.M. The role of stakeholder collaboration in culture-led urban regeneration: A case study of the Gwangju project, Korea. *Cities* **2015**, *44*, 29–39. [CrossRef]

50. Latour, B. *Science in Action: How to Follow Scientists and Engineers through Society*, 1st ed.; Harvard University Press: Boston, MA, USA, 1987.
51. Sheng, J.; Han, X. Practicing policy mobility of payment for ecosystem services through assemblage and performativity: Lessons from China's Xin'an River Basin Eco-compensation pilot. *Ecol. Econ.* **2022**, *191*, 29–39. [CrossRef]
52. Brill, F.; Conte, V. Understanding project mobility: The movement of King's Cross to Brussels and Johannesburg. *Environ. Plan. C Politics Space* **2019**, *38*, 79–96. [CrossRef]
53. Gonzãlez, S.; Bilbao and Barcelona 'in Motion'. How Urban Regeneration 'Models' Travel and Mutate in the Global Flows of Policy Tourism. *Urban Stud.* **2011**, *48*, 1397–1418. [CrossRef]
54. Moore, S.A.; Raco, M.; Clifford, B. The 2012 Olympic Learning Legacy Agenda—The intentionalities of mobility for a new London model. *Urban Geogr.* **2018**, *39*, 214–235. [CrossRef]
55. Hult, A. The circulation of Swedish urban sustainability practices: To China and back. *Environ. Plan. A* **2015**, *47*, 537–553. [CrossRef]
56. Ward, K. Business Improvement Districts: Policy Origins, Mobile Policies and Urban Liveability. *Geogr. Compass* **2007**, *1*, 657–672. [CrossRef]
57. Cook, I.R. Mobilising Urban Policies: The Policy Transfer of US Business Improvement Districts to England and Wales. *Urban Stud.* **2008**, *45*, 773–795. [CrossRef]
58. Cook, I.R. Private sector involvement in urban governance: The case of Business Improvement Districts and Town Centre Management partnerships in England. *Geoforum* **2009**, *40*, 930–940. [CrossRef]
59. Allen, J.; Cochrane, A. Beyond the Territorial Fix: Regional Assemblages, Politics and Power. *Reg. Stud.* **2007**, *41*, 1161–1175. [CrossRef]
60. Creswell, J.W.; Poth, C.N. *Qualitative Inquiry and Research Design: Choosing among FIVE Approaches*, 4th ed.; Sage Publications: London, UK, 2018.
61. Ritchie, J.; Lewis, J.; Nicholls, C.M.; Ormston, R. *Qualitative Research Practice: A Guide for Social Science Students and Researchers*, 2nd ed.; Sage Publications: London, UK, 2013.
62. Busan Smart Eco Delta City Plan. Available online: https://smartcity.go.kr/en (accessed on 11 December 2021).
63. Lim, J. *Korea's Smart City Policy and Strategies*; Ministry of Land Infrastructure and Transport: Sejong City, Korea, 2019.
64. What Is the Presidential Committee on the 4th Industrial Revolution? Available online: https://www.4th-ir.go.kr/#about_4thir (accessed on 11 December 2021).
65. The Presidential Committee on the 4th Industrial Revolution (South Korea). *Sustainable City Which Improves Citizens' Quality of Life, Promoting to Create a Human-Oriented Global Innovative City*; The Presidential Committee on the 4th Industrial Revolution: Seoul, Korea, 2018.
66. Act on the Promotion of Smart City Development and Industry. Available online: https://elaw.klri.re.kr/eng_service/lawView.do?hseq=50634&lang=ENG (accessed on 11 December 2019).
67. Park (National Assembly News ON, South Korea). *Land Infrastructure & Transport Committee in the National Assembly Voted for 28 Acts Regarding Smart City*; National Assembly Secretariat: Seoul, Korea, 2019.
68. Key Performance Indicators (KPIs) and Standards for Smart Sustainable Cities. Available online: https://www.itu.int/en/ITU-D/Regional-Presence/AsiaPacific/Documents/Module%203%20Smart%20Sustainable%20Cities%20KPIs%20Draft%20H.pdf (accessed on 1 March 2018).
69. K-water. Busan Smart Eco Delta City Plan. In *CITY*, 1st ed.; Busan Metropolitan City Corporation, Busan Metropolitan City & K-water, Eds.; K-water: Deajeon, Korea, 2018.

sustainability

MDPI

Article

Effect of *hukou* Accessibility on Migrants' Long Term Settlement Intention in Destination

Peilin Li [1], Yufeng Wu [2,*] and Hui Ouyang [3]

[1] Institute of Spatial Planning and Regional Economy, Chinese Academy of Macroeconomic Research, Beijing 100038, China; peilinli.camr@gmail.com
[2] Department of Geography, University College London, Gower Street, London WC1E 6BT, UK
[3] Institute of Market and Price Research, Chinese Academy of Macroeconomic Research, Beijing 100038, China; oyhbj@163.com
* Correspondence: yufeng.wu.17@ucl.ac.uk

Abstract: Migrants' long-term settlement intention in urban areas has been emphasized by both policy makers and researchers in promoting urbanization and coordinating regional economic development. This study advances the body of knowledge by investigating the effect of what E.S. Lee has proposed as 'intervening obstacles' in the 'push-and-pull' theory—the difficulty in obtaining *hukou* in migration destination, on their long-term settlement intention in urban areas. Logistic regressions were applied to examine the effect of urban registered residence system (the *hukou* system) accessibility on migrants' long-term settlement intention in urban areas, as well as the determinants of subjective evaluated difficulty in obtaining urban *hukou*, based on a nation-wide large-scale survey in 46 Chinese cities. Our results suggest that difficulty in obtaining urban *hukou* does play an important role in shaping country-wide population movement. However, the negative impact of hukou difficulty on migrant workers' residence intention is not linear, and only when the threshold in obtaining *hukou* is too high and difficult to achieve will migrant workers choose to return to their hometown in the long term. Moreover, the subjective evaluation of difficulty is further influenced by personal capability and living conditions in cities. This study provides pragmatic implications for administrations from either push side or pull side to improve habitant-related development strategies.

Keywords: *hukou*; intervening obstacles; long-term settlement intention; migrants; push-and-pull theory

Citation: Li, P.; Wu, Y.; Ouyang, H. Effect of *hukou* Accessibility on Migrants' Long Term Settlement Intention in Destination. *Sustainability* **2022**, *14*, 7209. https://doi.org/10.3390/su14127209

Academic Editors: Mengqiu Cao, Claire Papaix, Benjamin Büttner and Tianren Yang

Received: 2 May 2022
Accepted: 10 June 2022
Published: 13 June 2022

1. Introduction

Since the reform and opening up in China, migrants from rural to urban areas have become an indispensable driving force of China's economic development [1–3]. The growth rate of the migrants slowed down recently but still exceeded 290 million, accounting for 20.8% of the total population in 2019 [4]. Most of them have realized the transition from agricultural to nonagricultural in occupations rather than in their lives because they have not yet obtained urban registered residency (called *hukou* in the following sections), which is an identification document where general household information such as names, marital status and one's place of residence were recorded. Therefore, high difficulty in obtaining an urban *hukou* has been considered as an important factor that prevents migrants from moving to urban areas but also affects their daily life and consumption level [5]. In addition, *hukou* not only has population registration functions but also is an important administrative tool to distribute key welfare such as access to primary and secondary schools, affordable housing and medical insurance reimbursement ratios. The long-standing *hukou* system also prevents migrant workers from integrating into local society and even suffer discrimination from the labour market [6]. The *hukou* system and its subsidiary social welfare distribution system in Chinese cities is accordingly an intervening obstacle in the 'push-and-pull' theory. The research of *hukou*'s impact on long-term settlement intention provides ideal evidence in the effects of institutional intervening obstacle in developing countries, where countries such as China are enduring fast urbanization.

In the past, scholars have constructed a corresponding evaluation index system to measure the difficulty of obtaining *hukou* according to the specific requirements of policies in cities [7–9]. However, this approach is based on the strong assumption that migrants in the same cities feel the same way about the difficulty of obtaining *hukou*, which ignores the heterogeneity of the individual. As an improvement, this paper measures the difficulty of obtaining *hukou* based on respondents' subjective judgments from the survey question: '*How do you think of the requirements for obtaining a local hukou in your current city?*'. In addition, this paper also referred to the experience of previous scholars by exploring the influencing factors and their differences from four dimensions: individual attributes, economic status, mobility characteristics and social integration status.

Specifically, based on a panoramically representative survey in 46 cities in China in 2020, this paper analyses the relationship between the difficulty of obtaining local *hukou* and the long-term settlement intention. Moreover, this paper attempts to quantitatively evaluate for the first time the impact of this obstacle on migrants' long-term settlement intention in urban areas. It contributes to the development of the 'push-and-pull' theory for other economics managing to design wise immigration policies that well balance inbound labor and talent supplies, permanent residency threshold, aging society, and social welfare fund management.

The outline of this paper is as follows: the Section 2 reviews the influencing factors on long-term settlement intention, particularly from the institutional perspective. The Section 3 introduces *hukou* system, its reform process, and explains what makes it an intervening obstacle in the 'push-and-pull' mechanism. The Section 4 presents research data and methodology. The Sections 5 and 6 illustrate the analyses of preliminary and empirical results, respectively, followed by conclusion and policy recommendations.

2. Three Factors That Have Major Impact on Long-Term Settlement Intention

The study on migration behaviour can be traced back to the end of the 19th century [10] and has become quite mature at the present stage. Among them, the factors affecting the long-term settlement of the labour force can be summarized into three aspects: economic, family and destination characteristics factors.

2.1. Economic Perspectives

'Push-and-pull' theory is recognized as one of the earliest theories of population mobility [11]. It suggests the purpose of migration is to improve their living standard [12]. This means that migrants will hesitate to stay in urban regions when their living conditions do not improve or when there are better investment opportunities in their hometown [13]. The other situation is that the expected income of agricultural production is constantly increasing, while the migrants have to bear a lot of potential risks in urban regions. Therefore, they may consider returning to the countryside so that they can also enjoy the happiness of their family [14]. Chinese scholars have long tried to explain the phenomenon of labour mobility in China by push-and-pull theory. For example, Liu established an urbanization population model based on the push–pull theory, which took the GDP, consumption and regional total population as functions, and used the model to predict and analyse the urbanization population of Shaanxi Province [15]. When comparing the influence factors of Chinese internal migration with those of international migration. Li [16] found that underemployment and poverty in rural areas, rapid development of capital-intensive technology in cities, government development policies leaning toward cities, and concentration of economic activities in urban areas are the common pushing and pulling factors.

Unlike the 'push-and-pull' theory, Lewis [17] only focused on the labour migration behaviours from rural agricultural sector to urban industry. His two-sector model emphasizes that the key drive of labour migration is the higher wage level. Compared with the agricultural sector, a higher level of labour productivity in the urban modern industrial sector leads to higher wage. Meanwhile, the urban industrial sector has unlimited ability to absorb the migrant labour force under Lewis' model. Under this strong assumption, labour will reside in urban regions permanently until the end of their working life. In reality, the urban industrial sector has a certain limit to absorb labour. Moreover, with the continuous outflow of labour, agricultural marginal productivity will begin to increase. By then, wages were set by the market, and the agricultural and industrial sectors competed together for labour on the basis of their respective productivity [18]. In this case, the willingness of the labour force to stay in the urban areas depends only on the wage level in both places. In addition, Ranis and Fei [18] also argued that when real wages do not meet their expectations, they will also consider leaving. Many scholars have drawn on the insights of Lewis and Todaro to explain the large flows of rural-to-urban migration in China. They generally agree that the higher wages or expected incomes in urban areas are fundamental drivers of rural to urban migration [19,20].

Economic theories mainly analyse the reasons that hinder the labour force from settling down in the destination from the perspectives of wage level and human capital. These theories imply that migration behaviour is to maximize individual utility. Obviously, they ignore the role of households in the migration process.

2.2. Family Perspectives

Different from the Neoclassical theory, the New Economic of Labour Migration (NELM), which emerged in the 1980s, believes that the pursuit of labour migration is to maximize the benefits of the whole family rather than individual [21]. NELM theory regards labour mobility as family risk-sharing behaviour. As a whole, the family can distribute its labour force in different industries or regions and carry out risk diversification among all family members, minimizing the financial risk level of the whole family. The income of family members is highly complementary and negatively correlated. Therefore, the migrants have the obligation to send their income back or back to supplement the family's needs. On the other hand, migrants also can receive support from his/her family [22]. This theory partly explains the phenomenon of labour mobility even when there is no significant difference in wage income between regions. It suggests that the migration of workers is temporary, and that they will leave their destinations to return to their hometown once they reach the earning target their families expect.

NELM essentially begins to shed the light on the importance of blood relationship on migration behaviour. On this basis, a large number of scholars began to try to explore the issue of labour migration from the perspective of sociology. The life course approach holds that the study of an individual's life should be conducted in the context of a specific society, structure and culture [23], which is increasingly used to study migration behaviours [24]. Scholars have introduced the concept of family solidarity to explain why family ties contribute to migration behaviour [25,26]. This means that there is an obligation and responsibility among family members to take care of those in need. Although migrants provide financial support to the family by moving out to work, this also limits their possibilities for those intergenerational care exchanges [27]. The study found that the vulnerability of left-behind women is increased after husband's migration alone [28]. This vulnerability is reflected in the increase in labour burden and responsibility, emotional damage and other aspects [16]. For instance, studies in Nepal and Pakistan have found that in households where remittances earn less, the burden of labour is heavier for women left behind [29]. Scholars from China and India have studied the mental health of left-behind women and found that their psychological problems, such as psychological pressure and loneliness, are more serious than those of non-left-behind women [30]. Besides that, left-behind children's school performance and unhealthy behaviours (smoking, internet addiction, etc.) are also associated with a lack of parental care [31–33].

2.3. Destination Characteristics Factors

The external factors that influence the long-term migration intention can be divided into two perspectives: the local amenities and institutional factors.

Local facilities are considered to be important factors in destination influencing migration behaviour. When choosing a destination for migration, people are more likely to move to an area with a higher quality of life, even if it is more densely populated and housing prices are higher [34]. The effect of natural amenities such as climate has been tested in the U.S. Based on the data after World War II, Rappaport [34] found that residential movement in U.S. relates to the warm winters. Unnatural amenities also affect migration behaviours. For instance, high-quality consumer goods and services are more conducive to a high human capital migrants' inflow [35]. Education quality at a university also enhances their willingness to stay at a destination as recent graduates have stronger competitive edges locally in earlier career stages [36].

On the other hand, the influence of institutional factors cannot be ignored. The research of western scholars in this aspect focuses on transnational migration. The research on migrants from Albania in Western Europe found that to be true. In these areas, more than 10 percent of the population has gone abroad to work. The income of these people is one of the most important sources of income for their families. However, about 55% of them do not have the legal permanent residence permit, or some have only obtained a short-term job permit. About 70% of them return for good [37]. A study of global asylum applications since 2000 by Hatton [38] found that a third of the decrease in asylum applications to Europe, North America and Australia was due to stricter policies.

Previous studies on China's internal migration have found that *hukou* is the main reason for the weak social status of migrants, which affects their residence intention. Although the *hukou* system has been loosened, allowing migrants to live and work in cities without having to migrate, they still suffer social exclusion because of their household registration status [39]. A study in Hubei province found that because of the *hukou* system, migrants' access to some basic public services are restricted, preventing them from truly integrating into urban areas [40]. When Liu [15] studied the attitudes of local residents towards migrants, he found that local residents generally agree with the contribution of migrants to the local area, but they also hold that migrants should not have the same rights as local people in some public services such as unemployment relief and low-rent housing. Therefore, the *hukou* system not only affects migrants' rights to public services, but also create identity discrimination among residence. The higher the perception of fairness, the stronger the willingness to stay in the city, which even has a moderating effect on the initial willingness to stay [41].

3. The *hukou* System

3.1. The Fundamental Role of hukou System in China

China's *hukou* system essentially performs three functions: population registration, mobility restriction, and competitive welfare restriction.

Population registration function: in 16 July 1951, the Ministry of public security promulgated the *Provisional Regulations on City Household Registration Management*, which established the function of population registration in a registered residence system. Because it defines regulation for social affair management such as birth, death, immigration, relocation, social change and social identity, this function has its counterpart in the *hukou* system in Japan and the social security system in the United States.

Mobility restriction function: Based on the distinction between "agricultural household registration" and "non-agricultural household registration" in the *Household Registration Regulations Of The People's Republic Of China* passed by the Standing Committee of the National People's Congress in January 1958, the provisions of the Ministry of public security on the *Handling of Household Registration Migration (Draft)* "in August 1964 established restrictions on moving from rural areas to cities and market towns; and restrictions on moving from market towns to cities. " Consequently, Chinese cities are regarded collectively as welfare highland, with walls defined. The *hukou* system has become an administrative tool in restricting inbound migrants for long-term settlement.

Competitive welfare restriction function: What makes China's *hukou* system different from other countries' population management systems is that it artificially divides urban welfare according to its competitive attributes in the time when social production is not as high as nowadays. Noncompetitive welfare refers to public goods that have positive externalities, such as the degree of cleanliness of one city, the accessibility of municipal infrastructure and convenience. The number or quality of these benefits does not decline sharply due to the increase in people. Residents, no matter original or newcomer, can enjoy the same level of benefits. Competitive welfare refers to public service that has relatively high incremental cost due to limited professional resources such as teachers and doctors, or dedicated facilities such as schools and hospital beds. These services cover the field of healthcare, compulsory education, affordable housing, etc. The investment on these public services tightly links to local fiscal expenditure that mainly come from land transaction fees and cooperation tax, rather than property tax (this might also explain why municipal administrations are generally keen on inviting investment but are less enthusiastic in inviting population under the current tax system). Therefore, the *hukou* system protects vested population (citizens with local *hukou*) by setting access threshold on competitive benefits, such as public-school qualifications, college entrance examination qualifications, house purchase qualifications, car purchase qualifications, and medical insurance reimbursement ratios.

Under the current system, the mobility restriction function of registered residence system makes it possible to maintain the basic functions of a city and maintain public order. Through the administrative control of settlement conditions, settlement procedures and annual *hukou* quotas, cities are able to handle corresponding demand according to their own public service carrying capacity.

3.2. hukou Is an Intervening Obstacle in the 'Push-and-Pull' Theory

During the development of the 'push-and-pull' theory, E.S. Lee [12] argued that the mobility of migrants is not only affected by the 'push' and 'pull' factors from their hometown and destination but is also affected by intervening obstacles, such as distance and transportation between hometown and destination, cultural and dietary differences and the immigration laws.

The competitive welfare restriction function theoretically makes *hukou* an intervening obstacle besides the 'push-and-pull' mechanism, because it does not restrict migrants from entering the urban labor market at the present stage but restricts their right to obtain equal public services (esp. competitive welfare that are fundamental in access equal local development opportunity) in the city. For instance, participation in the middle school entrance examination and college entrance examination outside migrants' children's *hukou* registration place have been challenging. First, they are required to provide evidence that their parents are legally domiciled and employed locally (e.g., most provinces stipulate that in order to take the exam in the destination, the children who have migrated with parents need to provide a certificate of residence of their parents, a proof of stable occupation and a number of years of social security payment from their parents). Second, most cities do not open all types of public secondary schools to the children of migrants. Megacities such as Beijing, Shanghai and Tianjin only allow children of migrants to take entrance exams of secondary vocational schools.

3.3. The Reform of hukou System

The establishment of *hukou* system can be traced back to 1958, when the Standing Committee of the National People's Congress passed the Household Registration Ordinance. It stipulated that "citizens migrating from rural areas to urban areas must hold an employment certificate, a certificate of enrolment from educational institutions, or a permission document from the urban household registration authority". From the 1960s to the 1970s, the *hukou* system saw strengthened restrictions on the movement of people between urban and rural areas legally. For example, in 1964, the Ministry of Public Security issued regulations to restrict population movement from two aspects: (1) from rural areas to cities; (2) from towns to cities.

Due to China's market-oriented reform in the 1990s, the rapid development of urban industry led to an increasing demand for labour, which provided incentive for the reform of the *hukou* system to gradually expand from small towns to cities. The State Council approved pilot schemes for reforming the *hukou* administration system in small towns in 1997, allowing rural residents who already work and live in small towns and meet certain conditions to apply for permanent *hukou* locally. After 2000, some local governments began to explore the path of household registration reform in cities. Cities such as Shenyang and Anshan introduced policies in 2010 to encourage talented people to transfer their *hukou* [42].

In recent years, the state has accelerated the reform of the *hukou* system. In 2013, the promulgation of the CPC Central Committee on reform of the overall number of major issues signifies the beginning of the systematic reform of the *hukou* system. In 2014, the State Council issued a guideline on the reform of the *hukou* system, which stated that by 2020, about 100 million migrants and other permanent residents would be encouraged to register as urban residents [43]. In 2019, the National Development and Reform Commission issued the *Key Tasks for New Urbanization Construction*. Under the plan, cities with a population under 3 million should remove all limits on *hukou*—household registration—and cities with populations between 3 million and 5 million should relax restrictions on new migrants [43]. Table 1 shows the relevant documents and main contents of *hukou* reform in recent years.

Table 1. The timeline of *hukou* system reform by city scales.

Documents	Key Contents					
	Megacities	**Super Cities**	**Type I Big Cities**	**Type II Big Cities**	**Medium Sized Cities**	**Small Cities**
	More than 10 Million	**5 to 10 Million**	**3 to 5 Million**	**1 to 3 Million**	**500,000 to 1 Million**	**Below 500,000**
CPC Central Committee on reform of the overall number of major issues (11/2013)	Strictly control the size of the population		Establish reasonable requirement for household registration		Lifted the restrictions in an orderly manner	Fully lift restrictions on household registration
13th Five-Year Plan-the plan to help 100 million migrants settle in cities (09/2016)	Megacities and super cities with a low household registration share should further reduce the requirements for the *hukou* of migrants		The requirement on social security should not exceed 5 years		The requirement on social security should not exceed 3 years	
			The household registration requirements such as housing purchases and investment taxes were abolished			
				Points system for household registration was abolished		
Key Tasks on Urbanization in 2019 (04/2019)	Improved the points system based on residence years and participation in social security		Restrictions in key groups will be lifted across the board	Fully lift restrictions on household registration		
Opinions of the CPC Central Committee and the State Council on Improving the Systems and Mechanisms for Market-based Allocation of Factors of Production (03/2020)	1. Megacities and super cities will continue to adjust and improve points-based household registration policies. 2. Promote mutual recognition of household registration requirements in urban agglomerations such as the Yangtze River Delta and the Pearl River Delta. 3. Continue to relax restrictions on urban household registration except in some mega-cities.					
Key Tasks on Urbanization and Urban-Rural Integrated Development in 2020 (04/2020)	Continue to improve the point-based household registration policies in megacities and Type I big cities, and ensure that the number of years of social security payment and residence accounts for the main proportion.			Urge those three types of cities to fully lift restrictions on *hukou*.		

4. Data and Methods

4.1. Data

A survey of migrants' long-term residence intention was conducted in April 2020. Questionnaires were handed out randomly in four types of location—the four first-tier global cities, cities in developed coastal regions, other provincial capitals/subprovincial cities, other prefecture-level cities (Table 2 and red dots in Figure 1). The selection of survey locations was based on popularity of the city in attracting cross-region migration. A total of 23,381 surveys were collected, 99.36% (23,232) of which were valid.

Table 2. Four types of cities surveyed.

Regions	Cities	Observation	Percentage
First-tier global cities (4)	Beijing, Shanghai, Guangzhou, Shenzhen	2529	10.89%
Coastal cities (7)	Dongguan, Jiaxing, Nantong, Suzhou, Taizhou (Jiangsu province), Taizhou (Zhejiang province) and Zhongshan	3420	14.72%
Provincial capitals and sub-provincial cities (14)	Chengdu, Dalian, Guiyang, Hangzhou, Jinan, Nanjing, Ningbo, Qingdao, Shenyang, Wuhan, Xian, Changsha, Zhengzhou and Chongqing	8056	34.68%
Prefecture-level cities (21)	Anyang, Baoji, Heze, Jinhua, Linyi, Luoyang, Nanchong, Shantou, Shangqiu, Weifang, Wenzhou, Xiangyang, Xuzhou, Yantai, Yan' an, Yichang, Yingkou, Yulin, Zhoukou, Zhuzhou, Zunyi	9227	39.72%
Total		23,232	100%

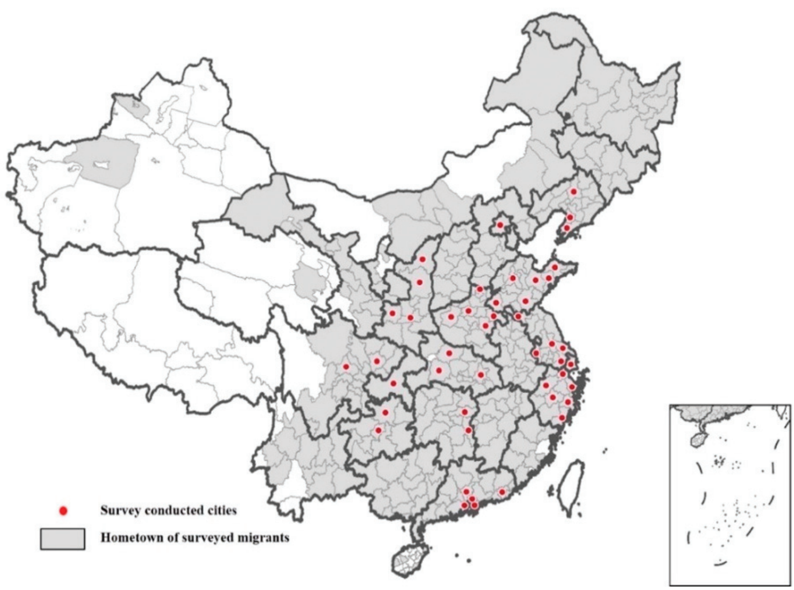


Figure 1. Distribution of cities surveyed and where surveyed migrants come from.

In our survey, 6973 respondents said they were not sure of their long-term residence intentions and were therefore not considered in this study. In addition, 895 respondents that did not answer questions about the difficulty of the local household registration system were also discarded. Finally, 10 respondents did not provide valid information required for some independent variables and were then discarded. Thus, the final valid observations were 15,355 covering all 46 surveyed cities. These respondents came from 304 prefecture-level cities (90.2% of the total 337 mainland prefecture-level cities in 2020). The distributions of regions and demographic characteristics of these 15,355 observations and the whole observations did not display significant statistical differences. It suggests that our sample could be legitimately used to reflect the nature of the whole sample.

4.2. Methodology

In order to better understand the long-term residence intention of migrants in China, this paper mainly adopts two quantitative research methods, descriptive statistical analysis and binary logistic regression modeling. In our case, we defined the dependent variable 'long-term settlement intention' based on the question, '*What are your long-term residence plans in the future?*'. The respondents who choose '1. Purchase commercial housing locally. 2. Rent a house locally. 6. Stand in line to apply for affordable housing locally' have settlement intention in destination in long-term. The difficulty of obtaining a local *hukou* is considered as the key dependent variable in our study, which is based on the question '*How do you think of the requirements for obtaining a local hukou in your current city?*'. Other control variables include personal characteristics (gender, education, marital status, age and land right in hometown), migration characteristics (employment, income level and migration duration of migration) and destination characteristics (Ln (GDP per Capita), education resources and medical resources) (see Table 3 for summaries).

Table 3. Socioeconomic characteristics and long-term settlement intention of the sample studied.

(Observation = 15,355)					
Variable	**Description**	**Mean/Percentage**	**Std. Dev**	**Min**	**Max**
	Dependent Variable				
Settlement intention	Local Hometown	0: 64.44% 1: 35.56%	-	1	2
	Independent Variables				
Subjectively evaluated difficulty in obtaining *hukou* in migrant destination (will be called *hukou difficulty* afterward)	Not difficult A bit difficult Very difficult	0:16.39% 1:42.00% 2:41.62%	-	1	3
Gender	Male Female	0:40.28% 1:59.72%	-	1	2
Education	Below College College and above	1:60.81% 2:39.19%	-	1	2
Marital Status	Unmarried Married	1:22.85% 2:77.15%	-	1	2
Age (Mean)		35	8.29	17	71
Whether own land in hometown	No Yes	1:46.49% 2:53.51%	-	1	2
Employment	Unemployed General staff Senior manager Employer	1:14.48% 2:77.14% 3:7.16% 4:1.22%	-	1	4
Income Level	Less than 3500 3501–5000 5001–8000 over 8000	1:41.46% 2:35.62% 3:17.70% 4:5.22%	-	1	4
Distance	Within City Cross city Interprovincial	48.49% 19.26% 32.24%	-	1	3
Duration	less than 1 year 1–5 years over 5 years	1:11.30% 2:26.55% 3:62.16%	-	1	3
Regions	Eastern Central Western	1:61.54% 2:20.81% 3:17.65%	-	1	3
Ln (GDP Per Capita)		10.80	0.17	9.98	12.15
Education Resources	The number of schools (per 10,000)	1.34	0.41	0.6	6.2
Medical Resources	The number of hospitals (per 10,000)	46.52	18.06	10.96	84.12

The binary logistic model works by adapting the standard random utility model to our specific problem of resident intention choice as follows:

$$U_{ij} = \beta_j X_{ij} + \varepsilon_{ij} \quad (1)$$

where i refers to the individual and j to the type of intention. X_{ij} is a vector of independent variables such as gender, age, education, etc.) and ε_{ij} is a stochastic error component. Then the probability of choosing a given alternative can be shown as

$$\mathrm{P_j} = P_r(U_{ij} > U_{ik}), \forall k \neq j \quad (2)$$

Obviously, the sum of the four probabilities must equal 1,

$$\sum_{j=1}^{J} P_{ij} = 1 \quad (3)$$

Then, followed Long and Freese (2005), the multinomial logit model is given as follows:

$$P_{ij} = \frac{\exp(\beta_j X_{ij})}{\sum_{j=1}^{J} \exp(\beta_j X_{ij})} \quad (4)$$

Finally, the estimation of parameter β_j is solved by using the maximum likelihood estimation methods operationalized with Stata.

5. Preliminary Analysis

5.1. Basic Characteristics and Long-Term Settlement Intention

Overall, Chi square test showed that the difference in all variables across groups (hometown and local) was statistically significant ($p < 0.05$). In terms of personal characteristics, about 56.05% of migrants are male in the local group, more than 10 percent points lower than the hometown group. It suggests that male workers are more likely to return to their hometown (see Table 4). Moreover, compared with the hometown group, a higher proportion of unmarried and young workers choose to stay locally. Moreover, well-educated (College and above) migrants are more likely to stay rather than return. About 47.29% of migrant workers have college and above degrees in the local group, about 23 percentage points higher than the return group. Migrants who have land rights in their hometown seems more likely to return than stay. Nearly 49% of workers in the local group state that they own lands in their hometown, 13 percent points lower than the return group.

Considering migration characteristics, 11.2% of workers in local group are unemployed, 6 percentage points lower than the return group (see Table 4). In terms of income level, the low-income level (less than 3500 RMB per month) takes up a higher proportion in the local group than the hometown group. This indicates that migrants with lower income level might be more willing to return home in the long-term. Migrants who have been local for more than five years are more likely to stay. A total of 65.37% of migrants in the local group have been living locally more than 5 years, over 9 percentage points higher than the hometown group. Lastly, as the distance increased, migrants were more likely to return home. Table 4 indicates that among respondents in the returning group, 42.25% were long-distance interprovincial migrants to other provinces, a significantly higher proportion than the local group.

Destination characteristics also differ between the two groups. In terms of regions, eastern migrants accounted for 59.27% in local group, more than 6 percent lower than the hometown group (see Table 4), which suggests that migrants in eastern China have a stronger desire to return home than other regions. It is worth noting that economic status of two groups has not much difference according to GDP. Finally, Table 4 shows that the medical and educational resources in the cities of migrant workers who are willing to return home are slightly lower than those of migrant workers who are willing to stay in local areas.

Table 4. Basic characteristics of migrants by different long-term settlement intention.

Basic Characteristics		Hometown	Local
Gender%	Female	33.64	43.95
	Male	66.36	56.05
Marital Status%	Unmarried	20.64	24.07
	Married	79.36	75.93
Age (Mean)		34	36
Education%	Below College	75.48	52.71
	College and above	24.52	47.29
Whether own land in hometown%	No	38.03	51.15
	Yes	61.97	48.85
Employment%	Unemployed	18.79	12.10
	General staff	74.14	78.80
	Senior manager	6.04	7.78
	Employer	1.03	1.32
Income Level%	Less than 3500	38.29	43.21
	3501–5000	38.23	34.18
	5001–8000	18.59	17.21
	over 8000	4.89	5.40
Duration%	less than 1 year	15.64	8.90
	1–5 years	28.04	25.72
	over 5 years	56.33	65.37
Distance%	Within City	38.09	54.23
	Cross City	16.66	20.70
	Inter provincial	45.25	25.07
Regions%	Eastern	65.65	59.27
	Central	19.90	21.32
	Western	14.45	19.42
Ln (GDP in Capita) (mean)		10.80	10.81
Education Resources at hometown(mean)	The number of schools (per 10,000)	1.37	1.32
Medical Resources at hometown(mean)	The number of hospitals (per 10,000)	41.41	37.29

5.2. What Kind of People Think It Difficult to Get a Local hukou?

This part of the analysis preliminarily presents *hukou difficulty* among different socioeconomic groups. As shown in Table 5, for migrants with different education levels, 48.60% of migrants with low educational background perceive that it is too difficult to obtain local *hukou* currently, and this figure gradually decreases with the level of education increase. Only 30.77% of migrants with college degree or above have the same feeling. On the other hand, 47.72% of well-educated migrants find it a bit difficult to obtain a local *hukou* but believe that they would meet the requirements in the future. It suggests that the current *hukou* condition still casts hurdle for migrants with lower education levels.

In terms of income, as the income level rises, it becomes less difficult for migrants to obtain a local *hukou*. A total of 41.08% of migrants in low-income group (less than 3500) believe that the current *hukou* condition is too difficult for them. This figure did not change much in the wage range between 3501 and 8000. However, as the income level reaches 8000, the proportion of migrants who perceive *hukou* difficulty as high drop to 34.45%, which is significantly lower than other income groups.

Table 5. Subjective evaluation of difficulty in obtaining local hukou by demographic characteristics.

		Not Difficult	a Bit Difficult	Very Difficult
Education%	Below College	13.09	38.31	48.60
	College and above	21.50	47.72	30.77
Income Level%	Less than 3500	16.60	42.32	41.08
	3501–5000	15.59	41.17	43.24
	5001–8000	16.52	41.76	41.72
	over 8000	19.60	45.94	34.46
Living Conditions%	Houseowner	27.21	52.01	20.78
	Renting	10.24	36.83	52.93
	Dorms or others	11.82	37.15	51.03
Duration%	less than 1 year	10.37	35.27	54.35
	1–5 years	14.38	41.54	44.09
	over 5 years	18.34	43.42	38.24

According to the current *hukou* policy, purchasing a house locally is still one of the key approaches in obtaining *hukou* in some cities. Table 5 also shows the attitudes of migrants towards *hukou* with different living conditions. First, only 20.78% migrants who own houses in destinations think it is too difficult to obtain a *hukou*. This number goes over 50% in other two groups (renting and living in dorms). This result might be due to the existence of survivor bias. On the one hand, buying a house might help migrants to gain a local *hukou* easier; on the other hand, it is likely that migrants themselves find it is not difficult to gain a local *hukou*, so they are willing to buy a house locally.

In terms of migration duration, with the increase in migration duration, the proportion of migrants who perceive obtaining local *hukou* as very difficult showed a downside trend, decreasing from 54.35% to 38.24%. This might be because of the recent *hukou* reform's emphasis on duration-orient policy, based on living duration and working duration locally. Consequently, as duration in destination increases, the chance of satisfying local requirement in obtaining *hukou* goes higher.

6. Empirical Analyses

6.1. Modelling the Long-Term Settlement Intention in China

In order to better understand influencing factors of residence intention, this paper establishes four binomial logistic models with residence intention as the dependent variable. Model 1 includes only the subjectively evaluated *hukou* difficulty as an independent variable. Variables of personal characteristics, migration characteristics and destination characteristics were successively added in Model 2 to Model 4 on the basis of Model 1 (see Table 6). The explanatory power of Model 1 to Model 4 was gradually enhanced according to the Pseudo R2.

In Model 1, key independent variable *hukou* was introduced. The positive coefficient suggested that compared with migrants who feel it is not difficult to obtain a local *hukou*, those who find it difficult are more likely to stay in the destination for a long term, but this result is not statically significant. Moreover, the negative value of *very difficult* variable meaning that migrants who found that it is very difficult to obtain a *hukou* locally were more likely to return to their hometowns than to stay is a result that was statistically significant. However, endogenous issues might exist in this simple regression, which mainly comes from the missing variables at the city and individual levels. For instance, *hukou* threshold is closely related to city characteristics such as the economy, population and industrial development. The more developed a city's economy is, the more intensive its industries are, consequently the more attractive it would be to migrants, and the higher the threshold of household registration would be (due to the constraints of population carrying capacity and management capacity of the city). In Model 2–4, the characteristic variables at the individual, migration and destination levels are gradually controlled, which significantly alleviates endogenous problems caused by the omission of variables. The coefficients of *hukou* difficulty are becoming significant in both 'a bit difficult' and 'very difficult'. This indicates that when migrants find it a little difficult to obtain a local *hukou*, but they can meet the requirements later, they are more willing to stay in the destination for a long time. However, when migrant workers find it is very difficult to meet the *hukou* requirements, they tend to return home in the future rather than stay locally.

Table 6. Binomial logistic regression on influential factors of the long-term settlement intention (Ref = Hometown).

Long Term Residential Intention	Model 1	Model 2	Model 3	Model 4
hukou (Ref = Not Difficult)				
A bit difficult	0.0205	0.0642	0.150 **	0.162 **
	(0.40)	(1.20)	(2.75)	(2.96)
Very difficult	−0.701 ***	−0.546 ***	−0.270 ***	−0.232 ***
	(−13.86)	(−10.39)	(−4.91)	(−4.18)
Marital Status (Ref = Unmarried)				
Married		0.0196	−0.124 *	−0.134 **
		(0.41)	(−2.44)	(−2.62)
Age		−0.00674 **	−0.0143 ***	−0.0136 ***
		(−2.72)	(−5.51)	(−5.21)
Gender (Ref = Female)				
Male		−0.289 ***	−0.258 ***	−0.277 ***
		(−7.72)	(−6.49)	(−6.90)
Education (Ref = Below college)				
College and Above		0.823 ***	0.715 ***	0.722 ***
		(20.44)	(17.00)	(17.05)
Land Right (Ref = Without)				
With		−0.337 ***	−0.317 ***	−0.313 ***
		(−8.96)	(−8.24)	(−8.11)
Migration Duration (Ref = Less than 1 year)				
1 to 5 years			0.314 ***	0.342 ***
			(5.02)	(5.44)
Over 5 years			0.606 ***	0.640 ***
			(10.03)	(10.54)
Migration Distance (Ref = Within City)				
Cross City			−0.118 *	−0.0625
			(−2.34)	(−1.20)
Interprovincial			−0.730 ***	−0.622 ***
			(−16.60)	(−12.97)
Income (Ref = less than 3500)				
3501–5000			−0.137 **	−0.123 **
			(−3.19)	(−2.84)
5000–8000			−0.0914	−0.0772
			(−1.63)	(−1.35)
Over 8000			0.0652	0.0750
			(0.71)	(0.81)
Employment (Ref = Unemployed)				
General staff			0.256 ***	0.270 ***
			(4.96)	(5.18)
Senior manager			0.365 ***	0.434 ***
			(4.08)	(4.81)
Employer			0.553 **	0.573 **
			(3.17)	(3.27)
Destination Region (Ref = Eastern)				
Central Region				0.00941
				(0.18)
Western Region				0.120 *
				(2.20)
LnGDP				0.297 **
				(2.64)
Doctor				−0.00711 ***
				(−5.74)
School				−0.297 ***
				(−6.45)
_cons	0.895 ***	1.110 ***	1.001 ***	−1.681
	(20.37)	(10.94)	(8.23)	(−1.38)
N	15355	15355	15355	15355
Pseudo R2	0.022	0.0639	0.0914	0.0969

t statistics in parentheses; * $p < 0.05$ ** $p < 0.01$ *** $p < 0.001$.

According to the regression results of Model 4, individual characteristic variables have significant impacts on long-term residence intention in destination. Compared with female migrants, male migrants are less likely to stay in the destination. This result is inconsistent with Siu and Unger's findings; they argue that female immigrants do not have much advantage in the labour market, so they are more inclined to stay at home to take care of children and the elderly [44]. One of the possible explanations is that male migrants are more likely to migrate alone, while other family members, such as children and wives, are left behind in hometowns. Thus, male migrants are likely to have a stronger desire to return to their hometown in the long-term. Compared with low-educated migrants, the stay intention of migrants with higher education is stronger and statistically significant. This may be because well-educated migrants are more competitive in the labour market and can better adapt to local life so that they are more willing to stay in the long-term. The results of Model 4 also show that married and aged migrants show less inclination to stay. The odds ratio of land variable is 0.786, indicating that migrants with land rights in their hometown are more inclined to return in the long-term.

Four migration characteristic variables in the model also showed significant correlations with residence intention. Compared with migrant workers who are unemployed, migrant workers with stable employment have a stronger desire to stay in local areas for a long time. It is also worth noting that the higher the position of migrant workers, the stronger the intention of residence. In terms of income level, compared with the reference group whose income level was less than 3500, migrants who earn from 3500 to 5000 are less likely to stay, but the medium and high-income (over 5000) group were not statistically significant. With the increase in migration duration, migrants are more inclined to stay in the destination. This match anecdotal experience that the longer the migrants stays in the local area, the more stable the local social network and living state will be, the stronger the social adaptability to the local will be, and the stronger the residence intention will be. Moreover, the increasing magnitude of migration distance suggests that there is a linear negative relationship between migration distance and migrant workers' stay intention in the destination, but it is not statically significant for medium-distance cross-city migration.

Migrant's stay intention in the destination is also related to destination characteristics. The coefficients of central and western regions variables indicate that migrants who migrate to these two regions are more willing to stay in the local area than those in the eastern region, but it is not significant for the central region. This may be due to the low level of living costs and housing prices in the western region, which encourage migrants to stay in the long term. A stronger level of economic development (GDP per capita) will also significantly enhance migrants' willingness to stay. The main reason is that economic growth will lead to an increase in job opportunities, which will attract migrants to stay in their destinations. Finally, consistent with the preliminary result, there is a negative correlation between education and medical resources and migrants' willingness to stay, that is, the higher the level of these two resources, the more reluctant migrants are to stay. One possible explanation for this result is that at present, the allocation of several key public resources is mainly based on *hukou* in most cities. Migrants without a local *hukou* therefore have to pay a higher price to access many public resources, such as medical fee. Therefore, the unequal distribution of public resources caused by the *hukou* system restrains migrants' willingness to stay.

6.2. Robustness Check

Based on the above analysis of the current *hukou* system reform, the objective difficulty of obtaining local *hukou* is related to the city scale (see Table 1). Therefore, the robustness test of this part will follow that of previous scholars [8,9] and take objective difficulty (i.e., city scales) as the core dependent variable to further examinate the relationship between *hukou* accessibility and long-term settlement intention. Specifically, we divided the sample cities into three levels according to their population size. More specifically, we divided the sample cities into three levels according to their scale:

Level 1 (most difficult): Beijing, Shanghai, Guangzhou, Shenzhen.

Level 2 (a bit difficult): Shenyang, Chengdu, Hangzhou, Jinan, Ningbo, Qingdao, Suzhou, Wuhan, Xian, Changsha, Chongqing.

Level 3 (not difficult): The rest of the cities.

Interestingly, the results of Model 5 in Table 7 are similar to those of our models above. To be specific, taking migrants in cities without *hukou* threshold (Not difficult) as a control group, those in cities with certain *hukou* difficulty tend to stay local, but this result is not significant. However, for migrants in Beijing, Shanghai, Guangzhou and Shenzhen, their willingness to stay in their destinations for a long time is weakest, and they are more inclined to return to their hometown. The results of the rest of the control variables are the same as those above and will not be repeated here.

Table 7. Binomial logistic regression on influential factors of the long-term settlement intention (Ref = Hometown).

Long Term Residential Intention	Model 5
hukou (Ref = Not Difficult)	
A bit difficult	0.001
	(0.01)
Very difficult	−0.485 ***
	(−6.47)
Marital Status (Ref = Unmarried)	
Married	−0.136 **
	(−2.66)
Age	−0.0131 ***
	(−5.01)
Gender (Ref = Female)	
Male	−0.300 ***
	(−7.47)
Education (Ref = Below college)	
College and Above	0.767 ***
	(18.24)
Land Right (Ref = Without)	
With	−0.316 ***
	(−8.19)
Migration Duration (Ref = Less than 1 year)	
1 to 5 years	0.369 ***
	(5.87)
Over 5 years	0.674 ***
	(11.10)
Migration Distance (Ref = Within City)	
Cross City	−0.107 *
	(−2.06)
Interprovincial	−0.671 ***
	(−14.20)
Income (Ref = less than 3500)	
3501–5000	−0.120 **
	(−2.76)
5000–8000	−0.0510
	(−0.90)
Over 8000	0.124
	(1.35)
Employment (Ref = Unemployed)	
General staff	0.291 ***
	(5.58)
Senior manager	0.461 ***
	(5.11)
Employer	0.623 ***
	(3.56)
Destination Region (Ref = Eastern)	
Central Region	−0.0269
	(−0.51)
Western Region	0.0994
	(1.78)
LnGDP	0.302 **
	(2.69)
Doctor	−0.00357 *
	(−2.39)
School	−0.273 ***
	(−5.58)
_cons	−1.922
	(−1.58)
N	15355
Pseudo R2	0.0947

t statistics in parentheses; * $p < 0.05$ ** $p < 0.01$ *** $p < 0.001$.

7. Conclusions

Since the reform and opening up, due to the differences in economic development between urban and rural areas and between regions in China, a large number of migrant workers have flowed from rural areas to cities and from central and western regions to eastern regions. Unable to obtain local *hukou* (household registration), they are not truly local and cannot enjoy their fair share of local public resources. Since 2013, the household registration system has been further reformed. This study advances the body of knowledge by investigating the effect of what E.S. Lee has proposed 'intervening obstacles' in the 'push-and-pull' theory. Based on a nation-wide large-scale survey in 46 Chinese cities, this paper studies the relationship between the difficulty of obtaining a local *hukou* and long-term residence intention. The main conclusions are as follows.

First, an investigation on influence factors on migrants' subjective evaluations on *hukou difficulty* presents that migrants with low education, low income and no property in destination might be vulnerable under the current *hukou* system. This implies that the current *hukou* system mainly unfriendly to migrant workers with low human capital and weak economic conditions.

Second, if other control variables remain unchanged, this paper found that the negative impact of *hukou* difficulty on migrant workers' residence intention is not linear, and only when the threshold in obtaining *hukou* is too high and difficult to achieve will migrant workers choose to return hometown in the long term. This may indicate that after nearly 10 years of household registration (*hukou*) system reform, most cities have gradually achieved equal access to basic public services, and migrant workers can enjoy more public services than before, though not necessarily the same as the local. As a result, *hukou* in many cities is no longer the decisive factor in determining whether migrant workers will stay in the destination for a long time. However, although China's household registration system (*hukou*) reform has been improving, it still hinders migrants' residence intention to some extent and has considerable potential to be optimized. We believe that current household registration (*hukou*) system has two influences on migrants' residence intention: first, migrants who without local *hukou* cannot enjoy public services such as medical services and social security services equally with local people; also, migrants without local *hukou* cannot easily reunite with their families locally because they do not have access to local public resources such as public schools for their children equally. Moreover, the long-standing *hukou* system leads to the lack of parental companionship and care for left-behind children, which has a negative impact on their physical and mental health [45]. That may encourage migrant workers to return home in the long term. In this sense, the application of E.S. Lee's 'intervening obstacles' in the push–pull theorem could be extended to administrative barriers. The mechanism of this obstacle is, however, not as linear as physical distance might do. This provides implication for countries and regions within country globally to facilitate immigration policies and designation of benefits granted to non-citizen. Further research on the threshold that influence residence intention is necessary to collect more empirical evidence for this viewpoint.

Finally, the results of our model show that the human capital level of migrant workers, such as educational background and income level, is negatively correlated with residence intention. This may be because they have always been on the margins of local society and have been unable to integrate into local society due to the restrictions of the *hukou* system.

In terms of policy suggestions, the author suggests that future urban development strategies should give more consideration to migrants, especially in the distribution of educational resources, medical resources and other welfare. Thus, it can promote migrant workers to better integrate into the local society and enhance their willingness to stay. In particular, three policy tools are proposed in line with the findings. First, an 'intervention unobstructed tool' needs to be implemented to hedge the current obstacles. In detail, the current residence permit (similar to greencard that allows migrants who reside in destination for more than half year but have not yet obtained local *hukou*) system is suggested to upgrade so that non-*hukou* migrants could enjoy key settlement benefits in cities, including safe, clean, affordable housing, equal compulsory education opportunity regardless of parental *hukou* status, higher medical insurance reimbursement ratios. Second, investment on public services and facilities needs to be based on settle population size, rather than size of population with local *hukou*. Third, distribution of national fiscal and land resources in this field is suggested to shift from GDP and income level base to inbound migrants' size base, in order to match the service and settlement demand of incremental migrants under the current taxation schemes in urban China.

There are also some obvious limitations in our research. For example, the sampling time of this study is from 2020. Due to the impact of COVID-19, many migrant workers could not go out for work normally and even chose to return to their hometown, thus causing some deviation in the results. Moreover, the objects of our study are local migrant workers. Migrant workers who have returned to their hometown are not considered, so the problem of survivor bias will also occur in this research.

Author Contributions: Conceptualization, H.O.; Formal analysis, Y.W.; Methodology, P.L.; Project administration, P.L.; Resources, H.O.; Supervision, Y.W.; Writing—review & editing, P.L. All authors have read and agreed to the published version of the manuscript.

Funding: This research is funded by the National Social Science Fund (NSSF) Major Program with Grant No. 22ZDA056.

Institutional Review Board Statement: The study was conducted in accordance with the Declaration of Helsinki, and approved by the Institutional Review Board of Institute of Spatial Planning and Regional Economy of the Chinese Academy of Macroeconomic Research (30 May 2021).

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: The data presented in this study are not publicly available to protect the privacy of the study's participants.

Acknowledgments: Yufeng Wu would like to thank Rong Zhou for her comments on an earlier draft of this paper.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Zhang, G.S.; Tian, Z.Y. China's Rural Labor Mobility in the 40 Years of Reform and Opening-up: Changes, Contributions and Prospects. *Issues Agric. Econ.* **2018**, *6*, 23–35.
2. Cai, F.; Wang, D.W. Sustainability of economic growth and labor contribution in China. *Econ. Res. J.* **1999**, *10*, 62–68.
3. Wu, S.L. The Contribution of Agricultural Labor Migration to Economic Growth in China. *Econ. Res. J.* **2016**, *2*, 97–110.
4. National Bureau of Statistics in China. 2020. Available online: http://www.stats.gov.cn/english/ (accessed on 17 January 2021).
5. Tan, J.; Xu, H.; Yu, J.; Radu, V. Consumption and savings of migrants in China–social cohesion perspective. *Econ. Res.-Ekon. Istraživanja* **2021**, 1–18. [CrossRef]
6. Huang, B.; Zhu, Y. Higher Education Expansion, the Hukou System, and Returns to Education in China. IZA Discussion Paper No. 12954. 2020. Available online: https://papers.ssrn.com/sol3/papers.cfm?abstract_id=3542623 (accessed on 1 May 2022).
7. Wang, M.W.; Lu, E.P. Household registration status, social capital and household financial investment. *South China Financ.* **2017**, *8*, 11–20.
8. Zhang, J.P.; Lu, C. A Quantitative Analysis on the Reform of Household Registration in Chinese Cities. *China Econ. Q.* **2019**, *18*, 10–30.
9. Zhang, J.; Huang, J.; Wang, J.; Guo, L. Return Migration and Hukou Registration Reform in Chinese Cities. *Econ. Res. J.* **2020**, *7*, 175–189.
10. Ravenstein, E.G. The laws of migration. *J. Stat. Soc. Lond.* **1885**, *48*, 167–235. [CrossRef]
11. Tobler, W. Migration: Ravenstein, Thornthwaite, and beyond. *Urban Geogr.* **1995**, *16*, 327–343. [CrossRef]
12. Lee, E.S. A theory of migration. *Demography* **1966**, *3*, 47–57. [CrossRef]
13. Murphy, R. *How Migrant Labor Is Changing Rural China*; Cambridge University Press: Cambridge, UK, 2002.
14. Lucas, R.E.B.; Stark, O. Motivations to Remit: Evidence from Botswana. *J. Political Econ.* **1985**, *93*, 901–918.
15. Liu, L.P. Communication and Attitude: Migrants in the Eyes of Urban Residents. *J. Sun Yat-Sen Univ. (Soc. Sci. Ed.)* **2008**, *48*, 183–192.
16. Li, C.; Liu, H.; Jia, D.; Jia, H.; Zhang, J.; Liu, X.; Qi, M.; Wang, F. Survey of marital quality in left-behind and non-left-behind women. *Chin. Ment. Health J.* **2014**, *28*, 283–287.
17. Lewis, W.A. Economic development with unlimited supplies of labour. *Manch. Sch.* **1954**, *22*, 139–191. [CrossRef]

18. Ranis, G.; Fei, J.C. A theory of economic development. *Am. Econ. Rev.* **1961**, *51*, 533–565.
19. Zhao, Y. Leaving the Countryside: Rural-to-urban Migration Decisions in China. *Am. Econ. Rev.* **1999**, *89*, 281–296. [CrossRef]
20. Zhang, K.H.; Song, S. Rural-urban Migration and Urbanization in China: Evidence from Time-series and Coss-section Analyses. *China Econ. Rev.* **2003**, *14*, 386–400. [CrossRef]
21. Stark, O.; Bloom, D.E. The new economics of labor migration. *Am. Econ. Rev.* **1985**, *75*, 173–178.
22. Stark, O.; Taylor, J.E. Migration Incentives, Migration Types: The Role of Relative Deprivation. *Econ. J.* **1991**, *101*, 1163–1178. [CrossRef]
23. Elder, G.H., Jr.; Johnson, M.K.; Crosnoe, R. The emergence and development of life course theory. In *Handbook of the Life Course*; Springer: Boston, MA, USA, 2003; pp. 3–19.
24. Coulter, R.; Ham, M.V.; Findlay, A.M. Re-thinking residential mobility: Linking lives through time and space. *Prog. Hum. Geogr.* **2016**, *40*, 352–374. [CrossRef]
25. Rossi, P.H.; Rossi, A.S. *Of Human Bonding: Parent-Child Relations across the Life Course*; Aldine de Gruyter: New York, NY, USA, 1990.
26. Bengtson, V.L.; Roberts, R.E. Intergenerational solidarity in aging families: An example of formal theory construction. *J. Marriage Fam.* **1991**, *53*, 856–870. [CrossRef]
27. Kõu, A.; Mulder, C.H.; Bailey, A. 'For the sake of the family and future': The linked lives of highly skilled Indian migrants. *J. Ethn. Migr. Stud.* **2017**, *43*, 2788–2805. [CrossRef]
28. Gulati, L. Coping with male migration. *Econ. Political Wkly.* **1987**, *22*, WS41–WS46. Available online: https://www.jstor.org/stable/4377661 (accessed on 1 May 2022).
29. Smith-Estelle, A.; Gruskin, S. Vulnerability to HIV/STIs among rural women from migrant communities in Nepal: A health and human rights framework. *Reprod. Health Matters* **2003**, *11*, 142–151. [CrossRef]
30. Burazeri, G.; Goda, A.; Tavanxhi, N.; Sulo, G.; Stefa, J.; Kark, J.D. The health effects of emigration on those who remain at home. *Int. J. Epidemiol.* **2007**, *36*, 1265–1272. [CrossRef]
31. Giannelli, G.C.; Mangiavacchi, L. Children's schooling and parental migration: Empirical evidence on the 'left-behind'generation in Albania. *Labour* **2010**, *24*, 76–92. [CrossRef]
32. McKenzie, D.; Rapoport, H. *Can Migration Reduce Educational Attainment? Evidence from Mexico*; The World Bank: Washington, DC, USA, 2006.
33. Gao, Y.; Li, L.P.; Kim, J.H.; Congdon, N.; Lau, J.; Griffiths, S. The impact of parental migration on health status and health behaviours among left behind adolescent school children in China. *BMC Public Health* **2010**, *10*, 56. [CrossRef]
34. Rappaport, J. Moving to nice weather. *Reg. Sci. Urban Econ.* **2007**, *37*, 375–398. [CrossRef]
35. Glaeser, E.L.; Kolko, J.; Saiz, A. Consumer city. *J. Econ. Geogr.* **2001**, *1*, 27–50. [CrossRef]
36. Ciriaci, D. Does university quality influence the interregional mobility of students and graduates? The case of Italy. *Reg. Stud.* **2014**, *48*, 1592–1608. [CrossRef]
37. Labrianidis, L.; Kazazi, B. Albanian return-migrants from Greece and Italy: Their impact upon spatial disparities within Albania. *Eur. Urban Reg. Stud.* **2006**, *13*, 59–74. [CrossRef]
38. Hatton, T.J. The rise and fall of asylum: What happened and why? *Econ. J.* **2009**, *119*, F183–F213. [CrossRef]
39. Lu, M.; Jiang, S.; Zuo, T. Fairness and Happiness. *Stud. Labor Econ.* **2014**, *2*, 26–47.
40. Deng, D.S.; Hu, H.W. Mobility, deprivation, exclusion and integration: Social integration and the acquisition of the right to security. *Chin. J. Popul. Sci.* **2007**, *6*, 14–24.
41. Qian, W.R.; Li, B.Z. The effect of the degree of achievement of original intention and perception of fairness on migrants' willingness to stay in cities and its intergenerational differences. *Manag. World* **2013**, *9*, 89–101.
42. Xiao, L. *Nongmingong Chengshi Hukou Xingwei Yanjiu*, 1st ed.; China Financial and Economic Publishing House: Beijing, China, 2019.
43. Qiu, H.; Zhou, W.J. A Study on Migrants Settling Willingness and Its Influencing Factors. *Popul. J.* **2020**, *41*, 91–100.
44. Siu, K.; Unger, J. Work and family life among migrant factory workers in China and Vietnam. *J. Contemp. Asia* **2020**, *50*, 341–360. [CrossRef]
45. Liu, H.; Rizzo, J.A.; Fang, H. Urban-rural disparities in child nutrition-related health outcomes in China: The role of hukou policy. *BMC Public Health* **2015**, *15*, 1159. [CrossRef]

sustainability

MDPI

Article

Exploring the Group Difference in the Nonlinear Relationship between Commuting Satisfaction and Commuting Time

Jiankun Yang [1,2], Min He [1] and Mingwei He [1,*]

1 Faculty of Transportation Engineering, Kunming University of Science and Technology, Kunming 650500, China; 20181109002@stu.kust.edu.cn (J.Y.); minhe@kust.edu.cn (M.H.)
2 School of Mechanical and Electrical Engineering, Kunming University, Kunming 650214, China
* Correspondence: kmhmw@kust.edu.cn

Abstract: Analyzing commuting-time satisfaction could help to improve the subjective well-being of society. This study aimed to explore the nonlinear relationship between commuting satisfaction and commuting times in different groups and its influencing factors. An empirical study was conducted in Kunming, China. Firstly, applying a random forest algorithm revealed that there was a nonlinear relationship between commuting satisfaction and commuting time. Secondly, the k-means clustering algorithm was used to divide the respondents into three types of commuter: short-duration-tolerant (group 1), medium-duration-tolerant (group 2), and long-duration-tolerant (group 3). It was found that the commuting-time satisfaction of these three clustered groups had different threshold effects. Specifically, the commuting satisfaction of group 1 showed a nonlinear downward trend, which decreased significantly at 12 and 28 min, respectively; the commuting satisfaction of group 2 rapidly decreased at 35 min; the commuting satisfaction of group 3 first increased in the range of 20–30 min, decreased significantly after 45 min, and decreased sharply above 70 min. These time thresholds were consistent with the ideal commuting times (ICTs) and tolerance thresholds of the commuting times (TTCTs) of the three clustered groups, which indicates that the ICT and TTCT had significant effects on commuting satisfaction. Lastly, the results of the multinominal logistic model showed that variables such as the commuting mode, job–housing distance, income, and educational background had significant effects on the three clustered groups. The policy implications of the study are that commuting circles should be planned with the TTCT as a constraint boundary and ICT as the optimal goal; in addition, different strategies should be adopted for different commuting groups to improve commuting satisfaction.

Keywords: commuting satisfaction; commuting time; nonlinearity; group difference; threshold effect; commuting preference and tolerance

Citation: Yang, J.; He, M.; He, M. Exploring the Group Difference in the Nonlinear Relationship between Commuting Satisfaction and Commuting Time. *Sustainability* **2022**, *14*, 8473. https://doi.org/10.3390/su14148473

Academic Editors: Mengqiu Cao, Claire Papaix, Tianren Yang and Benjamin Büttner

Received: 3 April 2022
Accepted: 1 July 2022
Published: 11 July 2022

1. Introduction

Commuting satisfaction affects physical and mental health, job performance, life satisfaction, well-being, etc. Studying the influencing factors of commuting satisfaction is important for improving public health, increasing economic efficiency, and promoting social sustainability. Commuting satisfaction is a key indicator for measuring citizens' subjective well-being [1–3], evaluating the level of urban transport services [4,5], and evaluating sustainable social development [6,7]. How to improve commuting satisfaction is a common concern for city managers, planners, and researchers in related fields. The factors affecting commuting satisfaction mainly include the commuting time [8,9], commuting mode [10–13], built environment [14,15], service level [16,17], and perceived attitude [18,19]. For the commuting mode, there are a few reasons why walking or cycling are associated with higher satisfaction, such as moderate commuting times and lower commuting costs [20], more exposure to green space [21], increased social interaction, and the promotion of physical and mental health [22]. Congestion is the reason for low satisfaction with car commuting [23,24]. Service levels regarding transfers, connections, departure frequencies, platform facilities, and information acquisition are the reasons for low satisfaction with public transportation (buses and subways) [25–27]. For built environments, the residents of compact urban neighborhoods have better commuting satisfaction than residents of sprawling suburban neighborhoods [28]; the walking satisfaction can be explained by the safety, lack of congestion, and cleanliness of sidewalks [29]; the availability of bike lanes and whether buses are running along the bike lanes affect the commuting satisfaction for cyclists [30]. For preferences and attitudes, a mismatch between the chosen commuting mode and preferred commuting mode has a negative impact on commuting satisfaction [11,31]; commuters who have a positive attitude towards commuting activities have higher satisfaction levels [32–34].

Commuting time is seen as an important influence on commuting satisfaction, the complex relationship between commuting satisfaction and commuting time has been a focus of attention [9,35,36]. When other variables are controlled, some research argues that there is a negative linear effect of commuting time on commuting satisfaction [37–39]. However, other research found, through hypothetical experiments, that there is a nonlinear relationship between commuting satisfaction and commuting time, with ideal commuting times (10–20 min) and acceptable commuting times (30–40 min) being responsible for this nonlinear relationship [40]. People have the best commuting experience and perceived emotions at the ideal commuting time [41]; conversely, when the commuting time exceeds the acceptable or tolerable threshold, they show significant negative emotions and attitude evaluations [42]. The results of statistical modeling support a weak positive effect of an ideal commuting time on commuting satisfaction [43], while the effect of tolerance thresholds on satisfaction has rarely been empirically studied.

The above results have opened up new perspectives for exploring the complex relationship between commuting satisfaction and commuting time. However, three questions deserve further exploration. Firstly, do the nonlinear characteristics of commuting-time satisfaction differ between hypothetical and actual contexts? Analyzing this issue can help to understand the impact of commuting time on satisfaction from both subjective and objective perspectives, and then formulate more effective policies to improve commuting-time satisfaction. Secondly, although the ideal commuting time has a positive effect on commuting satisfaction, the magnitude of the positive effect is relatively small, which leads to the question of whether all commuting groups are the most satisfied around the ideal commuting time. Studying this question can compensate for the lack of attention in the existing literature to group heterogeneity in satisfaction with ideal commute time. Thirdly, both the ideal commuting time and the tolerance threshold have group differences, and these two subjective time thresholds are the key points at which commuting satisfaction changes; therefore, is there also a group difference in commuting-satisfaction change with commuting time, and which factors can explain these differences? Exploring this question contributes to closing the gap in the published literature on commuting satisfaction in terms of nonlinearity and heterogeneity to develop differentiated and personalized urban transport policies.

To answer the above three research questions, firstly, the overall laws of commuting-satisfaction change regarding the hypothetical commuting time and actual commuting time were compared. Next, *k-means clustering* was conducted by combining the actual, ideal, and tolerance values of the respondents' commuting times, and classifying them into three groups: short-duration tolerance, medium-duration tolerance, and long-duration tolerance. Furthermore, *the random forest algorithm* was applied to examine the group difference in commuting-time satisfaction. Finally, *a multinomial logistic regression model* was developed to identify the explanatory variables significant for the three clustered groups.

The novelty of this study is threefold: firstly, it shows that commuting satisfaction is inconsistent with regard to the hypothetical commuting time and actual commuting time, which means that commuters' attitudes to commuting times in hypothetical scenarios are different from their perceived experiences of actual commuting times. Previous studies focused either on the relationship between commute satisfaction and hypothetical commute time or on the relationship between commute satisfaction and actual commute time; they did not analyze the difference in changes in commute satisfaction between these two scenarios. This findings tells us that when developing an optimization strategy for commute-time satisfaction, we should not only start from hypothetical scenarios, it is also necessary to integrate actual situations. Secondly, a fresh finding is that ideal or moderate actual commuting times have a positive effect on commuting satisfaction only for the long-duration-tolerance commuting group, which is not universal. The implication of this finding is that strategies to improve commuting satisfaction by shortening commuting time to ideal expectations are the most effective for long-duration-tolerance commuters. Lastly, the study reveals that there is a group difference in the nonlinear relationship between commuting satisfaction and the actual commuting time; on this basis, it was verified that the commuting-time boundary points that caused these nonlinear changes were close to the ideal commuting time and tolerance threshold of the commuters. Considering individual preferences and tolerance for commuting, this study provides a new perspective for analyzing the threshold effect of commute time satisfaction. This finding enriches the knowledge of threshold theory in terms of commuting satisfaction nonlinearity and heterogeneity.

The second part of the article provides a literature review of the relationship between commuting satisfaction and commuting time. The third section introduces the study's objectives, data, and methods. The fourth section presents the findings and discusses them. The final section draws conclusions and policy implications and outlines the limitations.

2. Literature Review

Commuting satisfaction is a perceptual emotional and cognitive evaluation of the difference between commuters' expectations of service levels and their actual commuting experiences [41]. Higher levels of travel services lead to better perceptions and emotions [44]. Commuting time is a key measure of the service level; it has a significant impact on commuting satisfaction. Some research concludes that commuting satisfaction is negatively correlated with commuting time. Olsson et al. [45] found that the longer the actual commuting time (ACT), the lower the commuting satisfaction. Higgins et al. [24] showed that the proportion of dissatisfied samples became larger as the ACT increased. Zhu et al. [46] revealed that trip duration had a negative association with commuting mood. Two empirical studies in China have also shown that commuting satisfaction decreases with increasing ACT [47,48].

Other research shows a nonlinear relationship between commuting satisfaction and commuting time. Young [49] found that commuting satisfaction rose first and then decreased with the hypothetical commuting time (HCT). Subsequently, the relevant literature on the positive utility of an ideal commuting time and the negative utility of an acceptable (tolerable) commuting time emerged [50–54]. The ideal commuting time (ICT) reflects commuters' preferences for commuting times; people's ICTs are mainly around 10–20 min [55,56], while the tolerance threshold for commuting times (TTCT) reflects commuters' tolerance of commuting times; people's TTCTs was 30–40 min [57,58]. The researchers asked the respondents to evaluate their satisfaction with different hypothetical commuting times; they found that the commuting satisfaction increased before an HCT of 15 min, while it dropped sharply after 30 min, showing significant nonlinear distribution characteristics [36,40,42]. Zhao et al. [59] found that commuting satisfaction was highest when the commuting time was 10–30 min.

Recently published literature strengthens the research on the nonlinearity of commute-time satisfaction. The route-analysis model constructed by Humagain et al. [43] showed that the ICT had a weak positive effect on commuter satisfaction. From the perspective of commuter cognitive dissonance, Ye et al. [41] showed that commuter satisfaction increased before the ICT and decreased after the ICT. Jang et al. [9] obtained an opposite nonlinear relationship through machine learning; that is, commuter-time satisfaction first decreased (0–35 min) and then increased (36–70 min). The reason behind this is that some commuters are willing to accept a longer commuting time to obtain a better living environment. Further research by Humagain et al. [36] observed group differences in the relationship between commuting satisfaction and HCT and showed that the nonlinear relationship only applied to a small number of commuters.

These research findings have opened a new window for exploring the complex relationship between commuting satisfaction and commuting time. However, two questions still need to be explored. Firstly, is there a difference between the hypothetical commuting-time satisfaction (experimental scenario) and actual commuting-time satisfaction (objective reality)? In addition, both the ideal commuting time and the tolerance threshold have group differences, and these two subjective commute time boundary points have a significant impact on commuter satisfaction, which means that it is valuable to reveal group differences in commute-time satisfaction from the perspective of commuters' preferences over and tolerance of commute times.

3. Research Data, Objectives, and Methods

3.1. Implementation of the Survey

As the capital city of China's Yunnan Province, Kunming is a regional international city in Southwest China. "*The Commuting Monitoring Report for 36 Major Cities in 2020, China*" shows that the commuting-monitoring indicators for Kunming are similar to those of other cities [60], which means that using Kunming as a study case is representative. The paper-assisted personal interviewing (PAPI) technology was used to implement the survey. The PAPI implementation steps are "design questionnaires, train investigators, conduct trial surveys, optimize questionnaires, conduct formal surveys, eliminate invalid questionnaires, and establish a database". Although the implementation cost of the PAPI survey method is relatively high, its advantage is that investigators not only provide necessary explanations to respondents' questions through face-to-face interviews, but also directly observe the statuses of the respondents filling in the questionnaires, which is helpful for preliminarily judging the quality of returned questionnaires.

Taking into account the aggregation of the people flow, the spatial distribution of the samples, and the feasibility of the implementation, the survey selected eight core commercial complexes in different locations. The eight commercial complexes were the Joy-City Business Center (Wuhua District), Shuncheng Business Center (Wuhua District), Tongde Plaza (Panlong District), Wanda Plaza (Xishan District), Dadu Shopping Mall (Guandu District), International Ginza Complex (Guandu District), Wuyue Plaza (Chenggong District), and No.1 City of Colorful Yunnan (Chenggong District). The specific survey locations were mostly cafes, milk-tea shops, bookstores, and parent waiting areas in children's training centers. The consumers in these places are generally in a leisure state, and they were more willing to listen to the surveyor's introduction and agree to the survey.

Before the survey was carried out, the supervisor conducted the necessary training for the investigators, so that the investigators could master the precautions and basic skills for a random sampling survey. Two investigators formed a group; one was responsible for instructing the respondents to fill in the questionnaire, and the other was responsible for recording the respondents' times for answering the questionnaire. The investigators uniformly wore white work clothes with a logo and wore the official investigation work permit issued by the institute on their chests, to gain the trust and support of the customers as much as possible. The investigators randomly asked the customers if they were willing to take the survey, and told them that, if they completed the questionnaire, they would receive a red envelope with RMB 10 of cash, which reduced the rejection rate and encouraged the respondents to fill out the questionnaire carefully.

The final version of the questionnaire was revised based on the feedback from the pilot survey in April 2020. Two offline random sample surveys were conducted on commuters in Kunming. The first formal survey was conducted in May 2020, obtaining 352 valid samples (sample 1); the second formal survey was conducted in January 2021, collecting 224 valid samples (sample 2). Through data cleaning, samples that were incomplete and with answering times of less than 8 min (an empirical value obtained in the trial survey) were eliminated, and 576 complete samples were finally obtained. The average commute time of sample 1 and sample 2 were 28.1 and 26.1 min, respectively. The Mann–Whitney U test was performed on these two independent samples, and it was found that their commute-time distributions were not significantly different ($p > 0.1$); The average commuting satisfaction of sample 1 and sample 2 were 4.5 and 4.7, respectively; the Mann–Whitney U test showed that there was no significant difference in the distribution of commuting satisfaction between these two independent samples ($p > 0.1$). These test results demonstrated that there was no statistical difference between the two samples, and they could be combined for this study. Furthermore, in sample 1, the proportions of active commuting, cars, e-bikes, and public transportation were 21.9%, 33.0%, 20.1%, and 25.0%, respectively, while in sample 2, the proportions of these four commuting modes were 25.9%, 26.9%, 16.7%, and 30.6%, respectively. These two sets of data were similar, indicating that there was no obvious deviation between the two samplings.

3.2. Data from the Survey

3.2.1. Commuting Time

Three questions were set in the questionnaire to obtain the respondents' ACTs, ICTs, and TTCTs. Question 1: "On average, how many minutes does it take to commute from your residence to your workplace by your most frequently used commuting mode?" (ACT); question 2: "What is your preferred ideal commute time in minutes from your residence to your workplace?" (ICT); and question 3: "What is the maximum commute time you can tolerate in minutes from your residence to your workplace?" (TTCT). The ACT reflects a retrospective estimate of the respondents' average daily commuting time in actual situations. The ICT presents the respondents' ideal preferences for commuting times in hypothetical situations. The TTCT refers to psychologically tolerable or acceptable commuting times for the respondents.

The average ACT, ICT, and TTCT obtained in this survey were 27.1, 17.5, and 37.8 min, respectively. In addition, as shown in Table 1, the proportion of the respondents whose ACTs were within their ICTs was 29.8%, while that of the respondents whose ACTs exceeded their TTCTs was 18.3%; these findings are similar to those of other researchers. A survey conducted in Kunming in 2014 found that the average ACT, ICT, and TTCT were 28.7, 18.6, and 37.4 min, respectively; in addition, the ACT was less than or equal to the ICT in 28.7% of their samples, and the ACT was greater than the TTCT in 15.3% of their samples [61].

Table 1. The description of the samples.

Variables	Categories	Assignment	Sample Size	Proportion/%
Gender	Male	0	328	56.9%
	Female	1	248	43.1%
Age	18–30 years old	1	304	52.7%
	31–40 years old	2	212	36.8%
	41–60 years old	3	60	10.5%
Education	High school and below	1	94	16.4%
	College and undergraduate	2	421	73.1%
	Postgraduate and above	3	61	10.5%
Monthly income	<RMB 5000	1	260	45.1%
	RMB 5000–7000	2	170	29.5%
	>RMB 7000	3	146	25.4%
Job–housing relationship	Balance (SDTC < 5 km)	1	350	60.7%
	Mild distance (5 km ≤S DTC ≤ 9 km)	2	140	24.4%
	Severe distance (SDTC > 9 km)	3	86	14.9%

Table 1. *Cont.*

Variables	Categories	Assignment	Sample Size	Proportion/%
Commuting mode	Active (walking, cycling, and shared bicycles)	1	138	23.9%
	Car (private cars, taxis, and shared cars)	2	172	29.8%
	E-bikes (e-bicycles, e-mopeds)	3	106	18.5%
	Public transportation (subway and buses)	4	160	27.8%
Commuting time	ACT ≤ ICT	1	172	29.8%
	ICT < ACT < TTCT	2	299	51.9%
	ACT ≥ TTCT	3	105	18.3%

3.2.2. Commuting Mode

The commuting mode in this study refers to the travel mode respondents most frequently used to commute from their residence to the workplace on workdays. All the samples included four types of commuting mode: active commuting (walking, cycling, and shared bicycles), cars (private cars, taxis, and shared cars), e-bikes (electric bicycles, electric mopeds), and public transportation (subway and buses). E-bikes mainly include three types of electric bicycles, electric mopeds, and electric scooters [62]. The e-bikes in this study refer to electric mopeds (motorcycle type, driven by electric motors, without pedals) and electric bicycles (bicycle type, mainly powered by electricity, supplemented by human power, with pedals). In Kunming, the users of such e-bikes need to register them with the relevant government department and apply for a license.

The proportions of cars and public transportation were 29.8% and 27.8%, respectively. These survey data are slightly higher than the corresponding statistical data in the "*Kunming Urban Transportation Annual Development Report in 2019, China*", which reports that the travel sharing rates for cars and public transportation were 25.9% and 25.4%, respectively [63]. Since the report's classification of other commuting modes is inconsistent with this study, no explanation for the sample proportions of active commuting and e-bikes is provided here.

It should also be pointed out that the reason e-bikes are listed separately in this study is that the commuting share rate of e-bikes is not low in Kunming [64]. Furthermore, there are essential differences in the performance functions (speed, acceleration/deceleration, and physical energy consumption) of the e-bike and active modes (walking and cycling) [65]. Listing e-bikes as active commute modes would not be conducive to analyzing the group differences in commuting satisfaction. In addition, during the questionnaire survey, there was no COVID-19 spread in Kunming; its urban commuting system operated as usual; which can be intuitively inferred from the above data on the commuting time and commuting mode.

3.2.3. The Job–Housing Relationship

The questionnaire asked about the names of the communities where the respondents lived and worked. On the Baidu map, the centroid of the community where each respondent lives and works were marked, and each interviewee's job–housing relationship was measured based on the straight-line distance between the two centroids (SDTC). We referred to the indicator of happy commuting (commuting distance within 5 km) and the average commuting distance in Kunming (7.5 km) in "*National Commuting Monitoring Report for Major Cities in 2020, China*" [60]. The respondents' job–housing relationships were divided into three ordered categories: SDTC within 4 km was defined as a job–housing balance; SDTC within the range of 5 to 9 km was defined as the mild job–housing distance; SDTC exceeding 9 km was defined as severe job–housing distance.

3.2.4. Commuting Satisfaction

This study measured commuting satisfaction with the HCT [40]. A total of six hypothetical scenarios were set up, each of which corresponded to a different HCT. An option that matched the respondent's attitude reflection from five satisfaction options (very satisfied, satisfied, neutral, dissatisfied, and very dissatisfied) was chosen. The first scenario had a commuting time of 0 min, with an additional note that it meant "telecommuting"; the second scenario had a commuting time of 15 min because people's ICTs were concentrated in the range of 10–20 min [41,50,55,56]; therefore, setting the items in this way was helpful for analyzing the changes in commuting satisfaction around the ICT; the commuting times of the third and fourth scenarios were 30 and 45 min, respectively, because the respondents' acceptable or tolerable commuting times were mainly concentrated in the range of 30–45 min [36,42,57,58], and the context set in this way helped to reveal the changing characteristics of commuting satisfaction when the commuting time approached or exceeded the TTCT. To analyze the impact of long or extreme commuting [66–69] on commuting satisfaction, the last two scenarios of commuting times of 60 and 75 min were also set.

This study also measured the respondents' satisfaction with their actual commutes. The *scale of travel satisfaction* (STS) focuses on the two dimensions of commuters' cognitive and affective evaluations of commuting activities in reality [70]. A total of nine items were set in the STS to measure commuting satisfaction. The STS has been proven to be practical and reliable by some empirical studies [23,71,72]. To ease the test burden on respondents, Ye et al. [41,73] reduced the items of the STS to seven and applied it to a commuting-satisfaction study of Xi'an citizens, in China. Since their results showed that the reduced version of the STS (STS-R) was still effective, this study also applied it. The seven items of the STS-R are shown in Table 2. In each item, −3 means very dissatisfied, 0 means neutral, and +3 means very satisfied. The reliability and validity of the seven questions of the STT-R were tested; the results showed that *Cronbach's alpha* and *KMO* were 0.923, 0.915, indicating that the internal consistency of the STT-R was good and the seven survey questions were valid.

Table 2. The scales of commuting satisfaction.

The Worst (−3)	Please Evaluating Real Feeling on Your Commute	The Best (+3)
I felt commute time was pressed	−3 −2 −1 0 +1 +2 +3	I felt commute time was relaxed
I was stressed	−3 −2 −1 0 +1 +2 +3	I was calm
I was tired	−3 −2 −1 0 +1 +2 +3	I was alert
I was bored	−3 −2 −1 0 +1 +2 +3	I was enthusiastic
I felt the service level of the commute was bad	−3 −2 −1 0 +1 +2 +3	I felt the service level of the commute was good
I think this commute worked poorly	−3 −2 −1 0 +1 +2 +3	I think this commute worked well
I think this commute is the worst I can think of	−3 −2 −1 0 +1 +2 +3	I think this commute is the best I can think of

3.3. Objectives and Methods

Research objective 1: Examining differences in commuter satisfaction with changes in HCT and ACT, respectively. On one hand, the commuting satisfaction under the hypothetical scenario was categorized; those who selected "very satisfied" and "satisfied" were defined as the satisfied type, while those who selected "very dissatisfied" and "dissatisfied" were defined as the dissatisfied type, and those who selected the intermediate option were defined as the neutral type. For each HCT, the proportions of respondents in these three categories were counted separately to plot the distribution of the commuting satisfaction along with the HCT. On the other hand, for ease of calculation, 4 was added to each measured value obtained by STS-R, so a score of 1 represented very dissatisfied, a score of 4 represented neutral, and a score of 7 represented very satisfied. On this basis, the arithmetic mean of the seven question items was calculated, which was the actual commuting satisfaction. *A random forest algorithm* was used to explore the nonlinear relationship between actual commuter satisfaction and the ATC.

Research objective 2: Revealing the differences in commuting satisfaction with ACT among clustered groups. First, *the k-means clustering algorithm* [74] was used to divide all the respondents into different groups. Second, *the random forest algorithm* [75] was applied to draw the relationship of local dependency between commuting satisfaction and

ACT for clustered groups. Furthermore, the respective nonlinear characteristics of their commuting-time satisfaction could be intuitively observed. Finally, from the perspective of commuters' psychological preferences and tolerance of commuting times, the ICTs and TTCTs of the clustered groups were introduced and combined with the nonlinear changing characteristics of their commuting-time satisfaction to capture the time-threshold effect of commuting satisfaction.

Research objective 3: Identifying influencing factors of clustered groups with differences in commute time satisfaction. *A multinominal logistic regression model* [76] was set up, with the clustered groups of different commuting-time satisfaction levels as the unordered categorical dependent variable. The independent variables were commuting mode, job–housing relationship, and individual characteristics.

4. Results and Discussion

4.1. Change in Commuting Satisfaction with Hypothetical Commuting Time and Actual Commuting Time

Figure 1 shows the change in the sample proportion distribution of the commuting satisfaction under the hypothetical situation. When the HCT was 15 min, the proportion of respondents who were satisfied was the highest, reaching 81%, which supports the previous research results; that is, when the commuting time is close to the ICT (10–20 min), the commuting satisfaction is the best [36,40,42]. This phenomenon can be explained by cognitive dissonance theory, which states that people's feelings and experiences are the best when attitudes (ideal preferences) and behaviors (real situations) are in harmony [77]. As the HCT of 15 min aligns with people's ideal commute time, this value could offer commuters the best experience. In addition, commuting utility theory can also be used as an explanation for this phenomenon, which holds that ideal commuting time brings positive utility to people [50].

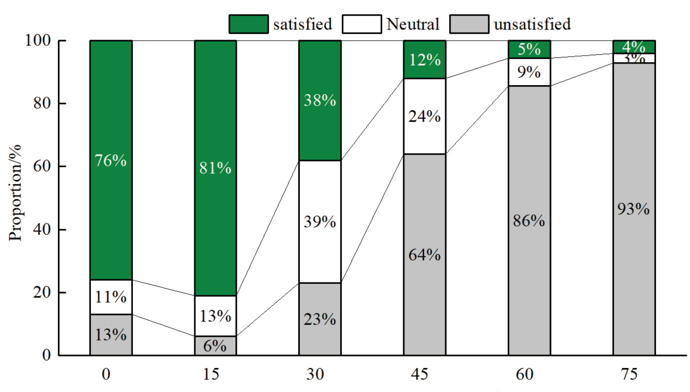


Figure 1. The proportions of commuting satisfaction under hypothetical commuting times.

When the HCT was 0 min, the proportion of respondents who were satisfied dropped by 5 percentage points, but it was still as high as 76%, which indirectly shows that the respondents had relatively optimistic responses to telecommuting. Furthermore, this proportion is larger than the findings of other scholars [36,40,42,49] and smaller than those of Humagain [36], which may be related to the differences in the study region, and the possibility that the demand for telecommuting was stronger during the epidemic cannot be ruled out.

When the HCT increased from 15 to 30 min, the proportion of the respondents who answered that they were satisfied quickly dropped from 81% to 39%, while the proportion of the respondents who answered that they were dissatisfied increased from 6% to 23%. Similarly, when the HCT increased from 30 to 45 min, the proportion of respondents expressing dissatisfaction increased significantly, from 23% to 64%. The explanation for these statistical results is similar to the findings of other countries; that is, people have acceptable or tolerable thresholds for commuting times at the psychological level [36,40,42,57]. There was a significant drop in perceived satisfaction when the HCT exceeded 60 min; the majority of the respondents stated that they were dissatisfied; this is in line with reality, because people's perceived moods under long or extreme commuting are mostly negative [38,67]. Interestingly, when the HCTs were 45, 60, and 75 min, 12%, 5%, and 4% of the samples responded with satisfaction, respectively, indicating that a small number of the respondents still showed a willingness to accept long commuting times, which may have been the result of respondents' benefit trade-offs [8]. These results suggest that it is necessary to explore group differences in commuting-time satisfaction.

Generally, there was a nonlinear variation in the commuting satisfaction with the HCT. The participants responded positively to telecommuting. The commuting satisfaction presented a weak growth trend in the range of 0–15 min. When the HCT was in transit from 15 to 30 min, the commuting satisfaction decreased for the first time. When the HCT exceeded 30 min and approached 45 min, the commuting satisfaction decreased significantly for the second time. However, this is only a statistical result under hypothetical conditions it is necessary to further explore the changing characteristics of commute-time satisfaction in actual situations.

To reveal how commuting satisfaction changes with the ACT, the *random forest algorithm* was used to plot the local dependence relationship of the respondents' commuting satisfaction with the ACT. Taking 70% of the samples as the training set and 30% of the samples as the test set, the goodness-of-fit (explained variability) of the model was 77%. As shown in Figure 2a, the overall trend of the commuting satisfaction decreased nonlinearly as the commuting time increased. The decline in commuting satisfaction was significant before the ACT of 30 min; particularly within the range of 20–25 min, the decline in commuting satisfaction was the greatest; after 30 min, the decline in commuting satisfaction was relatively flat; few upward trends in commuting satisfaction were observed before the ACT of 20 min.

These results suggest that the respondents' stated commuting satisfaction in the hypothetical scenario was not entirely consistent with their perceived commuting satisfaction in the face of the ACT. Although the commuting satisfaction showed nonlinear changes with commuting time in both contexts, the positive effect of a moderate or ideal commuting time on commuting satisfaction was not captured in reality; furthermore, only 5% of the sample showed an increase in commuting satisfaction, even when the HCT increased from 0 to 15 min. Therefore, one question that arises is whether the notion that ideal commute times lead to positive commuting satisfaction is only applicable to a minority of commuters, and not a universal observation.

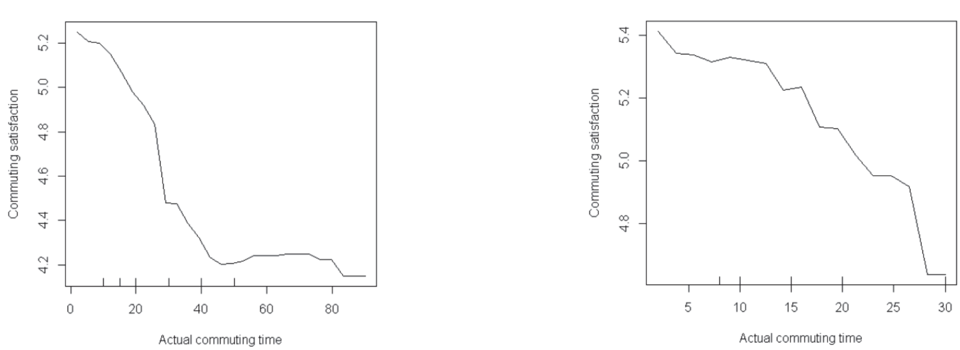
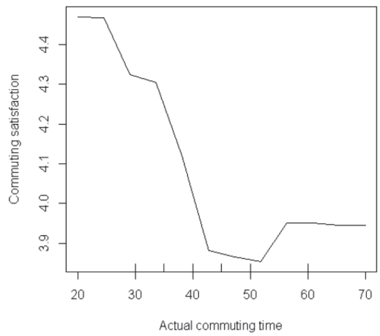
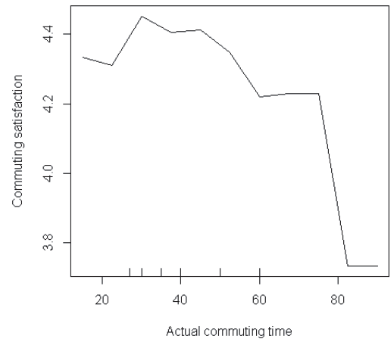


Figure 2. *Cont.*



(c)



(d)

Figure 2. The nonlinear relationship between commuting satisfaction and actual commuting time. Note: (**a**) Total sample; (**b**) Group 1; (**c**) Group 2; (**d**) Group 3.

4.2. Group Differences in the Nonlinear Relationships between Commuting Satisfaction and Actual Commuting Time

The question of whether there was a group difference in the relationship between commuting satisfaction and commuting time was explored. First, the total samples were *k-means* clustered with three indicators: ICT, TTCT, and ACT. These variables reflected the three dimensions of the commuters' ideal preferences, tolerance levels, and actual experiences of commuting times, which is more comprehensive than clustering with only one of them. Because these three indicators are group differences, the clustering groups obtained by them may help to explore the group difference in commuting-time satisfaction.

The theoretical basis for clustering the respondents using these three variables is that the ICT reflects commuters' preferences in terms of commuting times [50,53]. When the ACT is close to the ICT, the perceived satisfaction of commuters is better [41,43,78]. While the TTCT reflects commuters' tolerance of commuting times [57,58], When the ACT approaches or even exceeds the TTCT, the negative motions of commuters significantly increase [54], which leads to a sharp satisfaction decrease [40,42]. In addition, the advantage of clustering respondents in this way is that it not only reflects the relationship between the actual commuting time and commuting satisfaction, but also helps to reveal the specific impact of respondents' subjective commuting-time boundary points on commuting satisfaction.

As shown in Table 3, the average TTCTs for the three commuting groups obtained by clustering were 28.8, 39.0, and 63.7 min, respectively. In addition, the distribution of the TTCTs of the three clustered groups was found to be significantly different ($p < 0.001$) by the *Kruskal–Wallis* non-parametric test, which further illustrates the validity of the clustering. This study refers to the three clusters as "group 1: short-duration-tolerance commuters", "group 2: medium-duration-tolerance commuters", and "group 3: long-duration-tolerance commuters", respectively.

Table 3. Average ICTs, ACTs, and TTCTs for three clustered groups.

Variable	Cluster 1	Cluster 2	Cluster 3	All-Sample Average
Average ICT/min	13.61	21.95	23.84	19.80
Average ACT/min	16.05	40.22	42.55	32.94
Average TTCT/min	28.78	38.89	63.75	43.81

Next, the *random forest algorithm* was used to establish the local dependence relationship between the commuting satisfaction and ACT of each clustered group. In each clustered group, 70% of the samples were used as the training set and 30% of the samples were used as the test set. The goodness-of-fit (variability explained) of the *random forest models* for these three cluster groups was 72%, 84%, and 68%, respectively. As shown in Figure 2b, the commuting satisfaction of group 1 changed slowly before the ACT was 15 min, and decreased in the 15–25 min range; when the ACT exceeded 25 min, the commuting satisfaction decreased significantly. As shown in Figure 2c, the commuting satisfaction of group 2 decreased rapidly when the ACT was about 35 min. However, when the ACT exceeded 40 min, the decrease in commuting satisfaction was significantly weakened, and a slight rebound occurred after 50 min. As shown in Figure 2d, when the ACT was between 20 and 30 min, the commuting satisfaction of group 3 showed an upward trend, and it declined after 45 min. Especially when the ACT exceeded 70 min, the commuting satisfaction sharply declined; this is yet another demonstration of the negative impact of extreme commuting on commuting experience.

These nonlinear threshold effects can be clearly explained from the perspective of commuting individuals' preferences regarding and tolerance of commuting times. The average ICT and TTCT for the short-duration-tolerance commuting group were 13.6 and 28.8 min, respectively, which were close to the time thresholds at which the commuting satisfaction for this group decreased significantly. The average ICT and TTCT for the long-duration-tolerance commuting group were 24 and 63.7 min, respectively, which fell exactly in the rising and falling range of the commuting satisfaction for this group. Similarly, the average TTCT for the medium-duration-tolerance commuting group was 39 min, which coincides with the time threshold for a rapid decrease in commuting satisfaction for this group. The behavioral threshold theory is helpful for analyzing changes in commuting-time satisfaction [40]. The theory contends that commuters have an acceptable or tolerable threshold for commuting times. Different commuter groups may have different tolerance thresholds, so the time-threshold effect of commuting satisfaction is also different.

Firstly, these results show that there was a nonlinear relationship between commuting satisfaction and commuting time. The decline in commuting satisfaction with commuting time exhibited nonlinear characteristics that changed significantly at specific thresholds, and these commuting-time thresholds were very close to the average ICT and TTCT. Secondly, there was a group difference in the nonlinear relationship between commuting satisfaction and commuting time. The commuters who tolerated longer commuting times tended to have a larger time threshold, which affected their commuting satisfaction with a significant decrease. Finally, in the lower range of the actual commuting times, the commuting satisfaction of group 1 did not change significantly, and the commuting satisfaction of group 2 decreased slightly, while the commuting satisfaction of group 3 increased. This suggests that ideal or moderate commuting times have no apparent negative perceived utility for the majority of commuters; instead, there is a positively perceived utility for long-duration-tolerance commuters. Without a different group breakdown of the commuters in terms of actual commuting time, the local characteristics of the positive effect of the commuting time on commuting satisfaction would not be visible. It would also not be possible to capture the time threshold that led to a significant decrease in commuting satisfaction among the different commuting groups.

4.3. The Influencing Factors of the Clustered Group with Different Levels of Commuting Satisfaction

To identify the influencing factors of the clustered groups with different levels of commuting satisfaction, we visualized the average satisfaction and the proportional distribution of the three clustered groups for the commuting mode, job–housing relationship, and individual characteristics. Next, we constructed *a multinominal logistic regression* model to test the statistical significance.

As shown in Table 4, group 3 had the largest proportion of public transport commuters, group 1 had the largest proportion of active commuters, and the proportion of car commuters was the largest in group 2. The four commuting modes in descending order of commute satisfaction were walking and cycling (5.33), e-bikes (4.75), public transportation (4.61), and cars (4.50), which is roughly the same as the conclusions of other studies. Active commuting always results in the highest satisfaction [10,12,73]; sometimes car commuting has the lowest satisfaction [19]; and sometimes public transit commuting has the lowest satisfaction [10,13]. This may be related to regional differences.

Table 4. Sample distribution of three clustered commuter groups.

Variable	Categories	Average Satisfaction	Group 1		Group 2		Group 3	
			Sample	Proportion	Sample	Proportion	Sample	Proportion
Commuting mode	Active (walking, cycling, and shared bicycles)	5.33	114	35.1%	13	9.0%	11	10.1%
	Car (private cars, taxis, and shared cars)	4.50	75	23.1%	61	42.3%	36	33.3%
	E-bikes (e-bicycles, e-mopeds)	4.75	75	23.1%	17	11.8%	14	12.9%
	Public transportation (subway and buses)	4.61	60	18.5%	53	36.8%	47	43.5%
Job–housing distance	Balance (SDTC < 5 km)	4.97	239	73.7%	60	41.6%	51	47.2%
	Mild distance (5 km ≤ SDTC ≤ 9 km)	4.56	64	19.7%	45	31.2%	31	28.7%
	Severe distance (>9 km)	4.30	21	6.4%	39	27.0%	26	24.0%
Gender	Male	4.80	173	53.3%	91	63.1%	64	59.2%
	Female	4.74	151	46.6%	53	36.8%	44	40.7%
Age	18–30 years old	4.81	189	58.3%	60	41.6%	55	50.9%
	31–40 years old	4.77	110	33.9%	64	44.4%	38	35.1%
	41–60 years old	4.61	25	7.7%	20	13.5%	15	13.8%
Education	High school and below	4.98	61	18.8%	23	15.9%	10	9.2%
	College and undergraduate	4.74	242	74.6%	98	68.0%	81	75.0%
	Postgraduate and above	4.67	21	6.4%	23	15.9%	17	15.7%
Monthly income	<RMB 5000	4.78	150	46.2%	61	42.3%	49	45.3%
	RMB 5000–7000	4.90	110	33.9%	36	25.0%	24	22.2%
	>RMB 7000	4.63	64	19.7%	47	32.6%	35	32.4%

The largest proportion of respondents whose job–housing distance was balanced belonged to group 1; the largest proportion of respondents whose job–housing distance was mild belonged to group 2. The average commuting satisfaction of the commuters with a balanced job–housing distance was 4.97; that of commuters with a mild job–housing distance was 4.56; and that of the commuters with a severe job–housing distance was 4.30. These data show that the more balanced the job–housing distance, the higher the commute satisfaction.

The smallest percentage of male respondents belonged to group 1, while the largest percentage of female respondents belonged to group 1. The male respondents had a higher average commute satisfaction than the female respondents. The respondents with high-school degrees and below comprised the largest proportion in group 1 and displayed the highest levels of commute satisfaction; the respondents with postgraduate education comprised the smallest proportion in group 1 and had the lowest commute satisfaction. The proportion of respondents with a personal monthly income of more than RMB 7000 in group 1 was 19.7%, and their commuting satisfaction was 4.63, which was lower than for those with a personal monthly income of less than RMB 7000. In terms of the respondents' ages, group 1 had the largest percentage of respondents aged 18 to 30; the respondents were less satisfied with their commute as they grew older.

The above descriptive statistics show that the respondents with different commuting modes, job–housing relationships, and individual characteristics had different likelihoods of belonging to the different clustered groups, and their average satisfaction was also different.

As shown in Table 5, the *likelihood ratio test* of the model was significant, indicating that the independent variables helped to improve the explanatory power of the model. In addition, the *three pseudo-R-square values* (*McFadden, Cox–Snell, and Negorko*) of the model were 0.140, 0.242, and 0.281, respectively, which showed that the model explains about 20% of the variance of the original variable.

Table 5. The fit information for the model.

Model	Model Fitting Conditions			Likelihood Ratio Test		
	AIC	BIC	–2log	Chi-Square	Degrees of Freedom	Sig.
Intercept only	789.239	797.951	785.238	NA	NA	NA
The final model	677.983	791.241	625.983	159.256	24	0.000
R^2	*McFadden*			0.140		
	Cox–Snell			0.242		
	Negorko			0.281		

As shown in Table 6, the estimation results of each independent variable in the model were as follows. Compared with group 2, the active commuters were more likely to belong to group 1, and this probability was 7.14 (100/14) times that of the public transport commuters; the e-bike commuters were more likely to belong to group 1, and this probability was 3.45 (100/29) times that of the public transport commuters. Compared with group 1, the probability of active commuters, e-bike commuters, and car commuters belonging to group 3 was 0.133, 0.270, and 0.516 times that of the public transit commuters, respectively. These results suggest that the active commuters were the most likely to comprise the short-duration-tolerance commuting group, followed by the e-bike commuters, while the public-transit commuters were the most likely to be in the long-duration-tolerance commuting group, followed by the car commuters. As shown in Table 7, the survey data also showed that the average ACT and TTCT of the public-transport respondents were 34.2 and 42.6 min; those of the respondents who commuted by e-bike were 22.9 and 36.9 min, while those of the active commuters were 16.9 and 31.9 min.

Compared with group 2, the odds of commuters with a balanced job–housing distance being in group 1 were 5.75 (1000/174) times those of commuters with a severe distance between in their job and their housing; the odds of commuters with a mild job–housing distance being in group 1 were 2.50 (1000/400) times those of commuters with a severe job–housing distance. These results show that the more balanced the job–housing distance for the commuters, the more likely they were to belong to the short-duration-tolerance commuting group. Compared with group 1, commuters with a balanced job–housing relationship were 0.225 times more likely to be in group 3 than commuters with a severe distance between their work and their housing; the odds of commuters with mild job–housing distances being in group 3 were 0.424 times those of commuters with severe job–housing distances, which means that the greater the job–housing distance, the more likely the commuters were to belong to the long-duration-tolerance commuting group. Generally, the greater the job–housing distance, the longer the commuting time. The estimated results are in line with reality. In the survey data, the ACT and TTCT of the respondents with balanced job–housing relationships were 22.8 and 35.8 min, respectively, while those of the respondents with severe job–housing distances were 37.2 and 44.4 min, respectively.

Compared with group 1, the odds of commuters with college and undergraduate degrees being in group 2 or 3 were 0.438 and 0.472 times those of commuters with post-graduate degrees and above. Compared with group 3, the odds of commuters with a high-school degree or below being in group 1 were 4.1 (1000/244) times those of commuters with a Master's degree or doctorate. These results show that the commuters with higher education levels were more likely to be in the long-duration-tolerance commuting group, and the commuters with lower education levels were more likely to be in the short-duration-tolerance commuting group. Compared with group 3, the odds of commuters whose monthly incomes were RMB 5000–7000 being in group 1 were 4.99 (1000/502) times those of commuters whose monthly incomes were more than RMB 7000, which indicates that the lower the monthly income, the more likely the commuters were to be in the short-duration-tolerance commuting group.

Table 6. Results of the multinominal logistic regression model.

Variable	Categories	Group 2			Group 3		
		B	Sig.	Exp(B)	B	Sig.	Exp(B)
Commuting mode	Active (walking, bike, and shared bicycles)	−1.966	0.000	0.140	−2.020	0.000	0.133
	Car (private cars, taxis, and shared cars)	−0.280	0.318	0.756	−0.662	0.030	0.516
	E-bikes (e-bicycles, e-mopeds)	−1.238	0.000	0.290	−1.310	0.000	0.270
	Public transportation (ref.)						
Job–housing distance	Balance	−1.746	0.000	0.174	−1.493	0.000	0.225
	Mild distance	−0.917	0.011	0.400	−0.858	0.028	0.424
	Severe distance (ref.)						
Gender	Male	0.466	0.050	1.594	0.309	0.222	1.363
	Female (ref.)						
Age	18–30 years old	−0.386	0.339	0.680	−0.257	0.551	0.773
	31–40 years old	0.227	0.567	1.255	−0.100	0.816	0.904
	41–60 years old (ref.)						
Education	High school and below	−0.760	0.101	0.468	−1.409	0.008	0.244
	College and undergraduate	−0.825	0.034	0.438	−0.751	0.068	0.472
	Postgraduate and above (ref.)						
Monthly income	<RMB 5000	0.253	0.413	1.287	0.122	0.709	1.129
	RMB 5000–7000	−0.497	0.113	0.608	−0.690	0.045	0.502
	>RMB 7000 (ref.)						
Intercept		1.760	0.001	NA	1.798	0.002	NA

A possible reason behind these results is that most of the low-education and low-income groups are migrant workers in cities in China; they rarely own property in the city and usually choose to rent apartments near their work locations or live in company-provided dormitories; therefore, their commuting times are relatively short, which also leads to a low level of commuting tolerance for this group. This reasoning is supported by the data in Table 7; the ACT and TTCT for the respondents with high-school or technical secondary school degrees were 24.2 and 34.5 min, respectively, which were lower than those for those with a college or university educational background (26.7 and 37.5 min) and those with postgraduate educational background (34.5 and 42.8 min). At the same time, the proportion of respondents with a low level of education and a balanced job–housing distance was 69.1%, which was significantly higher than that of the other two categories (61.0% and 45.9%).

The ACT and TTCT for the respondents with monthly personal incomes of less than RMB 7000 were 26.2 and 37.2 min, respectively, both of which were lower than those with monthly personal incomes of more than RMB 7000 (29.6 and 39.9 min). Meanwhile, the corresponding sample shares for these two categories of respondents with balanced job–housing relationships were 65% and 45.9%, respectively.

The model results also suggest that, compared with group 1, male commuters were more likely to be in group 2, and this probability was 1.594 times that of female commuters. In Chinese family structures, women have more family responsibilities, women are more likely to work close to where they live, which leads to women having shorter commuting times. The proportion of male commuters with severe job–housing distance was 2.9% higher than that of female commuters. The age of the commuters did not show statistical significance, which may have been due to the relatively low age of the respondents. Therefore, the samples could not effectively represent the overall characteristics of the commuters.

Table 7. Average commuting times and job–housing relationships of the different commuting groups.

Index		Average Commuting Time/min			Job–Housing Distance					
					Balance		Mild Distance		Severe Distance	
Variable	Category	ICT	ACT	TTCT	Sample	Proportion	Sample	Proportion	Sample	Proportion
Commuting mode	Active	15.09	16.92	31.92	109	79.0%	22	15.9%	7	5.1%
	Cars	18.25	31.05	38.72	84	48.8%	53	30.9%	35	20.3%
	E-bikes	16.36	22.96	36.89	71	67.0%	26	24.5%	9	8.5%
	Public transit	19.93	34.22	42.72	86	53.8%	39	24.4%	35	21.8%
Education	High school and below	15.22	24.17	34.57	65	69.1%	17	18.1%	12	12.8%
	College and undergraduate	18.15	26.63	37.89	257	61.0%	104	24.7%	60	14.3%
	Postgraduate and above	17.59	34.48	42.79	28	45.9%	19	31.1%	14	23.0%
Monthly income	<RMB 5000	16.96	26.31	37.06	180	69.2%	52	20.0%	28	10.8%
	RMB 5000–7000	17.75	26.06	37.35	103	60.5%	38	22.4%	29	17.1%
	>RMB 7000	18.62	29.55	39.90	67	45.9%	50	34.2%	29	19.9%
Gender	Male	18.33	27.25	38.46	197	60.1%	78	23.8%	53	16.1%
	Female	16.66	26.80	37.08	153	61.7%	62	25.0%	33	13.3%
Job–housing distance	Balance	16.72	22.83	35.74	NA	NA	NA	NA	NA	NA
	Mild distance	17.91	31.41	39.14	NA	NA	NA	NA	NA	NA
	Severe distance	20.75	37.16	44.42	NA	NA	NA	NA	NA	NA

5. Conclusions

This study took Kunming as a case study and revealed the nonlinear relationship between commuting satisfaction and commuting time in both hypothetical situations and actual situations. First, it was found that the nonlinear relationship between commuting satisfaction and hypothetical commuting times differed from that between commuting satisfaction and actual commuting times. Second, the three variables of the ideal commuting time, actual commuting time, and commuting-time tolerance threshold of the commuters were integrated to cluster the samples. On this basis, the random forest algorithm was used to reveal the nonlinear relationship between the commuting satisfaction and actual commuting times of the different clustered groups. Furthermore, from the perspectives of their preferences regarding and tolerance of commuting times, the threshold effect of the commuting times on commuting satisfaction was analyzed. Thirdly, some factors that could explain why the nonlinear relationship between commuting satisfaction and commuting time had group differences were extracted.

The conclusions of this study are as follows. Firstly, there was a nonlinear relationship between the commuting satisfaction and commuting times in both the hypothetical and actual situations, but their respective nonlinear features were not consistent. Specifically, the commuting satisfaction was better when the hypothetical commuting times were 0 and 15 min, and there was a slight increase in the range of 0–15 min; when the hypothetical commuting time increased from 30 to 45 min, the commuting satisfaction decreased significantly. In the actual situation, the commuting satisfaction of the whole sample tended to decrease slowly in the range of actual commuting times of 0–15 min, while there was a rapid decrease in the range of 22–28 min, with a continued decrease after the actual commuting time of 30 min, but at a slower rate. It was therefore concluded that the positive effects of moderate or ideal commuting times on commuting satisfaction only apply to a minority of commuters.

Secondly, there was a group difference in the nonlinear relationship between commuting satisfaction and actual commuting times. The commuting satisfaction of the short-duration-tolerance commuting group did not change significantly at 0–15 min, tended to decline above 15 min, and decreased significantly beyond 25 min. The commuting satisfaction of the medium-duration-tolerance commuting group decreased significantly at 35 min. The commuting satisfaction of the long-duration-tolerance commuting group increased with the actual commuting time (20–30 min), then fluctuated downwards (30–60 min), and decreased sharply when the actual commuting time exceeded 70 min. It follows that, when the actual commuting time was within the range of ideal commuting times, the perceived satisfaction of the short-duration-tolerance commuters remained largely unchanged, while the perceived satisfaction of the long-duration-tolerance commuters increased; when the actual commuting time exceeded the tolerance threshold, the perceived satisfaction of three clustered groups was severely reduced; as expected, extreme commuting led to very negative perceived experiences.

Finally, the study also concluded that variables such as the commuting mode, job–housing relationship, and individual characteristics provided significant explanations for differences in commuting satisfaction in the clustered group. The commuters who used active commuting modes, those with balanced job–housing relationships, and commuters with lower levels of education were the most likely to be in the short-duration-tolerance commuting group. Conversely, the commuters who used public transportation, those with severe job–housing distance, and highly educated commuters were the most likely to be long-duration-tolerant commuters.

The policy implications obtained from the conclusions are as follows. First, the results of the hypothetical situational experiment show that since the respondents reported a positive response to the 0 min of hypothetical commuting time, we can try to implement some moderate telecommuting systems to test whether remote working helps to improve commuting satisfaction and subjective well-being. Additionally, a dynamic evaluation of the effect of implementing remote work could be conducted to identify whether people's commuting demands are different in the short, medium, long term, as well as during the epidemic (a special period), which will help to provide policy advice for policymakers to formulate mechanisms for telecommuting.

Second, it is important to plan a commuting circle based on the time-threshold effect of nonlinear changes in commuting satisfaction, to try to use the commuting time tolerance threshold as a constraint boundary, and to move as close as possible to ideal commuting times.

Lastly, according to the group differences in the commuting-time satisfaction and its influencing factors, different strategies should be adopted for different commuting groups when formulating policies for urban transport optimization. For example, the commuting quality of the short-duration -tolerant commuters, most of whom live and work in the same area and use active commuting, may be further improved by enhancing the soft and hard facilities of the active travel system; for the long-duration -tolerant commuters, most of whom have a significant distance between their work and housing and use public transport to commute, the operation and service level of public transport could be improved in the short term to reduce their commuting pressure, and the allocation of resources could be optimized in the long term to achieve a relative balance between work and housing.

The limitation of this study is that the representativeness of the sample was not strong. For example, the proportion of commuters over 40 years old was slightly lower and the proportion of commuters with low education was also relatively small, which is related to the selection of commercial complexes as the survey locations. The method of approaching the respondents needs to be improved to ensure that the sample better captures the overall characteristics of commuters. The two surveys (May 2020 and January 2021) were both conducted in the urban area of Kunming, which inevitably resulted in a respondent answering the same questionnaire twice. Trying to avoid such survey issues could help to improve the data quality. Additionally, there are differences in transportation policies and commuting systems in different cities, which means that the perceived satisfaction of commuters in different cities may also be different. It would be interesting to explore the heterogeneity of commuting satisfaction in cities of different scales and its influencing factors.

Furthermore, this study only focused on the threshold effect of commuting satisfaction for different groups in terms of commuting time. In the future, the complex relationship between the commuting satisfaction and commuting times of different groups, including different commuting modes (especially multimodal commuting), different job–housing distances, and different built environments, could be explored. These studies will have potential value for the formulation of differentiated and humanistic urban transport policies.

It should also be added that future research could explore the correlation between commuting satisfaction and perceived utility; if the correlation is strong, the nonlinear characteristics of commuting satisfaction can be drawn upon to modify the perceived utility function, which may facilitate research on commuting-mode-choice behavior or the mutual transfer of commuting modes.

Author Contributions: Conceptualization, M.H. (Mingwei He), J.Y. and M.H. (Min He); methodology, J.Y., M.H. (Mingwei He); formal analysis, J.Y., M.H. (Mingwei He) and M.H. (Min He); investigation, J.Y.; data curation, J.Y., M.H. (Mingwei He); writing—original draft preparation, J.Y., M.H. (Mingwei He); writing—review and editing, M.H. (Mingwei He), J.Y. and M.H. (Min He); supervision, M.H. (Min He), M.H. (Mingwei He); funding acquisition, M.H. (Mingwei He). All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by the National Natural Science Foundation of China (No. 71861017); Yunnan Fundamental Research Projects (Grant no.202001AT070030).

Institutional Review Board Statement: The study was conducted according to the guidelines of the Declaration of Helsinki, and approved by the Ethics Committee of the Kunming University of Science and Technology (1 January 2020).

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: The data used to support the findings of this study are available from the authors upon request.

Conflicts of Interest: The authors declare that they have no competing interests.

References

1. Chatterjee, K.; Chng, S.; Clark, B.; Davis, A.; De Vos, J.; Ettema, D.; Handy, S.; Martin, A.; Reardon, L. Commuting and wellbeing: A critical overview of the literature with implications for policy and future research. *Transp. Rev.* **2020**, *40*, 5–34. [CrossRef]
2. Clark, B.; Chatterjee, K.; Martin, A.; Davis, A. How commuting affects subjective wellbeing. *Transportation* **2020**, *47*, 2777–2805. [CrossRef]
3. Mouratidis, K. Commute satisfaction, neighborhood satisfaction, and housing satisfaction as predictors of subjective well-being and indicators of urban livability. *Travel Behav. Soc.* **2020**, *21*, 265–278. [CrossRef]
4. Olawole, M.O.; Aloba, O. Mobility characteristics of the elderly and their associated level of satisfaction with transport services in Osogbo, Southwestern Nigeria. *Transp. Policy* **2014**, *35*, 105–116. [CrossRef]
5. Kim, J.; Schmocker, J.-D.; Yu, J.W.; Choi, J.Y. Service quality evaluation for urban rail transfer facilities with Rasch analysis. *Travel Behav. Soc.* **2018**, *13*, 26–35. [CrossRef]
6. Meng, B.; Zhan, D.; Hao, L. The Spatial Difference of Residents′Commuting Satisfaction in Beijing Based on Their Social Characteristics. *Sci. Geogr. Sin.* **2013**, *33*, 410–417.
7. Ye, R.; De Vos, J.; Ma, L. New insights in travel satisfaction research. *Transp. Res. Part D-Transp. Environ.* **2022**, *102*, 103163.
8. Morris, E.A.; Zhou, Y. Are long commutes short on benefits? Commute duration and various manifestations of well-being. *Travel Behav. Soc.* **2018**, *11*, 101–110. [CrossRef]
9. Jang, J.; Ko, J. Factors associated with commuter satisfaction across travel time ranges. *Transp. Res. Part F-Traffic Psychol. Behav.* **2019**, *66*, 393–405. [CrossRef]
10. De Vos, J.; Mokhtarian, P.L.; Schwanen, T.; Van Acker, V.; Witlox, F. Travel mode choice and travel satisfaction: Bridging the gap between decision utility and experienced utility. *Transportation* **2016**, *43*, 771–796. [CrossRef]
11. De Vos, J. Do people travel with their preferred travel mode? Analysing the extent of travel mode dissonance and its effect on travel satisfaction. *Transp. Res. Part A-Policy Pract.* **2018**, *117*, 261–274. [CrossRef]
12. St-Louis, E.; Manaugh, K.; van Lierop, D.; El-Geneidy, A. The happy commuter: A comparison of commuter satisfaction across modes. *Transp. Res. Part F-Traffic Psychol. Behav.* **2014**, *26*, 160–170. [CrossRef]
13. Handy, S.; Thigpen, C. Commute quality and its implications for commute satisfaction: Exploring the role of mode, location, and other factors. *Travel Behav. Soc.* **2019**, *16*, 241–248. [CrossRef]
14. Majumdar, B.B.; Jayakumar, M.; Sahu, P.K.; Potoglou, D. Identification of key determinants of travel satisfaction for developing policy instrument to improve quality of life: An analysis of commuting in Delhi. *Transp. Policy* **2021**, *110*, 281–292. [CrossRef]
15. Hook, H.; De Vos, J.; Van Acker, V.; Witlox, F. Do travel options influence how commute time satisfaction relates to the residential built environment? *J. Transp. Geogr.* **2021**, *92*, 103021. [CrossRef]
16. Sukhov, A.; Lattman, K.; Olsson, L.E.; Friman, M.; Fujii, S. Assessing travel satisfaction in public transport: A configurational approach. *Transp. Res. Part D-Transp. Environ.* **2021**, *93*, 102732. [CrossRef]
17. Kazemzadeh, K.; Ronchi, E. From bike to electric bike level-of-service. *Transp. Rev.* **2022**, *42*, 6–31. [CrossRef]
18. De Vos, J. Satisfaction-induced travel behaviour. *Transp. Res. Part F-Traffic Psychol. Behav.* **2019**, *63*, 12–21. [CrossRef]

19. Gerber, P.; Theriault, M.; Enaux, C.; Carpentier-Postel, S. Links between Attitudes, Mode Choice, and Travel Satisfaction: A Cross-Border Long-Commute Case Study. *Sustainability* **2020**, *12*, 9203. [CrossRef]
20. Mazurova, B.; Kollar, J.; Nedelova, G. Travel Mode of Commuting in Context of Subjective Well-Being-Experience from Slovakia. *Sustainability* **2021**, *13*, 3030. [CrossRef]
21. Ta, N.; Li, H.; Chai, Y.; Wu, J. The impact of green space exposure on satisfaction with active travel trips. *Transp. Res. Part D-Transp. Environ.* **2021**, *99*, 103022. [CrossRef]
22. Wild, K.; Woodward, A. Why are cyclists the happiest commuters? Health, pleasure and the e-bike. *J. Transp. Health* **2019**, *14*, 100569. [CrossRef]
23. Smith, O. Commute well-being differences by mode: Evidence from Portland, Oregon, USA. J. *Transp. Health* **2017**, *4*, 246–254. [CrossRef]
24. Higgins, C.D.; Sweet, M.N.; Kanaroglou, P.S. All minutes are not equal: Travel time and the effects of congestion on commute satisfaction in Canadian cities. *Transportation* **2018**, *45*, 1249–1268. [CrossRef]
25. Yang, M.; Zhao, J.; Wang, W.; Liu, Z.; Li, Z. Metro commuters' satisfaction in multi-type access and egress transferring groups. *Transp. Res. Part D-Transp. Environ.* **2015**, *34*, 179–194. [CrossRef]
26. Efthymiou, D.; Antoniou, C.; Tyrinopoulos, Y.; Skaltsogianni, E. Factors affecting bus users' satisfaction in times of economic crisis. *Transp. Res. Part A-Policy Pract.* **2018**, *114*, 3–12. [CrossRef]
27. Grise, E.; El-Geneidy, A. Transferring Matters: Analysis of the Influence of Transfers on Trip Satisfaction. *Transp. Res. Rec.* **2019**, *2673*, 254–265. [CrossRef]
28. Mouratidis, K.; Ettema, D.; Naess, P. Urban form, travel behavior, and travel satisfaction. *Transp. Res. Part A-Policy Pract.* **2019**, *129*, 306–320. [CrossRef]
29. Said, M.; Abou-Zeid, M.; Kaysi, I. Modeling Satisfaction with the Walking Environment: The Case of an Urban University Neighborhood in a Developing Country. Ph.D. Thesis, American University of Beirut, Beirut, Lebanon, 2015.
30. Echiburu, T.; Hurtubia, R.; Carlos Munoz, J. The role of perceived satisfaction and the built environment on the frequency of cycle-commuting. *J. Transp. Land Use* **2021**, *14*, 171–196. [CrossRef]
31. Humagain, P.; De Vos, J.; Singleton, P.A. Analyzing travel captivity by measuring the gap in travel satisfaction between chosen and alternative commute modes. *Transp. Res. Part D-Transp. Environ.* **2021**, *97*, 102965. [CrossRef]
32. Manaugh, K.; El-Geneidy, A.M. Does distance matter? Exploring the links among values, motivations, home location, and satisfaction in walking trips. *Transp. Res. Part A-Policy Pract.* **2013**, *50*, 198–208. [CrossRef]
33. Wei, D.; Cao, X.; Wang, M. What Determines the Psychological Well-Being during Commute in Xi'an: The Role of Built Environment, Travel Attitude, and Travel Characteristics. *Sustainability* **2019**, *11*, 1328. [CrossRef]
34. De Vos, J.; Singleton, P.A.; Garling, T. From attitude to satisfaction: Introducing the travel mode choice cycle. *Transp. Rev.* **2022**, *42*, 204–221. [CrossRef]
35. Jun, M.-J.; Kwon, K.-H.; Jeong, J.-E. An evaluation of the value of time for commuting in Seoul: A life satisfaction approach. *Int. J. Sustain. Transp.* **2019**, *13*, 703–709. [CrossRef]
36. Humagain, P.; Singleton, P.A. Exploring satisfaction with travel time profiles towards understanding intrinsic utilities of travel time. *Travel Behav. Soc.* **2021**, *24*, 22–33. [CrossRef]
37. Mokhtarian, P.L.; Papon, F.; Goulard, M.; Diana, M. What makes travel pleasant and/or tiring? An investigation based on the French National Travel Survey. *Transportation* **2015**, *42*, 1103–1128. [CrossRef]
38. Morris, E.A.; Guerra, E. Are we there yet? Trip duration and mood during travel. *Transp. Res. Part F-Traffic Psychol. Behav.* **2015**, *33*, 38–47. [CrossRef]
39. Lancee, S.; Veenhoven, R.; Burger, M. Mood during commute in the Netherlands What way of travel feels best for what kind of people? *Transp. Res. Part A-Policy Pract.* **2017**, *104*, 195–208.
40. Milakis, D.; Cervero, R.; van Wee, B.; Maat, K. Do people consider an acceptable travel time? Evidence from Berkeley, CA. *J. Transp. Geogr.* **2015**, *44*, 76–86. [CrossRef]
41. Ye, R.; De Vos, J.; Ma, L. Analysing the association of dissonance between actual and ideal commute time and commute satisfaction. *Transp. Res. Part A-Policy Pract.* **2020**, *132*, 47–60. [CrossRef]
42. Milakis, D.; van Wee, B. For me it is always like half an hour: Exploring the acceptable travel time concept in the US and European contexts. *Transp. Policy* **2018**, *64*, 113–122. [CrossRef]
43. Humagain, P.; Singleton, P.A. Investigating travel time satisfaction and actual versus ideal commute times: A path analysis approach. *J. Transp. Health* **2020**, *16*, 100829. [CrossRef]
44. Redman, L.; Friman, M.; Garling, T.; Hartig, T. Quality attributes of public transport that attract car users: A research review. *Transp. Policy* **2013**, *25*, 119–127. [CrossRef]
45. Olsson, L.E.; Garling, T.; Ettema, D.; Friman, M.; Fujii, S. Happiness and Satisfaction with Work Commute. *Soc. Indic. Res.* **2013**, *111*, 255–263. [CrossRef] [PubMed]
46. Zhu, J.; Fan, Y. Daily travel behavior and emotional well-being: Effects of trip mode, duration, purpose, and companionship. *Transp. Res. Part A-Policy Pract.* **2018**, *118*, 360–373. [CrossRef]
47. Zhu, J.; Fan, Y. Commute happiness in Xi'an, China: Effects of commute mode, duration, and frequency. *Travel Behav. Soc.* **2018**, *11*, 43–51. [CrossRef]

48. Zhu, Z.; Li, Z.; Chen, H.; Liu, Y.; Zeng, J. Subjective well-being in China: How much does commuting matter? *Transportation* **2019**, *46*, 1505–1524. [CrossRef]
49. Young, W.; Morris, J. Evaluation by individuals of their travel time to work. *Transp. Res. Rec. J. Transp. Res. Board* **1981**, *794*, 51–59.
50. Redmond, L.S.; Mokhtarian, P.L. The positive utility of the commute: Modeling ideal commute time and relative desired commute amount. *Transportation* **2001**, *28*, 179–205. [CrossRef]
51. Korsu, E. Tolerance to commuting in urban household location choice: Evidence from the Paris metropolitan area. *Environ. Plan. A-Econ. Space* **2012**, *44*, 1951–1968. [CrossRef]
52. Vale, D.S. Does commuting time tolerance impede sustainable urban mobility? Analysing the impacts on commuting behaviour as a result of workplace relocation to a mixed-use centre in Lisbon. *J. Transp. Geogr.* **2013**, *32*, 38–48. [CrossRef]
53. Le, H.T.; Buehler, R.; Fan, Y.; Hankey, S. Expanding the positive utility of travel through weeklong tracking: Within-person and multi-environment variability of ideal travel time. *J. Transp. Geogr.* **2020**, *84*, 102679. [CrossRef]
54. Ermagun, A.; Erinne, J.; Fan, Y. Travel duration tolerance: Examining the sensitivity of emotional well-being to trip duration. *Transp. Res. Part D-Transp. Environ.* **2022**, *102*, 103137. [CrossRef]
55. Paez, A.; Whalen, K. Enjoyment of commute: A comparison of different transportation modes. *Transp. Res. Part A-Policy Pract.* **2010**, *44*, 537–549. [CrossRef]
56. He, M.; Zhao, S.; He, M. Ideal Commute Time Analysis Based on Travelers Cognition. *J. Transp. Syst. Eng. Inf. Technol.* **2015**, *15*, 161–165.
57. He, M.; Zhao, S.; He, M. Tolerance threshold of commuting time: Evidence from Kunming, China. *J. Transp. Geogr.* **2016**, *57*, 1–7. [CrossRef]
58. He, M.; Cun, Y.; Shi, Z.; He, B. Distributional characteristics and influencing factors of tolerance threshold of commuting time for car users. *J. Shenzhen University. Sci. Eng.* **2021**, *38*, 340–346. [CrossRef]
59. Zhao, M.; Sun, L.; Tyler, N.; Lan, C. Development of Satisfaction Index of Commute Travel Based on Inductive Learning. *J. Tongji University. Nat. Sci.* **2011**, *39*, 1303–1306.
60. Chinese Institute of Urban Planning and Design. Commuting monitoring report for major cities in China. 2020. Available online: http://www.planning.org.cn/news/view?id=10640 (accessed on 2 April 2022).
61. He, M.; Zhao, S. Determinants of long-duration commuting and long-duration commuters' perceptions and attitudes toward commuting time: Evidence from Kunming, China. *IATSS Res.* **2017**, *41*, 22–29. [CrossRef]
62. Sun, S.; Yao, Y.; Xu, L.; He, X.; Duan, Z. The use of E-moped increases commute satisfaction and subjective well-being: Evidence from Shanghai, China. *Transp. Policy* **2022**, *117*, 60–73. [CrossRef]
63. Kunming Institute of Urban Transportation. *Kunming Urban Transportation Annual Development Report, China*. 2019. Available online: http://kmuti.km.org.cn/jtnb/2019 (accessed on 2 April 2022).
64. Cherry, C.R.; Yang, H.; Jones, L.R.; He, M. Dynamics of electric bike ownership and use in Kunming, China. *Transp. Policy* **2016**, *45*, 127–135. [CrossRef]
65. Kazemzadeh, K.; Bansal, P. Electric bike navigation comfort in pedestrian crowds. *Sustain. Cities Soc.* **2021**, *69*, 102841. [CrossRef]
66. Vincent-Geslin, S.; Ravalet, E. Determinants of extreme commuting. Evidence from Brussels, Geneva and Lyon. *J. Transp. Geogr.* **2016**, *54*, 240–247. [CrossRef]
67. Nie, P.; Sousa-Poza, A. Commute time and subjective well-being in urban China. *China Econ. Rev.* **2018**, *48*, 188–204. [CrossRef]
68. Kim, S.; Kim, Y.; Lim, S.-S.; Ryoo, J.-H.; Yoon, J.-H. Long Commute Time and Sleep Problems with Gender Difference in Work-Life Balance: A Cross-sectional Study of More than 25,000 Workers. *Saf. Health Work.* **2019**, *10*, 470–475. [CrossRef] [PubMed]
69. Zhao, P.; Liu, D.; Yu, Z.; Hu, H. Long commutes and transport inequity in China's growing megacity: New evidence from Beijing using mobile phone data. *Travel Behav. Soc.* **2020**, *20*, 248–263. [CrossRef]
70. Ettema, D.; Garling, T.; Eriksson, L.; Friman, M.; Olsson, L.E.; Fujii, S. Satisfaction with travel and subjective well-being: Development and test of a measurement tool. *Transp. Res. Part F-Traffic Psychol. Behav.* **2011**, *12*, 167–175.
71. Ettema, D.; Garling, T.; Olsson, L.E.; Friman, M.; Moerdijk, S. The road to happiness: Measuring Dutch car drivers' satisfaction with travel. *Transp. Policy* **2013**, *27*, 171–178. [CrossRef]
72. De Vos, J.; Schwanen, T.; Van Acker, V.; Witlox, F. How satisfying is the Scale for Travel Satisfaction? *Transp. Res. Part F-Traffic Psychol. Behav.* **2015**, *29*, 121–130. [CrossRef]
73. Ye, R.; Titheridge, H. Satisfaction with the commute: The role of travel mode choice, built environment and attitudes. *Transp. Res. Part D-Transp. Environ.* **2017**, *52*, 535–547. [CrossRef]
74. Celebi, M.E.; Kingravi, H.A.; Vela, P.A. A comparative study of efficient initialization methods for the k-means clustering algorithm. *Expert Syst. Appl.* **2013**, *40*, 200–210. [CrossRef]
75. Biau, G. Analysis of a Random Forests Model. *J. Mach. Learn. Res.* **2012**, *13*, 1063–1095.
76. Muller, C.J.; MacLehose, R.F. Estimating predicted probabilities from logistic regression: Different methods correspond to different target populations. *Int. J. Epidemiol.* **2014**, *43*, 962–970. [CrossRef] [PubMed]
77. De Vos, J.; Singleton, P.A. Travel and cognitive dissonance. *Transp. Res. Part A-Policy Pract.* **2020**, *138*, 525-536.
78. Pritchard, J.P.; Slovic, A.D.; Giannotti, M.; Geurs, K.; Nardocci, A.; Hagen-Zanker, A.; Tomasiello, D.B.; Kumar, P. Satisfaction with travel, ideal commuting, and accessibility to employment. *J. Transp. Land Use* **2021**, *14*, 995–1017. [CrossRef]

sustainability

Article

Analysis of Ride-Hailing Passenger Satisfaction and Life Satisfaction Based on a MIMIC Model

Gang Li [1,2], Ruining Zhang [3], Shujuan Guo [1,*] and Junyi Zhang [4]

[1] College of Transportation Engineering, Dalian Maritime University, Dalian 116026, China
[2] School of Traffic and Transportation Engineering, Dalian Jiaotong University, Dalian 116028, China
[3] Chengdu Metro Operation Co., Ltd., Chengdu 610031, China
[4] Graduate School for International Development and Cooperation, Hiroshima University, Hiroshima 739-8529, Japan
* Correspondence: guoshujuan@dlmu.edu.cn; Tel.: +86-13940801560

Abstract: Well-being enhancement is an essential goal of urban transportation. As an emerging and popular mode of urban transportation, the impact of the ride-hailing service on people's well-being has not been well examined, especially in developing countries. In order to study the influencing factors of ride-hailing passenger satisfaction and the relationship between passenger satisfaction and subjective well-being, a conceptual framework of the relationships between ride-hailing passengers' characteristics, the service quality of ride-hailing (service perception, operation service, external influence, and safety perception), passenger satisfaction, and life satisfaction is developed and verified with data collected in Dalian city, China. A comparative analysis between express and hitch in the ride-hailing service is conducted by a multiple indicators multiple causes model. The result shows that service perception, safety perception, external influence, and operation service have significantly positive effects on passenger satisfaction in both express and hitch, but they play diverse roles. Passenger satisfaction in express and hitch positively and differently affects their respective life satisfaction with the consideration of individual heterogeneity in terms of socio-economic characteristics. These findings complement the interaction mechanism of service quality, passenger satisfaction, and life satisfaction in the field of ride-hailing; they provide critical insights for ride-hailing platforms and policymakers to satisfy the diversified travel needs and the well-being improvement of the public.

Keywords: ride-hailing; passenger satisfaction; life satisfaction; multiple indicators multiple causes model; service quality

Citation: Li, G.; Zhang, R.; Guo, S.; Zhang, J. Analysis of Ride-Hailing Passenger Satisfaction and Life Satisfaction Based on a MIMIC Model. *Sustainability* **2022**, *14*, 10954. https://doi.org/10.3390/su141710954

Academic Editors: Mengqiu Cao, Claire Papaix, Tianren Yang and Benjamin Büttner

Received: 23 July 2022
Accepted: 27 August 2022
Published: 2 September 2022

1. Introduction

Ride-hailing refers to the business activities of building a service platform based on internet technology, integrating supply and demand information, and using qualified vehicles and drivers to provide taxi-booking services. In conjunction with rail transit and buses, ride-hailing, by overcoming the fixed route limitation and offering 24 h door-to-door services to the public, is considered to be an essential part of an urban public transportation system [1]. In the past several years, the ride-hailing platforms, such as Uber, Lyft, Didi Chuxing, and Grab, have developed rapidly, and their services have become increasingly prevalent all over the world [2,3]. In China, Didi Chuxing, the largest ride-hailing platform, provides several options, such as premier, express, and hitch, for a variety of travelers. According to the China Internet Network Information Center, the number of ride-hailing users in China reached 453 million by December 2021 [4]. Ride-hailing provides diversified travel options for urban residents, enhances their mobility, and facilitates their daily lives. The ride-hailing passengers have become an important group of trip makers in urban transportation. Exploring the travel behavior of ride-hailing passengers is conducive to transportation planning and policy formulation. The accurate market positioning and rational use of ride-hailing can meet the diversified travel needs of urban residents as well as promote the improvement of people's well-being through a pleasant travel experience, which contributes to the sustainable development of urban transportation.

At present, the research on ride-hailing mainly focuses on the characteristics of ride-hailing passengers [5,6], the temporal and spatial characteristics of ride-hailing trips [7–9], the impact of ride-hailing on other urban transportation modes [10–13], and the comparative analysis of different types of ride-hailing [14,15]. The service quality of ride-hailing is not only an important factor in improving passenger satisfaction with ride-hailing, it is also the key to maintaining the sustainable competitiveness of ride-hailing. Shah and Hisashi [16] analyzed the impact of ride-hailing service quality on passengers' behavior and attitude in developing countries by using a structural equation model (SEM). Nguyen-Phuoc et al. [17] used a partial least squares structural equation model (PLS-SEM) to study the perceived quality before using a ride-hailing service (such as safety, convenience, functionality, information accuracy, etc.) and after the service (such as reliability, convenience, etc.) on the willingness to continue the use of ride-hailing. Zuo et al. [18] conducted data mining for the network evaluation on the Didi Chuxing platform, analyzed the service process of ride-hailing based on the optimization method of the process chain network, and put forward corresponding suggestions for the service quality optimization. Rizki et al. [19] used the SEM to analyze the impact of service quality at different service stages on passengers' use frequency. Zhang and Zhang [20] improved the operation efficiency of different modes in the ride-hailing service by establishing a model of the vacant trip and loading rate assessment. In order to improve the service quality of ride-hailing, Sun and Ding [21] attempted to recognize the potential influencing factors with a two-level growth model.

Some studies further explore the interactions between service quality, passenger satisfaction, and loyalty. Cheng et al. [22] studied the factors affecting the online and offline service quality of ride-hailing driven by sharing economy and their impact on passenger satisfaction and loyalty, using a PLS-SEM. Nguyen-Phuoc et al. [1] analyzed the effects of perceived reservation software benefits, perceived discounts, and perceived service quality on ride-hailing passengers' satisfaction and loyalty, using a PLS-SEM, and found that perceived service quality is more important than other factors. Nguyen-Phuoc et al. [23] used a PLS-SEM to analyze the impact of perceived risk on the satisfaction and loyalty of ride-hailing passengers and found that the risks related to vehicles and drivers directly affected the satisfaction and loyalty of passengers. The articles above have not analyzed the external influences of ride-hailing on passenger satisfaction. With the rapid social and economic development, the urban transportation system in China is facing unprecedented challenges, such as traffic congestion, air pollution, and noise pollution. It has become very important for the passengers to evaluate these potential impacts of ride-hailing. This paper explores the impact of service quality on passenger satisfaction from four aspects: service perception (punctuality, convenience, and comfort); operation service (operation time range, operation area coverage, travel time, and travel cost); external influence (traffic congestion, noise pollution, and air pollution); and safety perception (information safety, personal safety, and traffic safety).

The analysis of individual heterogeneity is helpful to the formulation of transportation policy. There are few studies on the impact of personal heterogeneity on passenger satisfaction with ride-hailing. Existing studies have shown that socio-economic characteristics, such as age, education, occupation, and private car ownership, have a significant impact on the service quality and passenger satisfaction with transportation modes. Ingvardson and Nielsen [24] studied the critical elements of public transport satisfaction by using a multiple indicators multiple causes (MIMIC) model and found that there were obvious differences in the socio-economic characteristics in the passengers' satisfaction, and the satisfaction of young people with the service quality was lower than that of middle-aged and elderly people. De Oña [25] used a MIMIC model to analyze the impact of personal heterogeneity on service quality and passenger satisfaction with public transport modes and found that gender, income, and residence had an impact on service quality, while gender and education had an impact on passenger satisfaction. This paper analyzes the impact of personal socio-economic characteristics on latent variables to understand the population heterogeneity so that the ride-hailing platform can provide targeted services for its users and enhance the satisfaction and usage intention of ride-hailing passengers.

Promoting the subjective well-being (SWB) of the public is one of the critical goals in an urban transportation policy [26] which enhances social sustainability [27]. Recently, the relationship of travel satisfaction and SWB has been widely considered and discussed in travel behavior analysis. Scholars promote the cognition and emotional experience of people's travel as an important part of subjective well-being and as a new rule to measure transportation services [28,29]. SWB includes positive emotion, negative emotion, and life satisfaction. Life satisfaction is a cognitive assessment of a person's quality of life over a long period of time [30], which generally covers several dimensions, such as family life, work life, and leisure life [31]. Through the evaluation of the impact of car ownership and usage on travel and life satisfaction, Li et al. [26] found that car owners' attitudes towards the instrumental and affective roles of cars have a great positive influence on their travel and life satisfaction. De Vos et al. [32] explored the relationship between travel and well-being and confirmed that travel played a role in SWB through travel experience and activity participation. Yin et al. [33] revealed by an SEM that travel by subway significantly affected passengers' life satisfaction through the connecting bus service quality, walking environment, and travel satisfaction in China. Moeinaddini et al. [34] used a comprehensive dataset to illustrate that the public transport satisfaction is one of the important factors affecting life satisfaction in European cities. It facilitated the making of better decisions about European policies regarding urban life quality. Gärling and Connolly [35] found that increasing travel satisfaction can obviously reduce the negative impact on emotional well-being and life satisfaction. Ma et al. [36] found out that regular travel by bicycle had an influential effect on reducing psychological distress and improving life satisfaction.

The existing research on passenger satisfaction in ride-hailing mainly discusses the relationship between service quality, passenger satisfaction, and loyalty, which is limited to satisfying people's mobility and accessibility but rarely involves improving people's higher-level well-being needs. There is a gap of understanding of the mechanism of passenger satisfaction and individual life satisfaction in the ride-hailing field. Meanwhile, people usually evaluate the level of service of ride-hailing and show attitudes towards their lives differently due to the individual heterogenicity, which requires the implementation of different transportation policies towards different groups of targets. There is little research on the impact of individual heterogeneity of ride-hailing passengers on service quality, passenger satisfaction, and life satisfaction. The SEM is one of the most commonly used methods to explore the behavior intention, but this model ignores the heterogeneity of the socioeconomic characteristics of individuals. A few studies include the social and economic characteristics of travelers, such as gender, age, and income, in the SEM as a construct. However, as these characteristics have no commonality and cannot be measured by a Likert scale, it is unreasonable to regard them as the same construct. Moreover, even if they are included in the model, the impact of each social and economic characteristic on latent variables cannot be analyzed in depth. Therefore, some scholars put forward a MIMIC model on the basis of the SEM. As a MIMIC model has the advantage of considering the unobservable latent variables and better explaining the cause variables, such as personal socio-economic characteristics, over the traditional SEM, the main purpose of this study conducted by the MIMIC model is to construct and validate a conceptual framework representing the interrelationships between service quality, passenger satisfaction, and life satisfaction with the consideration of the heterogeneity of passengers in terms of socio-economic characteristics. This study contributes to both the theory and the practice of the ride-hailing service. The usage impact of ride-hailing, as an emerging and personalized travel mode for residents, on personal life satisfaction is examined. It theoretically contributes the mechanism between service quality, travel satisfaction, and life satisfaction in the literature, especially in the ride-hailing field, which is not explored in the previous studies. It also becomes a basis of the policy making for the improvement of the life quality of urban residents. From a practical perspective, this paper makes a comparative analysis of two kinds of widely used ride-hailing, express and hitch, with consideration of individual heterogeneity, aiming to promote the ride-hailing platform in order to provide targeted services for its users and improve the satisfaction and usage willingness of the ride-hailing passengers and to provide a theoretical basis and policy suggestions for the ride-hailing market segmentation.

The remainder of the paper is structured as follows. Section 2 describes the collection of the data and the respondents' characteristics; this is followed by the research method in Section 3, describing the research hypothesis of the ride-hailing passengers' socio-economic characteristics, service quality, passenger satisfaction, and life satisfaction. The model estimation is presented in Section 4. The findings are discussed in Section 5, followed by the conclusions in Section 6.

2. Questionnaire Survey and Data Analysis

2.1. Design and Implementation of Questionnaire

This survey adopts the method of combining the revealed preference survey and the stated preference (SP) survey. The main contents of the survey include three parts: basic personal and family information, usage and evaluation of ride-hailing on a daily trip, and SP in travel behavior. In the first two parts of the questionnaire, the five-point Likert scale was used to evaluate various ride-hailing services and personal life satisfaction, with 1, 2, 3, 4, and 5 indicating very dissatisfied, dissatisfied, average, satisfied, and very satisfied, respectively. This paper mainly uses the first two parts of the questionnaire to analyze the relationships between personal characteristics, service quality, travel satisfaction, and life satisfaction.

From May to June 2018, a random sampling survey was conducted in Xi'an Road, Qingniwa Bridge, High-Tech Wanda, and Huanan Square, four main business districts of Dalian city, Liaoning Province, China. These four survey areas are representative crowd gathering places in Dalian city, involving commercial, office, residential, and other land use, which makes it more convenient to investigate all kinds of people using ride-hailing. Several screening questions were used in the questionnaire to ensure that the respondents could be more representative of ride-hailing passengers and meet our survey needs. For example, "How old are you?" and "Have you ever used an express or hitch?" were used to select respondents in the survey. A total of 2158 questionnaires were distributed. After data processing, the questionnaires with contradictory contents and non-response items in the main variables were deleted. Finally, 1362 valid questionnaires were used for express and 1031 for hitch. Sections 2.2 and 2.3 explain the variables that were used in the analysis.

2.2. Descriptive Analysis of Data

Table 1 presents the demographic information of the respondents, such as gender, age, education, occupation, and family monthly income. This paper uses SPSS 26 to analyze the survey data. It can be seen that the proportion of men and women was relatively balanced in express and hitch. Nearly half of respondents were aged from 18 to 25 years old in express and hitch. The number of respondents aged from 26 to 30 and from 31 to 40 was roughly the same (about 22% of the total). The proportion of people over 40 who use ride-hailing was the lowest. More than half of the respondents in express and hitch had an undergraduate university degree, followed by college. In express, the respondents with a family monthly income of more than RMB 13,000 accounted for the largest proportion. Conversely, in hitch, the respondents with a family monthly income between RMB 5000 and 7000 accounted for the largest proportion. In both express and hitch, the lowest proportion of respondents comprised those with a family monthly income of less than RMB 5000. Generally, the passengers in express had a higher family monthly income than the ones in hitch. More than three quarters of the respondents in express and hitch had no children.

More than half of the respondents in express and hitch had private cars, and the proportion was a little larger in express than the one in hitch.

Table 1. Socio-economic characteristics of the sample.

Socio-Economic Characteristics (%)	Express n = 1362	Hitch n = 1031
Gender		
Male	52.4	52.5
Female	47.6	47.5
Age		
18–25	46.4	45.9
26–30	23.8	23.0
31–40	20.6	21.4
41–50	7.4	7.6
51 or above	1.8	2.1
Education		
High school or below	9.3	9.5
College	17.5	17.3
Undergraduate university degree	64.2	64.8
Postgraduate university degree or above	9.0	8.4
Occupation		
Worker	4.6	5.2
Farmer	0.3	0.6
Government officer	8.8	7.1
Student	38.1	38.8
Service industry personnel	12.8	15.3
Educational researchers	5.0	4.4
Medical staff	3.1	2.3
Management technician	10.0	9.9
Self-employed	8.7	7.4
Other	8.7	9.0
Family monthly income (RMB)		
<5000	9.9	12.3
5000–7000	20.5	23.2
7000–9000	17.2	17.8
9000–11,000	14.6	13.7
11,000–13,000	15.9	14.7
>13,000	22.0	18.3
Couple with children		
Yes	23.8	24.0
No	76.2	76.0
Car ownership		
Yes	62.4	58.4
No	37.6	41.6

2.3. Reliability and Validity Test of Data

In order to test the rationality of the questionnaire and the survey data quality, this paper tests the reliability and validity of the data with the help of SPSS 26 software. The reliability of the survey data was tested by a Cronbach's alpha coefficient. Generally, a Cronbach's alpha coefficient greater than 0.7 indicates that the data have strong internal consistency. The validity of the data was tested by KMO statistics and the Bartlett sphere test. Generally, the KMO value is >0.5 [37], the significance probability value of the Bartlett sphere test is $p < 0.001$ [38], and the factor loading in the component matrix is greater than 0.5 [38], indicating good validity.

The results in Table 2 show that except for the Cronbach's alpha coefficient of passenger satisfaction, the other Cronbach's alpha coefficients are greater than 0.7. Rhodes et al. [39,40]

showed that when the number of indicator variables used by the latent variables is smaller, i.e., passenger satisfaction with the two indicator variables of pleasant degree of taking ride-hailing and overall service evaluation, as included here, a Cronbach's alpha coefficient of 0.5 is acceptable and indicates stronger internal consistency. Therefore, the internal consistency of the questionnaire is ideal.

Table 2. Reliability and validity test of data.

Latent Variables		Indicator Variables	Cronbach's Alpha	KMO	Bartlett's Spherical Test	Factor Loadings
Express	Service perception	Punctuality Convenience Comfort	0.80	0.693	0.000	0.84 0.88 0.82
	Operation service	Operation time range Travel time Travel cost Operation area coverage	0.76	0.651	0.000	0.80 0.77 0.72 0.76
	External influence	Traffic congestion Noise pollution Air pollution	0.88	0.743	0.000	0.89 0.91 0.90
	Safety perception	Information safety Personal safety Traffic safety	0.84	0.717	0.000	0.86 0.89 0.85
	Passenger satisfaction	Pleasant degree of taking ride-hailing Overall service evaluation	0.48	0.500	0.000	0.81 0.81
	Life satisfaction	Health Work/study Free time Family life Social life	0.84	0.833	0.000	0.78 0.82 0.74 0.77 0.83
Hitch	Service perception	Punctuality Convenience Comfort	0.80	0.705	0.000	0.84 0.86 0.82
	Operation service	Operation time range Travel time Travel cost Operation area coverage	0.75	0.668	0.000	0.78 0.75 0.72 0.78
	External influence	Traffic congestion Noise pollution Air pollution	0.87	0.739	0.000	0.89 0.89 0.89
	Safety perception	Information Personal safety Traffic safety	0.85	0.727	0.000	0.87 0.89 0.87
	Passenger satisfaction	Pleasant degree of taking ride-hailing Overall service evaluation	0.50	0.500	0.000	0.82 0.82
	Life satisfaction	Health Work/study Free time Family life Social life	0.85	0.835	0.000	0.80 0.82 0.75 0.78 0.83

The KMO values of the data in Table 2 are all greater than 0.5, the significant probability p values of Bartlett spherical test are all less than 0.001, and the factor loadings in the component matrix are all greater than 0.5, indicating that the data validity is ideal. The indicator variables in the measurement model can be well explained by the corresponding latent variables.

3. Model

3.1. Multiple Indicators Multiple Causes Model

A multiple indicators multiple causes (MIMC) model can correct the deviation caused by the heterogeneity of user perception under different travel conditions and socio-demographic characteristics [41]. A MIMIC model describes the causal relationship between latent variables and between latent variables and indicator variables.

The latent variable linearly determined by a set of observable exogenous causes is

$$\eta = \Gamma x + \xi \tag{1}$$

The latent variable is linearly determined by observable endogenous indicators as follows:

$$y = \Lambda\eta + v \tag{2}$$

where η is a latent variable vector; x is the vector of the cause variable that is causally related to the latent variable η; y is the indicator variable vector that has a measurement relationship with the latent variable η; Γ and Λ are the parameter matrices to be estimated; and ξ and v are the measurement errors.

Equations (1) and (2) constitute the MIMIC model, in which the multiple causes part is represented by Equation (1), and the multiple indicators part is represented by Equation (2). According to this study, the specific expression of the multiple causes part of express is modelled as

$$\begin{aligned}\eta_{ln} = c_{l1}gender_n + c_{l2}young_n + c_{l3}middle_n + \\ c_{l4}mincome_n + c_{l5}hincome_n + c_{l6}car_n + \xi_n\end{aligned} \tag{3}$$

According to this study, the specific expression of the multiple causes part of hitch is

$$\begin{aligned}\eta_{ln} = c_{l7}young_n + c_{l8}middle_n + c_{l9}mincome_n \\ + c_{l10}bachelor_n + c_{l11}children_n + \xi_n\end{aligned} \tag{4}$$

where l indicates service perception, operation service, external influence, safety perception, passenger satisfaction, and life satisfaction. n is the observed individual. c represents the parameter to be estimated.

That is, the causes for the individual's latent preferences are gender (equal to one if male); young (equal to one if the individual's age is between 18 and 30 years old); middle (equal to one if the individual's age is between 31 and 40 years old); mincome (equal to one if the family monthly income is between RMB 9000 and 13,000); hincome (equal to one if the family monthly income is more than RMB 13,000); car (equal to one if car ownership is equal to one or greater); bachelor (equal to one if the individual's education is bachelor's degree or above); and the presence of children in the household (equal to one if there is a child in the household).

3.2. Research Hypothesis

The hypotheses are proposed from three aspects.

(1) The impact of service quality on passenger satisfaction.

The existing research shows that service quality, such as comfort [1], economy [1], and safety [23], directly affects passenger satisfaction. This paper discusses the impact of service quality on passenger satisfaction from four aspects: service perception, operation service, external influence, and safety perception. Therefore, the following hypotheses are proposed in this paper.

H1. *Service perception has a directly positive impact on passenger satisfaction.*

H2. *Operation service has a directly positive impact on passenger satisfaction.*

H3. *The satisfaction of external influence has a directly positive impact on passenger satisfaction.*

H4. *Safety perception has a directly positive impact on passenger satisfaction.*

(2) The impact of passenger satisfaction on life satisfaction.

Life satisfaction refers to the cognitive evaluation of a person's quality of life in a period of time [28]. De Vos argued that travel satisfaction will directly or indirectly affect life satisfaction [42]. Travel satisfaction could have a direct influence on life satisfaction through the spill-over effect of the subjective experience during travel, such as good impressions or emotions [29,42,43]. Travel satisfaction could play a role in life satisfaction indirectly through activity participation [44,45]. Travel satisfies personal daily activity needs, whose utility contributes to life satisfaction [29,46]. Meanwhile, satisfaction with various life domains theoretically contributes to overall life satisfaction [47]. Travel is an important part of personal life, so travel satisfaction conceptually has an effect on life satisfaction [33]. A positive impact of travel satisfaction by public transport on life satisfaction has been confirmed [33,34], and this study believes that the passenger satisfaction in ride-hailing travel also has a certain impact on the passenger's life satisfaction. Therefore, this paper proposes the following assumption.

H5. *Passenger satisfaction has a directly positive impact on life satisfaction.*

(3) The influence of the socio-economic characteristics of ride-hailing passengers on service quality, passenger satisfaction, and life satisfaction.

In the study of individual heterogeneity in other transport modes, it is concluded that socio-economic characteristics, such as age [24], occupation [24], gender [25], education [25], income [42], children [42], and car ownership [48], have significant differences in the latent variables. Therefore, this paper puts forward the following hypothesis for the ride-hailing service.

H6. *Socio-economic characteristics have a direct impact on service perception, operation service, external influence, safety perception, passenger satisfaction, and life satisfaction.*

Therefore, the hypothetical model framework of passenger satisfaction and life satisfaction for both express and hitch is shown in Figure 1.

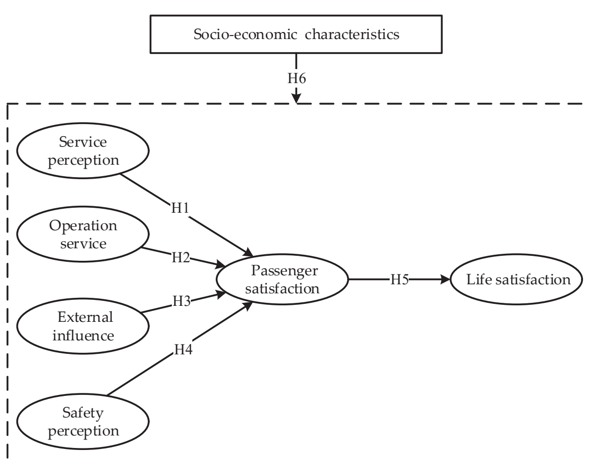


Figure 1. Framework of a hypothesis model for both express and hitch.

4. Model Results

4.1. Model Fitting Test

This paper uses Amos 21 to solve the MIMIC model to analyze the relationships between socio-economic characteristics, service quality, passenger satisfaction, and life satisfaction. According to Mardia's multivariate test statistics, it was found that the Mardia's multivariate test statistics of express and hitch were greater than 5, and the critical ratio was higher than 1.96, indicating that the data of both express and hitch deviated from the multivariate normal distribution at the 95% confidence level [49,50]. Therefore, this paper used Bollen–Stine bootstrapping procedures on 2000 samples to solve the violations of multivariate normality. After the adjustment of the Bollen–Stine bootstrap estimation method, the goodness of fit results of the model were obtained, as shown in Table 3. Their model fitting indices indicate the good establishments of the MIMIC models of express and hitch, where χ^2/df is less than 3, the root mean square error of approximation (RMSEA) is less than 0.08, and the values of the goodness of fit index (GFI), the adjusted goodness of fit index (AGFI), the comparative fit index (CFI), and the Tucker–Lewis index (TLI) were greater than 0.9.

Table 3. Goodness of fit of MIMIC models in express and hitch.

	χ^2	*df*	χ^2/df	RMSEA	GFI	AGFI	CFI	TLI
Express	363.12	293	1.24	0.01	0.98	0.97	1.00	0.99
Hitch	339.22	269	1.26	0.02	0.97	0.97	0.99	0.99

4.2. Structural Model Analysis

It can be seen from Table 4 that service perception, operation service, external influence, and safety perception have a significantly direct and positive impact on passenger satisfaction; so H1, H2, H3, and H4 are supported. Passenger satisfaction has a significantly positive impact on life satisfaction; so, H5 is supported. This result confirms that the satisfaction of ride-hailing passengers has a certain impact on their life satisfaction, which is consistent with the conclusions obtained for the subway and other public transportation [27,30].

Table 4. Results of hypothesis testing for express and hitch.

	Path	Estimate	*p* Value
Express	Passenger satisfaction←Service perception	0.363	***
	Passenger satisfaction←Operation service	0.535	***
	Passenger satisfaction←External influence	0.397	***
	Passenger satisfaction←Safety perception	0.374	***
	Life satisfaction←Passenger satisfaction	0.283	***
Hitch	Passenger satisfaction←Service perception	0.508	***
	Passenger satisfaction←Operation service	0.437	***
	Passenger satisfaction←External influence	0.438	***
	Passenger satisfaction←Safety perception	0.281	***
	Life satisfaction←Passenger satisfaction	0.246	***

Note: *** $p < 0.001$.

The effects of various latent variables of express are shown in Table 5. The total effect of operation service on passenger satisfaction is the largest, indicating that operation service is the key indicator to improve the passenger satisfaction of express, and the service level should be maintained and improved in four aspects: operation time range, operation area coverage, travel time, and travel cost. The impacts of the other latent variables on passenger satisfaction are external influence, safety perception, and service perception, respectively. Although the impacts of the three are similar, ride-hailing passengers pay a little more attention to the external influence than the other two in express. This can infer that ride-hailing passengers are relatively satisfied with the convenience and safety of the express and have a deeper feeling of the external influence caused by the express, such as traffic congestion. Therefore, the ride-hailing platforms should plan the routes more reasonably, regulate driving behavior, and reduce the impact on urban traffic as much as possible. The total effect of passenger satisfaction on life satisfaction is larger and significant, indicating that the passenger satisfaction brought by good express service and utilization experience does play a certain role in improving the life satisfaction of express passengers.

Table 5. Effects among the latent variables in express and hitch.

	Dependent Variable/Mediating Variable	Independent Variable	Direct Effect	Indirect Effect	Total Effect
Express	Life satisfaction	Service perception		0.103	0.103
	Life satisfaction	Safety perception		0.106	0.106
	Life satisfaction	External influence		0.112	0.112
	Life satisfaction	Operation service		0.152	0.152
	Life satisfaction	Passenger satisfaction	0.283		0.283
	Passenger satisfaction	Service perception	0.363		0.363
	Passenger satisfaction	Safety perception	0.374		0.374
	Passenger satisfaction	External influence	0.397		0.397
	Passenger satisfaction	Operation service	0.535		0.535
Hitch	Life satisfaction	Service perception		0.125	0.125
	Life satisfaction	Safety perception		0.069	0.069
	Life satisfaction	External influence		0.108	0.108
	Life satisfaction	Operation service		0.107	0.107
	Life satisfaction	Passenger satisfaction	0.246		0.246
	Passenger satisfaction	Service perception	0.508		0.508
	Passenger satisfaction	Safety perception	0.281		0.281
	Passenger satisfaction	External influence	0.438		0.438
	Passenger satisfaction	Operation service	0.437		0.437

Combined with Tables 4 and 5, the total effect of service perception on passenger satisfaction is the largest in hitch; safety perception has the smallest total effect on passenger satisfaction. External influence and operation service have basically the same impact on passenger satisfaction in hitch. The total effect of passenger satisfaction on life satisfaction is larger and significant, indicating that passenger satisfaction also plays a certain role in improving the life satisfaction of hitch passengers.

As shown in Table 6, the socio-economic characteristics of express passengers have a significant impact on service perception, external influence, safety perception, and life satisfaction and have no significant impact on operation service and passenger satisfaction; so, H6 is partially supported in express. The cause variables reflecting individual heterogeneity among express passengers are gender, age, family monthly income, and private car ownership. In the express, men have a positive impact on safety perception, the ages of 18–30 and 31–40 have a positive impact on service perception, and the higher age group is more sensitive to service perception. Ride-hailing passengers with a family monthly income of RMB 9000 or more have a significantly positive impact on life satisfaction, and the higher the family monthly income, the higher the life satisfaction, which is consistent with the existing research conclusions in the other fields. Ride-hailing passengers from high-income households (family monthly income > RMB 13,000) pay significant attention to the external influence (traffic congestion, noise pollution, and air pollution) brought by ride-hailing, which to some extent reflects the strong environmental awareness of high-income family passengers. The significant coefficient of private car ownership shows that a private car has an important positive effect on improving life satisfaction.

Table 6. Parameter estimation of the express MIMIC model.

	Gender	Young	Middle	Mincome	Hincome	Car
Service perception	-	0.097 **	0.116 ***	-	-	
Safety perception	0.090 **	-	-	-	-	
External influence					0.057 **	
Life satisfaction				0.076 **	0.130 ***	0.085 **
Operation service	-	-	-	-	-	
Passenger satisfaction	-	-	-	-	-	-

Note: *** $p < 0.001$, ** $p < 0.05$.

As shown in Table 7, the socio-economic characteristics of hitch passengers have a significant impact on safety perception, passenger satisfaction, and life satisfaction and have no significant impact on service perception, operation service, and external influence; so, H6 is partially supported in hitch. The causal variables reflecting individual heterogeneity among hitch passengers are age, education, family monthly income, and the presence or absence of children. The results show that people with low education (below undergraduate) pay more attention to the safety of hitch. Ride-hailing passengers with a bachelor's degree or above, with a family monthly income of RMB 9000–13,000, and with children have significant satisfaction with the use of hitch. Ride-hailing passengers aged from 18 to 40 have a positive impact on life satisfaction, which reveals that the use of ride-hailing can meet people's daily personalized travel needs and thereby promote the improvement of life satisfaction to a certain extent.

Table 7. Parameter estimation of the hitch MIMIC model.

	Young	Middle	Bachelor	Mincome	Children
Safety perception	-	-	−0.082 **	-	-
Passenger satisfaction	-	-	0.082 **	0.085 **	0.108 **
Life satisfaction	0.106 **	0.109 ***	-	-	-
Service perception	-	-	-	-	-
External influence	-	-	-	-	-
Operation service	-	-	-	-	-

Note: *** $p < 0.001$, ** $p < 0.05$.

4.3. Measurement Model Analysis

The multiple indicators part of the MIMIC model is a confirmatory factor analysis model. There are 3, 3, 4, 3, 2, and 5 indicator variables for the latent variables: service perception, safety perception, operation service, external influence, passenger satisfaction, and life satisfaction, respectively. As shown in Table 8, all the factor loadings in the measurement model are positive and significant, indicating that the indicator variables can well reflect the latent variables.

Among the indicator variables of service perception in express, convenience has the greatest impact. Express passengers are most concerned about personal safety in safety perception rather than traffic safety and information safety. The satisfaction of the operation time range mostly affects the passengers' evaluation of the express operation service. In the external influence, the three indicators are not much different, and the noise pollution caused by express has a little greater impact. In terms of passenger satisfaction in express, the overall service evaluation plays an important role. Compared with health, family life, and other aspects, people's social life satisfaction evaluation has the greatest impact on life satisfaction. The results reflected by the indicator variables of hitch are basically consistent with those of express, but air pollution and operation area coverage have a little greater impact on external influence and operation service, respectively.

Table 8. Results of express and hitch measurement models.

Latent Variables	Indicator Variables	Estimates	
		Express	Hitch
Service perception	Punctuality	0.739 ***	0.754 ***
	Convenience	0.858 ***	0.794 ***
	Comfort	0.693 ***	0.710 ***
Safety perception	Information safety	0.771 ***	0.789 ***
	Personal safety	0.858 ***	0.849 ***
	Traffic safety	0.755 ***	0.786 ***
Operation service	Operation time range	0.799 ***	0.770 ***
	Travel time	0.563 ***	0.544 ***
	Travel cost	0.513 ***	0.507 ***
	Operation area coverage	0.752 ***	0.772 ***
External influence	Traffic congestion	0.825 ***	0.825 ***
	Noise pollution	0.877 ***	0.826 ***
	Air pollution	0.835 ***	0.827 ***
Passenger satisfaction	Pleasant degree of ride-hailing	0.324 ***	0.319 ***
	Overall service evaluation	0.654 ***	0.682 ***
Life satisfaction	Health	0.688 ***	0.739 ***
	Work/study	0.744 ***	0.769 ***
	Free time	0.649 ***	0.663 ***
	Family life	0.698 ***	0.702 ***
	Social life	0.787 ***	0.777 ***

Note: *** $p < 0.001$.

5. Discussion

5.1. Theoretical Implications

This paper explores the influencing factors of ride-hailing passenger satisfaction and life satisfaction, which were not well examined in the previous studies of travel behavior, and complements the interaction mechanism of service quality, passenger satisfaction, and life satisfaction in the field of ride-hailing. Based on the data obtained from the travel behavior survey of residents who have used ride-hailing in Dalian, China, the conceptual framework of the direct and indirect influence relationships between service perception, operation service, external influence, safety perception, passenger satisfaction, and life satisfaction is verified, theoretically contributing to the knowledge of the formation of passenger attitudes (satisfaction) towards ride-hailing services from the influence factors of service perception, operation service, external influence, and safety perception. Exploring these factors affecting the satisfaction and life satisfaction of ride-hailing passengers is critical, particularly in the context of China where ride-hailing services are considered as a better diversified and personalized transport mode, complementing the urban public transportation.

The study has confirmed that there are significantly direct and positive influences of service perception, safety perception, external influence, and operation service on passenger satisfaction. In express, the total effect of operation service on passenger satisfaction is the largest. Passengers in express services have higher satisfaction when they enjoy a high-quality of operation service, including operation time range, operation area coverage, travel time, and travel cost. The influences of other latent variables on passenger satisfaction are external influence, safety perception, and service perception in turn, but such influences of the three are not much different. In hitch, the total effect of service perception on passenger satisfaction is the largest among the operation service, external influence, safety perception, and service perception, indicating that service perception in terms of punctuality, convenience, and comfort is an important factor in improving passenger satisfaction with hitch. Safety perception has the lowest effect on passenger satisfaction in hitch (the total effect was 0.281), inferring that the hitch passengers generally neglect safety protections issues, comparatively, when they pursue affordable hitch. In addition, with the insufficient safety protection measures of hitch provided by the Didi platform, two tragic casualty events consequently occurred in hitch, and the Didi hitch service was shut down and forced to rectify later in that survey year. The influences of external influence and operation service on passenger satisfaction are almost the same in hitch, which means the enhancement of the passenger satisfaction also needs to consider the external influences such as traffic congestion, noise pollution and air pollution, and operation services, such as operation time range and operation area coverage.

The satisfaction of express and hitch passengers has a significantly positive impact on their life satisfaction, which reveals that ride-hailing, as an important mode of urban transportation, has played a significant role in meeting diversified individual travel needs. Ride-hailing promotes the improvement of passengers' life satisfaction with the well passenger evaluation and the pleasure brought by the daily good service experience, which is in line with previous studies of the relationship between passenger satisfaction and life satisfaction in the public transport field [33,34]. This study contributes empirical evidence for the interaction mechanism between passenger satisfaction and life satisfaction in the ride-hailing field.

Furthermore, the finding of the study reveals a mediating role of passenger satisfaction between the relationships of service quality from the four aspects discussed above, including service perception, safety perception, external influence, operation service, and life satisfaction. These indirect relationships between these constructs were initially uncovered in this study, offering a basis to understand the formation of the mobility and well-being needs of ride-hailing passengers. As these factors, including service perception, safety perception, external influence, and operation service, have obviously affected passenger satisfaction, in order to enhance life satisfaction, the above-mentioned factors should be the direction of improvement in ride-hailing.

The findings of this study show that the socio-economic characteristics of ride-hailing passengers have a significant impact on service quality (service perception, safety perception, external influence, and operation service), passenger satisfaction, and life satisfaction. The socio-economic characteristics of express and hitch passengers have different effects on various latent variables. Family monthly income and private car ownership have a significant impact on life satisfaction in express passengers, while different age groups have a significantly positive effect on life satisfaction in hitch passengers. The different influencing rules of the passengers' socio-economic characteristics on latent variables reveal that express and hitch passengers have different individual heterogeneity, reflecting that ride-hailing platforms really need to provide different types of ride-hailing services for passengers with different needs. This study is an important supplement to the existing research about the impact of individual heterogeneity in terms of socio-economic characteristics on service quality, passenger satisfaction, and life satisfaction in the ride-hailing field and even in public transportation.

5.2. Practice Implications

From the practical perspective, several important implications in the study are suggested for ride-hailing platforms to improve the service quality of express and hitch, to distinguish the concerns of passengers between the two, and to enrich the understanding of the role and fair usage of ride-hailing in urban public transportation. All these point out the direction for policy-making and can effectively promote the improvement of the well-being of urban residents advocated by transportation policy makers through a good travel experience. With the purpose of improving the travel experience (passenger satisfaction) of ride-hailing that greatly contributes to the continuous usage intention of ride-hailing [15], ride-hailing platforms should first improve the operation service, which is the most critical factor affecting the passenger satisfaction in express. It is found that operation time range and operation area coverage have higher effects on operation service in express. Ride-hailing platforms should continue to keep the advantages of operation time and area coverage by positioning and expanding the operation service coverage according to the temporal and spatial needs of travelers in different cities and regions. Meanwhile, ride-hailing platforms should take various countermeasures to optimize the travel routes and should distribute discount coupons to reduce the travel time and cost to enhance the experience of the operation service. Correspondingly, as the most influential factor on passenger satisfaction in hitch is service perception, ride-hailing platforms should improve the level of service in terms of convenience by, for example, further improving the algorithm accuracy of the travel-demand matching between drivers and passengers and passengers and passengers, and by reducing the waiting time of passengers and making it more convenient to pick up and deliver passengers. Ride-hailing platforms should also pay attention to more accurate calculations and predictions of road condition information to ensure the timely delivery of passengers. Although taking hitch may be shared with others, based on its own operating characteristics, the platform should try to reduce the number of passengers in one trip and improve the comfort experience of passengers from the perspectives of the driver's attitude and the internal environment of the vehicle.

It is noteworthy that the significant impact of the external influence of ride-hailing on passenger satisfaction is an important finding. Since the birth of ride-hailing, there has been some controversy about the its negative effects on the urban transportation system, such as traffic congestion and environmental pollution [9,51]. With the continuous enhancement of people's awareness of environmental protection, the public is more concerned about the external influence of ride-hailing. The total effects of external influence on passenger satisfaction in express and hitch are statistically significant, and both reach about 0.4, which proves that. Nowadays, China is ambitiously promoting the strategy of green and low-carbon travel. By the end of March 2022, the number of new energy vehicles reached 8.915 million, accounting for 2.90% of the total number of cars in China [52]. New energy vehicles will be one of the main development directions of China's automotive industry in the future [53]. At present, some ride-hailing drivers have adopted hybrid and pure electric models to engage in the ride-hailing services, which greatly reduces fuel costs and exhaust emissions, and improves the economic and social benefits. The ride-hailing platform needs to make full use of high-tech technologies to reduce the impact of ride-hailing operations on traffic congestion. At the same time, it should comply with the national macro transportation policies and continue to encourage and actively promote the new energy vehicle strategy by means of publicity and subsidies and other means, so as to reduce environmental pollution. The authorities should develop a sustainable urban public transportation system in a more comprehensive way and provide the guidance and support of corresponding policies for the wide application of new energy vehicles for ride-hailing. This contributes to a sustainable city while meeting the diversified travel needs of urban residents and improving residents' life satisfaction.

In terms of safety perception, passengers in express pay much more attention to safety issues than those in hitch, based on the total effects, and furthermore, the significant effects order of the indicator variables is personal safety, information safety, and traffic safety. The ride-hailing platforms should continue to strengthen and improve the personal safety protection measures of passengers, such as continuously improving the review and training of ride-hailing drivers and using the real-time positioning and monitoring, the one-click alarm, etc., which are being widely used at present. Although the model results show that the influence of safety perception in hitch is relatively small, the murder of hitch passengers in 2018, after this survey, resulted in people's generally increasing awareness of personal safety in the use of hitch. In suburban areas at night, female passengers in particular are more inclined to choose other means of transportation rather than ride-hailing. The personal safety of ride-hailing passengers is more important when the monitoring system in developing countries is relatively backward. Secondly, with the wide application of the internet and big data technology, passengers are more sensitive to the protection of personal information. Ride-hailing platforms should take various effective measures to avoid passengers' concerns about the leakage and abuse of their own information. In contrast, passengers worry less about the traffic safety of using ride-hailing, which shows the current good daily operation of ride-hailing.

The order of the total effect of each latent variable on passenger satisfaction between express and hitch is different, indicating that express and hitch have different service characteristics, and the ride-hailing platforms need to continue to deepen the positioning and service level of express and hitch according to their characteristics so as to improve passenger satisfaction. This study provides specific suggestions for two types of ride-hailing to improve passenger satisfaction. The improvement of passenger satisfaction is not only conducive to maintaining the use intention of existing passengers, but also to encouraging potential users to take ride-hailing. As an important supplement to public transport, the passenger satisfaction of ride-hailing will have a significant impact on the life satisfaction of express and hitch passengers, which shows that improving the service quality (service perception, operation service, external influence, and safety perception) of ride-hailing and then improving passenger satisfaction is of great significance in improving citizens' life satisfaction.

The relationship between the socio-economic characteristics and various latent variables, including service quality, passenger satisfaction, and life satisfaction has shown that the personal heterogeneity plays obviously different roles in express and hitch. In order to improve passenger satisfaction and life satisfaction, attention should be paid to people in the express service aged 18–40 or their families with middle and high income (>RMB 9000) and with private cars, while strengthening the collection and feedback of other age groups and female passengers. The good experience of people with high education, middle income, and children or those aged 18–40 should be maintained in the hitch service. Meanwhile, the concerns of people with lower education on the safety of hitch should be strengthened. In these ways, ride-hailing platforms can provide accurate services for all types of passengers, improve the passengers' evaluation of ride-hailing, improve passengers' ride experience, and further expand potential users and improve the quality of life of the passengers.

At present, China is vigorously developing a modern urban public transportation system. As a newly emerging transportation mode under the sharing economy, ride-hailing meets people's personalized travel needs. For example, the express provides people with fast response and economic and comfortable travel services and hitch provides people with economy, convenience, and emission-reduction travel services. Ride-hailing needs accurate market positioning and rational use. While moderately competing with mass transit, it should play a more complementary role in enriching the travel modes of urban residents and organically combining with mass transit. For example, the authorities should guide and encourage the ride-hailing platform by supporting policy to solve the "first mile, last mile" problem of urban residents choosing long-distance public transport and by supporting their travel needs in the times and regions not covered by public transport. Ride-hailing, with its convenient reservation and economical and comfortable travel service, has attracted widespread use by Chinese residents, which may aggravate urban traffic congestion and cause air pollution. In order to realize the sustainable development of urban transportation, local governments should continue to promote the construction of a green and modern urban public transportation system, such as by expanding the coverage of urban public transport, extending the operation time of public transport on holidays, improving the transfer connections between urban public transport and urban external hubs such as railway stations, airports, and long-distance bus stations, and continuously improving the service level of mass transit by policy guidance. In this way, subway, bus, and ride-hailing become reasonably coordinated in the urban public transport system to meet the travel needs, improve the accessibility and pleasant travel experience, and thus promote life satisfaction for urban residents.

6. Conclusions

The relationships between service perception, operation service, external influence, safety perception, passenger satisfaction, and life satisfaction were first analyzed using data from a developing country in the context of a ride-hailing service. The findings in this study provide valuable insights into the theory and practice of economical ride-hailing types, i.e., express and hitch. With respect to the theory, this study complements the interaction mechanism between passenger satisfaction and life satisfaction in the field of public transportation, especially in the ride-hailing service, and enriches the understanding of the influencing factors on the ride-hailing passenger's satisfaction and life satisfaction. In addition, the impacts of individual heterogeneity in terms of socio-economic characteristics contributes to an important supplement to the existing research on ride-hailing. With respect to the practice, the finding in this study has shown the different influences of latent variables on travel satisfaction and life satisfaction and the different influences of indicator variables and cause variables on the latent variables in express and hitch, respectively. According to these influences, the ride-hailing platform should take differentiated countermeasures to specifically meet the diversified travel needs and improve the travel experience of urban residents so as to naturally improve their life satisfaction.

A few limitations that future research could address need to be acknowledged. First, the current framework of particularly referring to the relationship between passenger satisfaction and life satisfaction in the ride-hailing field is empirically examined in a developing country. The differences and similarities across countries should be investigated. Second, with the inclusion of the latent variables in this study, the complex mechanism of ride-hailing's service quality, passenger expectation and complaint, travel satisfaction, passenger loyalty, and subjective well-being, should be further explored to meet the travel mobility and higher needs of the public. Third, the impact of ride-hailing loyalty on the substitution of private car ownership is another interesting issue for the future.

Author Contributions: Conceptualization, G.L., R.Z., S.G. and J.Z.; methodology, G.L., R.Z., S.G. and J.Z.; software, G.L. and R.Z.; validation, S.G.; formal analysis, G.L. and R.Z.; investigation, G.L. and R.Z.; resources, G.L.; data curation, G.L. and R.Z.; writing—original draft preparation, G.L. and R.Z.; writing—review and editing, G.L., R.Z. and S.G.; visualization, G.L. and R.Z.; supervision, S.G. and J.Z.; project administration, G.L.; funding acquisition, G.L. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by the National Natural Science Foundation of China (grant No. 61803066), the China Postdoctoral Science Foundation (grant No. 2018M631781), the Social Science Planning Foundation of Liaoning Province (grant No. L21BGL009), and the Fundamental Research Funds for the Central Universities (grant No. 3132022190).

Institutional Review Board Statement: Ethical review and approval were waived for this study due to no personal identity were involved or reported.

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: Not applicable.

Acknowledgments: We are very grateful to the undergraduate and graduate students at Dalian Jiaotong University who helped with the data collection. We are also grateful to the editors and anonymous reviewers for their suggestions and comments.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Nguyen-phuoc, D.Q.; Su, D.N.; Tran, P.T.K.; Le, D.T.T.; Johnson, L.W. Factors influencing customer's loyalty towards ride-hailing taxi services—A case study of Vietnam. *Transp. Res. Part A Policy Pract.* **2020**, *134*, 96–112. [CrossRef]
2. Guo, Y.; Xin, F.; Barnes, S.J.; Li, X. A 2020 perspective on "Opportunities or threats: The rise of online collaborative consumption (OCC) and its impact on new car sales". *Electron. Commer. Res. Appl.* **2020**, *40*, 100932. [CrossRef]
3. Wang, S.; Noland, R.B. Variation in ride-hailing trips in Chengdu, China. *Transp. Res. Part D Transp. Environ.* **2021**, *90*, 102596. [CrossRef]
4. China Internet Network Information Center. *The 49th China Statistical Report on Internet Development*; China Internet Network Information Center: Beijing, China, 2022. Available online: http://www.cnnic.net.cn/hlwfzyj/hlwxzbg/ (accessed on 15 July 2022).

5. Young, M.; Farber, S. The who, why, and when of Uber and other ride-hailing trips: An examination of a large sample household travel survey. *Transp. Res. Part A Policy Pract.* **2019**, *119*, 383–392. [CrossRef]
6. Tirachini, A.; Del Río, M. Ride-hailing in Santiago de Chile: Users' characterisation and effects on travel behavior. *Transp. Policy* **2019**, *82*, 46–57. [CrossRef]
7. Li, T.; Jing, P.; Li, L.; Sun, D.; Yan, W. Revealing the varying impact of urban built environment on online car-hailing travel in spatio-temporal dimension: An exploratory analysis in Chengdu, China. *Sustainability* **2019**, *11*, 1336. [CrossRef]
8. Jin, G.; Cui, Y.; Zeng, L.; Tang, H.; Feng, Y.; Huang, J. Urban ride-hailing demand prediction with multiple spatio-temporal information fusion network. *Transp. Res. Part C Emerg. Technol.* **2020**, *117*, 102665. [CrossRef]
9. Du, J.; Rakha, H.A.; Breuer, H. An in-depth spatiotemporal analysis of ride-hailing travel: The Chicago case study. *Case Stud. Transp. Policy* **2022**, *10*, 118–129. [CrossRef]
10. Habib, K.N. Mode choice modelling for hailable rides: An investigation of the competition of Uber with other modes by using an integrated non-compensatory choice model with probabilistic choice set formation. *Transp. Res. Part A Policy Pract.* **2019**, *129*, 205–216. [CrossRef]
11. Acheampong, R.A.; Siiba, A.; Okyere, D.K.; Tuffour, J.P. Mobility-on-demand: An empirical study of internet-based ride-hailing adoption factors, travel characteristics and mode substitution effects. *Transp. Res. Part C Emerg. Technol.* **2020**, *115*, 102638. [CrossRef]
12. Shi, K.; Shao, R.; De Vos, J.; Cheng, L.; Witlox, F. The influence of ride-hailing on travel frequency and mode choice. *Transp. Res. Part D Transp. Environ.* **2021**, *101*, 103125. [CrossRef]
13. De Sá, A.L.S.; Pitombo, C.S. Methodological proposal for stated preference scenarios regarding an exploratory evaluation of ride-hailing implications on transit: A Brazilian context analysis. *Case Stud. Transp. Policy* **2021**, *9*, 1727–1736. [CrossRef]
14. Wang, Z.; Chen, X.; Chen, X.M. Ridesplitting is shaping young people's travel behavior: Evidence from comparative survey via ride-sourcing platform. *Transp. Res. Part D Transp. Environ.* **2019**, *75*, 57–71. [CrossRef]
15. Nguyen-phuoc, D.Q.; Tran, P.T.K.; Su, D.N.; Oviedo-Trespalacios, O.; Johnson, L.W. The formation of passenger loyalty: Differences between ride-hailing and traditional taxi services. *Travel Behav. Soc.* **2021**, *24*, 218–230. [CrossRef]
16. Shah, S.A.H.; Hisashi, K. Analyzing travelers' attitude towards ride-hailing services in developing countries: Case of Lahore, Pakistan. *IATSS Res.* **2022**, *46*, 223–235. [CrossRef]
17. Nguyen-phuoc, D.Q.; Vo, N.S.; Su, D.N.; Nguyen, V.H.; Oviedo-Trespalacios, O. What makes passengers continue using and talking positively about ride-hailing services? The role of the booking app and post-booking service quality. *Transp. Res. Part A Policy Pract.* **2021**, *150*, 367–384. [CrossRef]
18. Zuo, W.; Zhu, W.; Chen, S.; He, X. Service quality management of online car-hailing based on PCN in the sharing economy. *Electron. Commer. Res. Appl.* **2019**, *34*, 100827. [CrossRef]
19. Rizki, M.; Joewono, T.B.; Dharmowijoyo, D.B.; Prasetyanto, D. The effects of on-and before-journey advantages using ride-sourcing in Indonesia. *Sustainability* **2021**, *13*, 11117. [CrossRef]
20. Zhang, Z.; Zhang, N. Re-recognition of ride-sourcing service: From the perspective of operational efficiency and social welfare. *Sustainability* **2021**, *13*, 8198. [CrossRef]
21. Sun, D.J.; Ding, X. Spatiotemporal evolution of ridesourcing markets under the new restriction policy: A case study in Shanghai. *Transp. Res. Part A Policy Pract.* **2019**, *130*, 227–239. [CrossRef]
22. Cheng, X.; Fu, S.; De Vreede, G.J. A mixed method investigation of sharing economy driven car-hailing services: Online and offline perspectives. *Int. J. Inf. Manag.* **2018**, *41*, 57–64. [CrossRef]
23. Nguyen-phuoc, D.Q.; Oviedo-trespalacios, O.; Vo, N.S.; Le, P.T.; Van Nguyen, T. How does perceived risk affect passenger satisfaction and loyalty towards ride-sourcing services? *Transp. Res. Part D Transp. Environ.* **2021**, *97*, 102921. [CrossRef]
24. Ingvardson, J.B.; Nielsen, O.A. The relationship between norms, satisfaction and public transport use: A comparison across six European cities using structural equation modelling. *Transp. Res. Part A Policy Pract.* **2019**, *126*, 37–57. [CrossRef]
25. De Oña, J. The role of involvement with public transport in the relationship between service quality, satisfaction and behavioral intentions. *Transp. Res. Part A Policy Pract.* **2020**, *142*, 296–318. [CrossRef]
26. Li, S.A.; Guan, X.; Wang, D. How do constrained car ownership and car use influence travel and life satisfaction? *Transp. Res. Part A Policy Pract.* **2022**, *155*, 202–218. [CrossRef]
27. Ye, R. Impact of Individuals' Commuting Trips on Subjective Well-Being: Evidence from Xi'an. Ph.D. Thesis, University College London, London, UK, 2017. Available online: https://discovery.ucl.ac.uk/id/eprint/1560143 (accessed on 15 July 2022).
28. De Vos, J.; Witlox, F. Travel satisfaction revisited. On the pivotal role of travel satisfaction in conceptualising a travel behaviour process. *Transp. Res. Part A Policy Pract.* **2017**, *106*, 364–373. [CrossRef]
29. Ettema, D.; Gärling, T.; Olsson, L.E.; Friman, M. Out-of-home activities, daily travel, and subjective well-being. *Transp. Res. Part A Policy Pract.* **2010**, *44*, 723–732. [CrossRef]
30. Diener, E.; Diener, M.; Diener, C. Factors predicting the subjective well-being of nations. In *Culture and Well-Being*, 1st ed.; Diener, E., Ed.; Springer: Dordrecht, The Netherlands, 2009; Volume 38, pp. 43–70. [CrossRef]
31. Mouratidis, K. Commute satisfaction, neighborhood satisfaction, and housing satisfaction as predictors of subjective well-being and indicators of urban livability. *Travel Behav. Soc.* **2020**, *21*, 265–278. [CrossRef]
32. De Vos, J.; Schwanen, T.; Van Acker, V.; Witlox, F. Travel and subjective well-being: A focus on findings, methods and future research needs. *Transp. Rev.* **2013**, *33*, 421–442. [CrossRef]

33. Yin, J.; Cao, X.J.; Huang, X. Association between subway and life satisfaction: Evidence from Xi'an, China. *Transp. Res. Part D Transp. Environ.* **2021**, *96*, 102869. [CrossRef]
34. Moeinaddini, M.; Asadi-shekari, Z.; Aghaabbasi, M.; Saadi, I.; Shah, M.Z.; Cools, M. Applying non-parametric models to explore urban life satisfaction in European cities. *Cities* **2020**, *105*, 102851. [CrossRef]
35. Gärling, T.; Fors Connolly, F. Satisfaction with travel and the relationship to well-being. *Int. Encycl. Transp.* **2021**, 177–181. [CrossRef]
36. Ma, L.; Ye, R.; Wang, H. Exploring the causal effects of bicycling for transportation on mental health. *Transp. Res. Part D Transp. Environ.* **2021**, *93*, 102773. [CrossRef]
37. Lai, K.H.; Edwin Cheng, T.C.; Yeung, A.C. An empirical taxonomy for logistics service providers. *Marit. Econ. Logist.* **2004**, *6*, 199–219. [CrossRef]
38. Sun, S.; Duan, Z. Modeling passengers' loyalty to public transit in a two-dimensional framework: A case study in Xiamen, China. *Transp. Res. Part A Policy Pract.* **2019**, *124*, 295–309. [CrossRef]
39. Rhodes, R.E.; Plotnikoff, R.C.; Spence, J.C. Creating parsimony at the expense of precision? Conceptual and applied issues of aggregating belief-based constructs in physical activity research. *Health Educ. Res.* **2004**, *19*, 392–405. [CrossRef] [PubMed]
40. Shevlin, M.; Miles, J.N.V.; Davies, M.N.O.; Walker, S. Coefficient alpha: A useful indicator of reliability? *Personal. Individ. Differ.* **2000**, *28*, 229–237. [CrossRef]
41. Allen, J.; Muñoz, J.C.; De Dios Ortúzar, J. Modelling service-specific and global transit satisfaction under travel and user heterogeneity. *Transp. Res. Part A Policy Pract.* **2018**, *113*, 509–528. [CrossRef]
42. De Vos, J. Analysing the effect of trip satisfaction on satisfaction with the leisure activity at the destination of the trip, in relationship with life satisfaction. *Transportation* **2019**, *46*, 623–645. [CrossRef]
43. Bergstad, C.J.; Gamble, A.; Gärling, T.; Hagman, O.; Polk, M.; Ettema, D.; Olsson, L.E. Subjective well-being related to satisfaction with daily travel. *Transportation* **2011**, *38*, 1–15. [CrossRef]
44. Abou-Zeid, M.; Witter, R.; Bierlaire, M.; Kaufmann, V.; Ben-Akiva, M. Happiness and travel mode switching: Findings from a Swiss public transportation experiment. *Transp. Policy* **2012**, *19*, 93–104. [CrossRef]
45. Diener, E. Subjective well-being: The science of happiness and a proposal for a national index. *Am. Psychol.* **2000**, *55*, 34. [CrossRef] [PubMed]
46. Abou-Zeid, M.; Ben-Akiva, M. Well-being and activity-based models. *Transportation* **2012**, *39*, 1189–1207. [CrossRef]
47. Heller, D.; Watson, D.; Ilies, R. The role of person versus situation in life satisfaction: A critical examination. *Psychol. Bull.* **2004**, *130*, 574. [CrossRef]
48. Allen, J.; Muñoz, J.C.; De Dios Ortúzar, J. On evasion behaviour in public transport: Dissatisfaction or contagion? *Transp. Res. Part A Policy Pract.* **2019**, *130*, 626–651. [CrossRef]
49. Bollen, K.A.; Stine, R.A. Bootstrapping goodness-of-fit measures in structural equation models. *Sociol. Methods Res.* **1992**, *21*, 205–229. [CrossRef]
50. Cao, X.; Mokhtarian, P.L.; Handy, S.L. Do changes in neighborhood characteristics lead to changes in travel behavior? A structural equations modeling approach. *Transportation* **2007**, *34*, 535–556. [CrossRef]
51. Young, M.; Farber, S.; Palm, M. The true cost of sharing: A detour penalty analysis between UberPool and UberX trips in Toronto. *Transp. Res. Part D Transp. Environ.* **2020**, *87*, 102540. [CrossRef]
52. The Ministry of Public Security of the People's Republic of China. Available online: https://www.mps.gov.cn/n2254314/n6409334/c8451247/content.html (accessed on 15 July 2022).
53. General Office of the State Council. Available online: http://www.gov.cn/zhengce/content/2020-11/02/content_5556716.htm (accessed on 15 July 2022).

sustainability

Article

NOAH as an Innovative Tool for Modeling the Use of Suburban Railways

Maciej Kruszyna

Faculty of Civil Engineering, Wrocław University of Science and Technology (Politechnika Wrocławska), Wybrzeże Wyspiańskiego 27, 50-370 Wrocław, Poland; maciej.kruszyna@pwr.edu.pl

Abstract: The paper presents an innovative method called the "Nest of Apes Heuristic" (NOAH) for modeling specific problems by combining technical aspects of transport systems with human decision-making. The method is inspired by nature. At the beginning of the paper, potential problems related to modeling a suburban rail system were presented. The literature review is supplemented with a short description of known heuristics. The basic terminology, procedures, and algorithm are then introduced in detail. The factors of the suburban rail system turn into "Monkeys". Monkeys change their position in the nest, creating leaders and followers. This allows for the comparison of the factor sets in a real system. The case study area covers the vicinity of Wroclaw, the fourth largest city in Poland. Two experiments were conducted. The first takes into account the average values of the factors in order to observe the algorithm's work and formulate the stopping criteria. The second is based on the current values of the factors. The purpose of this work was to evaluate these values and to assess the possibilities of changing them. The obtained results show that the new tool may be useful for modeling and analyzing such problems.

Keywords: suburban railway; human behaviors; modeling; heuristics; algorithm; NOAH

Citation: Kruszyna, M. NOAH as an Innovative Tool for Modeling the Use of Suburban Railways. *Sustainability* **2023**, *15*, 193. https://doi.org/10.3390/su15010193

Academic Editors: Tianren Yang, Mengqiu Cao, Claire Papaix and Benjamin Büttner

Received: 22 October 2022
Revised: 12 December 2022
Accepted: 19 December 2022
Published: 22 December 2022

1. Introduction with the Literature Review

Suburban railways play or should play an important role in agglomerations as the main means of transport connecting the core with the surroundings. Significant numbers of lines, journeys, and seats can affect the choice of means of transport. This creates environmentally friendly travel. Modeling the use of suburban railways should take into account two main aspects: (a) rail operations and (b) cooperation in the transport system. A suburban railway works similarly to all other railways. It is slightly closer to metro systems due to high frequency, while being unlike long-distance rail due to higher stop density and lower speeds. Therefore, the typical problems of planning rail operations should be taken into account. There are numerous studies on these problems. Table 1 contains the list of publications analyzed in this paper concerning the considered problems and heuristic tools. In [1–24], researchers address the problems related to railway modeling, and the authors of [25–28] consider the demand side of transport systems. It is worth noting that [29], discussed below, does not exist in the table because of its review character. In [30–37], researchers address the problems of integration in a suburban transport system. Sources [38,39] show directions for future research, and sources [40–43] contain important definitions (they were not added to the table). In [44–53], authors present different tools used to solve some problems (partially not as transportation problems, but with methodologies inspiring the method presented here). The tools are discussed in Section 2.

Table 1. List of publications analyzed in this paper concerning the considered problems and heuristic tools.

Source	Problem	Tool
Canca et al., 2017 [1]	Line planning	O
Yan et al., 2019 [2]		MILP
Hickish et al., 2020 [3]	Network optimization	GA
Schlechte et al., 2011 [4]		NH
Weik et al., 2020 [5]	Nodes (location, classification)	NH
Ahmed et al., 2020 [6]	Station location	GA
Dong et al., 2020 [7]		O
Qiannan et al., 2022 [8]		NH
Binder et al., 2021 [9]	Timetable creation and rescheduling	SA
Jamili and Pourseyed Aghaee, 2015 [10]		SA
Shang et al., 2018 [11]		NH
Wang et al., 2018 [12]		MILP
Jensen et al., 2016 [13]		NH
Yin et al., 2021 [14]		O
Zhang et al., 2018 [15]		O
Zhang et al., 2019a [16]		MILP
Zhang et al., 2019b [17]		NH
Zhang et al., 2022 [18]		O
Zhao et al., 2021 [19]		MILP
Whitbrook et al., 2018 [20]		MS
Zheng et al., 2014 [21]		BBO
Satoshi et al., 2011 [22]	Operations (delay management, train routing)	TS
Sama et al., 2017 [23]		SI
Oneto et al., 2017 [24]		O
Xiao et al., 2018 [25]	Demand side of the transport system	NH
Shen et al., 2016 [26]		O
Wu et al., 2013 [27]		O
Liu et al., 2019 [28]		ANN
Hansson et al., 2021 [30]	Bus systems and networks	NH
Wei et al., 2021 [31]		NH
Ngo et al., 2021 [32]	Ride-hailing services	NH
Behrends, 2017 [33]	Nodes, coordination	NH
Stead et al., 2019 [34]		NH
Yang et al., 2020 [35]		GA
Lianhua and Xingfang, 2022 [36]		SA
Chen et al., 2020 [37]	Autonomous Vehicles	O
Lopez and Farooq, 2020 [39]	Smart mobility data-markets	BC
Xavier and Xavier, 2016 [44]	Not related to transport systems	O
Martinelli and Teng, 1996 [45]	Railway operations	ANN
Fischetti and Monaci, 2016 [46]	Not related to transport systems	MILP
Teodorovic, 2008 [47]	Transportation engineering (general)	SI
Venter and S.-Sobieski, 2004 [48]	Optimization of a transport aircraft wing	SI
Steiger et al., 2016 [49]	Transport data	SOM
Cesme and Furth, 2014 [50]	Traffic signals	SOM
Hua et al., 2020 [51]	Intelligent Control in Heavy Haul Railway	BC

Table 1. *Cont.*

Source	Problem	Tool
Kawaji et al., 2004, [52]	Not related to transport systems	O
Paradis et al., 2004, [53]	Not related to transport systems	O

Tool description: ANN = Artificial Neural Network, BBO = Biogeography-Based Optimization, BC = Blockchain Framework, GA = Genetic Algorithm, MILP = Mixed Integer Linear Programming, MS = Multiagent systems, NH = Not heuristic, O = other (heuristic), SA = Simulated Annealing, SI = Swarm Intelligence (incl. particle swarm intelligence, PSO, ant or bees colonies, ACO, BCO), SOM = Self Organized Maps, TS = Tabu Search.

Sometimes the problems classified in Table 1 are more complex. Dong et al. [7] integrate the planning of train stops with the timetable, and Yan et al. [2] integrate the timetable with route planning. Wang et al. [12] and Zhao et al. [19] combine train timetables and rolling stock. Zhang et al. [16] integrate train timetables and track maintenance scheduling.

The above characterized examples illustrate the offer (supply side of the transport system). On the other hand, the result in the form of passenger flow (demand side of the transport system) was taken into account, inter alia, in: Xiao et al. [25], Shen et al. [26], Wu et al. [27], and Liu et al. [28]. These works include passenger flow as a direct result of modeling or simulation. In many studies, passenger flow is a factor influencing the modeled parameters, such as train schedules.

Rail is not the only means of transport in suburban areas. The railway is or should be one of several integrated components that work together at different levels. Access to rail should be improved by means of "complementary tools or means of transport", forming a "delivery system" that includes local buses, private cars including car sharing, bicycles including rental, etc. It is important to optimize local systems, create nodes, and integrate tariffs and cost coordination. The importance of coordination studies is shown by a review by Liu et al. [29], who identified 135 papers on these topics. Further problems are related to the developing autonomy of vehicles. Examples of studies from recent years concerning cooperation in transport systems are presented in Table 1 ([25–28]).

Many parameters were taken into account in the models presented above. For example, Ahmed et al. [6] collect 27 input parameters, including: average travel speed, train headway, number of stations, spacing between stations, etc. The number of input parameters in Dong et al. [7] is 21 and includes, inter alia: the number of passengers arriving at the station, the number of trains, etc. A specific parameter is "passenger satisfaction" or "dissatisfaction" (Hickish et al. [3], Satoshi et al. [22], Stead et al. [34], Shen et al. [26]). Shen et al. [26] formulate nine elements creating passenger satisfaction: direction and guidance, cleanliness and comfort, speediness and convenience, safety and security, ticket service, equipment and facilities, staff service, information distribution, and convenient facilities for passengers.

Specific review studies (Liu et al. [29], Tang et al. [38]) formulate directions for future research. Integration with various planning activities is important. Data quality, data limitations or imperfections, uncertainty, and passenger behavior should be carefully considered. Modeling analyses should be more complex and include, inter alia, multi-objective optimization, multi-agent systems, and negotiations. Comprehensive and more flexible approaches will pay off.

All the parameters presented above affect the use of suburban railways. However, not only the "physical" ones (easy to identify and measure), such as speed or numbers, are important. Other parameters that are more difficult to identify and have a "psychological" aspect should also be taken into account. Lopez and Farooq [39] state that "*transportation data are shared across multiple entities using heterogeneous mediums*". Such data vary on certain days (not only working days and holidays, but some typical working days may also differ in passenger flow depending on weather, accidents, and random factors). The influence of bounded rationality and unbounded uncertainty is significant (Khisty and Arslan [40]). Similar problems are discussed by Li et al. [41] and Wu et al. [27]. They wrote that the assumption of rational passenger behavior is not correct. Taking into account the behavior of passengers requires the use of advanced and unconventional tools in modeling. Tools inspired by nature and social behavior are called "artificial intelligence" (AI) or "heuristics" (in a broader sense, not just as an optimization tool).

The main research goal of this paper is to create a new algorithm (NOAH) not as an optimization tool but as a method of observation of selected datasets. The reason for this is the problems with the identification of the close set of important factors and with the collection and selection of the data. Known and used methods have other assumptions. The proposed algorithm allows us to find new and nonobvious connections between the factors (these are not correlations in the strictly mathematical sense). Assumptions to create an algorithm will be formulated after the presentation of the heuristics (Section 2). The rest of this paper is organized as follows: Section 3 presents the new algorithm, and Section 4 shows an example of its application (with the description of the case study area, Section 4.1; collection of factors, Section 4.2; and two experiments, Sections 4.3 and 4.4). The last two sections contain a discussion and conclusions.

2. Heuristics as Inspirations from Nature

The term "heuristics" will be used here in a broader, philosophical sense, as defined by Kahneman [42]: "a heuristic is a mental shortcut that our brains use that allows us to make decisions quickly without having all the relevant information". In more "technical" literature, this concept or tool is often referred to as "computational intelligence" or "artificial intelligence". Regardless of the name, such tools are very popular and efficient in solving many problems, including modeling railways. Many tools developed in the last few decades can be considered "heuristics". Tang et al. [38] identify 139 articles from the last decade on the use of heuristics in railway systems.

The third column in Table 1 presents tools used to solve the collected problems. Most of them are heuristics. An element inspired by nature, especially simulated human or animal behavior, is important. New developments in "metaheuristics" and their applications are presented by Lau et al. [43]. They evoke, among others, a new method called "flying elephants" (Xavier and Xavier [44]), which shows interesting and intriguing assumptions and solutions.

Some studies include more than one tool, including Yang et al. [35], who compared the effectiveness of GA and MINLP. The set in Table 1 contains only selected sources from a very large database. The selection focuses on methods dedicated to railway modeling or on tools that will be inspirations for the method formulated in this paper. Specifically, these are relatively new studies using PSO, SCO, BCO, SOM, blockchain, multiagent, or BBO methods. For example, Zheng et al. [21] used the earlier concept of Simon [54], biogeography-based optimization, to analyze emergency railway wagon scheduling. Similarly, Hua et al. [51] used the Nakamoto blockchain concept [55] for intelligent control on heavy haul railways.

Summarizing the above description, the conditions for a new model of suburban railway use are summarized below. Railways function in the transport system, and cooperation with other modes of transport is necessary. We may collect a large amount of data, but we do not know the significance (impact) of each individual piece of information. There are many factors that influence the use of suburban rail, and their impacts may vary from day to day. Passenger behavior (including the choice of means of transport) is not rational. We should consider bounded rationality and unbounded uncertainty. The modeled object (railway in the transport system) is variable. The "optimal" solution probably does not exist; rather, we are looking for an "acceptable" solution. An acceptable solution contains a set of factors that are realizable and make economic sense. The results from the model can support the decision-making process—for example, when choosing a specific option, planning system development, etc. It is desirable to use a dedicated metaheuristic in the new model. SOM, multiagent, and blockchain elements inspire certain assumptions about the new proposal. In particular, solutions based on animal or human behavior will be useful for creating a new modeling tool.

So, the new model (algorithm) should be allowed to compare different data with higher or lower complexity to show potential sets of them. It will be possible to analyze both the existing (observed) data as well as more theoretical values. The process of comparison should be flexible and based on partially random procedures. The assumptions collected above can be realized using a specific heuristic. A novel heuristic will be proposed based on the specific behaviors of monkeys.

3. The NOAH Concept Based on the Behavior of Monkeys

A novel tool created here and called "NOAH" (Nest of Apes Heuristic) is inspired by the social behavior of groups of monkeys. Numerous studies and publications have been devoted to groups of monkeys from different monkey species—such as diana (Decellieres et al. [56]), vervet (Gareta Garcia et al. [57]), capuchin (Leca et al. [58]), gelada (Miller et al. [59]), or colobus (Wikberg et al. [60])—which create various nests with specific social behaviors. Colobus monkeys create specific "social networks" based on interactions [60]. A visualization (model) of such a network is presented in Figure 1 (part b). Diana monkeys form specific relationships called "dear-enemy" or "nasty-neighbor" depending on the type of habitat [56]. Distributed leadership has been observed in the nests of white-faced capuchins [58]. All members can initiate a group movement, and many members recruit followers. Wild female vervets adapt their maneuvering to different pressures [57]. They are characterized by rapid social plasticity and flexible changes in care patterns (described by the authors as "Machiavellian-like"—this "human" analogy is important here). Miller et al. [59] identify leaders in gelada nests under the influence of out-of-group paternity. The behavior of such species has been compared with other primates and has been linked to human mating systems, including behaviors jealousy (Scelza et al. [61]) and reproductive strategies (Scelza et al. [62]). The implications presented by Miller et al. in [59] refer to the "weirdness" of various human populations described by Heinrich et al. [63]. WEIRD here is an acronym standing for western, educated, industrialized, rich, and democratic. The authors conclude that not all human groups can be characterized as above. Other classified groups have different social behaviors. Therefore, their description should assume specific and partially unknown parameters.

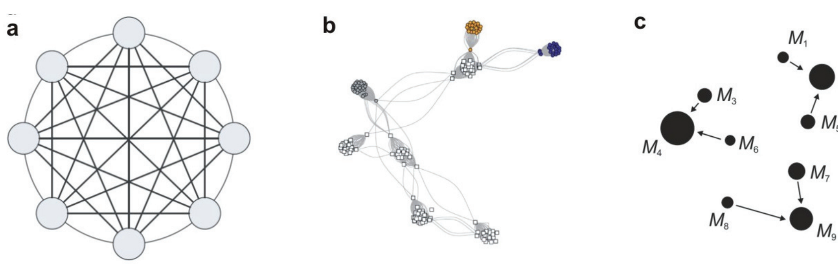


Figure 1. Different nests used in specific methods or models (**a**) SOM-like [21] (**b**) Colobus network [60] (**c**) NOAH.

Hypothetically and in accordance with the heuristic methods described in Section 2, the behaviors presented above can be used in an algorithm (NOAH) that can describe not only groups of animals, but also technical systems containing parameters (factors) related to human behavior (like choice of transport means). Especially useful can be changeable leadership in the nest and the behaviors of followers. The parameters will be associated with "monkeys"—individuals in the nest that change their behavior (monkey position) according to specific procedures including leader creation, observations by followers, importance and hierarchy of individuals, dynamic changes in the nest, etc.

Changes to the nest will modify individuals (factors) before the algorithm stops. It will be possible to analyze and observe different sets of parameters (monkeys), their interactions, and their correlations. NOAH does not specify an optimal solution but shows possible datasets for comparison. It helps in choosing one or more. The operation of NOAH is very similar to the SOM (self-organized maps) concept, the stages of the blockchain, or the multiagent concept. A graphical representation of the exemplary methods is shown in Figure 1. Part (a) of this figure shows an SOM-like network, part (b) shows the colobus monkey nest described earlier, and part (c) shows the monkey nest and interactions between leaders (big black spots) and followers (little black spots) according to the NOAH concept.

Important for the application of NOAH in selected problems is the selection of parameters (factors) and their conversion into "monkeys". Initially, the selection of parameters is made by an "expert" with the use of all of the available data. After the algorithm is stopped, the re-conversion procedure will follow. These elements will be described in Section 4 with a specific example. The basic and theoretical aspects of NOAH are presented here. Each monkey has a specific position in the nest that is variable. The monkey position values are limited to a range of 0 to 1 as defined by the procedures in NOAH.

A specific set of terms, parameters, and symbols used in NOAH is defined herein.

Nest (seat, habitat) is a set of individuals (representing factors in the model).

Position of the monkey in the nest, M_n, is a key variable in the algorithm. Each monkey changes its position in the nest, assuming the role of a leader or follower (representing variable values of factors and their importance in the model).

Steps (iterations) of changes in the nest, starting from zero, $i = 0$, are successive periods with a specific nest state (monkey position, i.e., factor values). The steps will continue until the socket is stable (will not change). See stopping criteria.

Importance of an individual, I_n, is a random variable indicating the subjective position of the monkey in the nest. The scope of this variable is determined by Formula (1).

$$I_n = random(0;1) \tag{1}$$

Hierarchy of an individual, H_n: This is a variable indicating a more objective position of the individual in the nest, assuming an actual value of M_n, a random importance I_n, a moderated followers coefficient L, and a number of steps i. The hierarchy is calculated using Formula (2).

$$H_n = \left| \frac{I_n - M_n}{L \cdot i} \right| \tag{2}$$

Followers coefficient (influence of leaders), L: This determines the time and efficiency of the algorithm (it should be precisely defined in accordance with the specification of the modeled problem). Its impact increases in subsequent iteration steps—see Formula (2). L values should oscillate around 1–3 (see example in Section 4).

Random hierarchy modifiers, R_n: These are used to modify the position of the monkey going to the next step of changes in the nest. The modifiers depend on the value of the hierarchy, taking into account the defined range of hierarchy modifiers according to Formula (3).

$$R_n = H_n \cdot random(R\mathrm{min}; R\mathrm{max}) \tag{3}$$

Range of hierarchy modifiers, Rmin and Rmax: This also determines the runtime and efficiency of the algorithm; the Rmin value should be negative and the Rmax value positive (see example in Section 4).

NOAH works according to the algorithm shown in Figure 2. The position of the monkey in the next step is calculated using Formula (4). The position is changed taking into account the values of random hierarchy modifiers with the restrictions determined by Formula (5).

$$M_n^{i+1} = M_n^i + R_n^i \tag{4}$$

$$0 \le M_n^{i+1} \le 1 \tag{5}$$

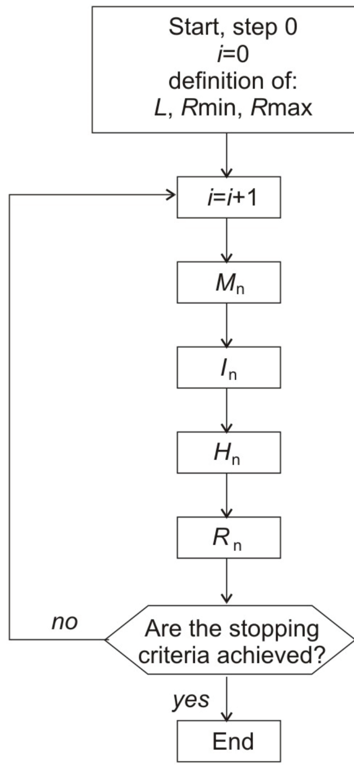


Figure 2. NOAH algorithm.

The progressing steps create a changeable nest with individuals who change their positions. That means the changeable values of factors are considered in the model. The leaders (factors with higher importance) are identified, observed, and analyzed. The whole nest (set of all factors) can be analyzed too. The algorithm heads to the nest stability, which means reducing the changes in the monkey's position during the steps. The tempo of such stabilization depends on the value of the followers coefficient and the range of hierarchy modifiers. However, specific stopping criteria are formulated. In each step the following "decisions measures" are calculated: M as the sum of all M_n, I as the sum of all I_n, H as the average from all H_n, and R as the average of all R_n. Consideration of these measures in the aspect of stopping criteria is shown in the example in Section 4.

The next steps of the algorithm create a changing nest with individuals of different positions. This refers to changes in the value of the factors included in the model. Leaders (factors of greater importance) are identified, monitored, and analyzed. The entire nest (set of all factors) can also be analyzed. The algorithm aims at nest stability, which means reducing the changes in the monkey's position during steps. The pace of such stabilization depends on the value of the followers coefficient and the range of hierarchy modifiers. Specific stopping criteria have been formulated. At each step, the following "decision measures" are calculated: M as the sum of all M_n, I as the sum of all I_n, H as the average of all H_n, and R as the average of all R_n. The inclusion of these measures in terms of the stopping criteria is illustrated in the example in Section 4.

4. Application Example of NOAH

4.1. Case Study

The case study area is located near Wrocław, the fourth major city in Poland. Wrocław is the core of an agglomeration with approximately 1 million inhabitants. The Wrocław railway junction is large and forms the basis of the shape of the suburban railway system. This system is under construction, and several railway lines are being rebuilt or extended. In December 2021, the rebuilt line connecting Wrocław with Jelcz through the Czernica community was opened after 20 years without passenger transport. The occurrence of the reopening provides an opportunity for specific research, including testing of the NOAH algorithm. The use of NOAH allows for temporary changes to the rail network to be taken into account, e.g., the closure of a specific section of the line. The situation of the temporary closure of one railway connection makes it possible to observe all public transport connections between Wrocław and Jelcz using only one corridor.

Several factors and their collections are considered. Among them are new railroads, bus lines, and parking lots. These data were compared with the observed values of the number of passengers, etc. Figure 3 shows the map of the case study area, taking into account different types of railway lines (older ones in black, new ones in blue, and temporarily closed ones in red), two groups of bus lines (correlated with the railway line in green and competitive with red railways), target area in terms of the area of the Czernica commune, and car parks at railway stations in this area (park and ride, PR). Based on these conditions, 16 factors are formulated to be considered in the NOAH model.

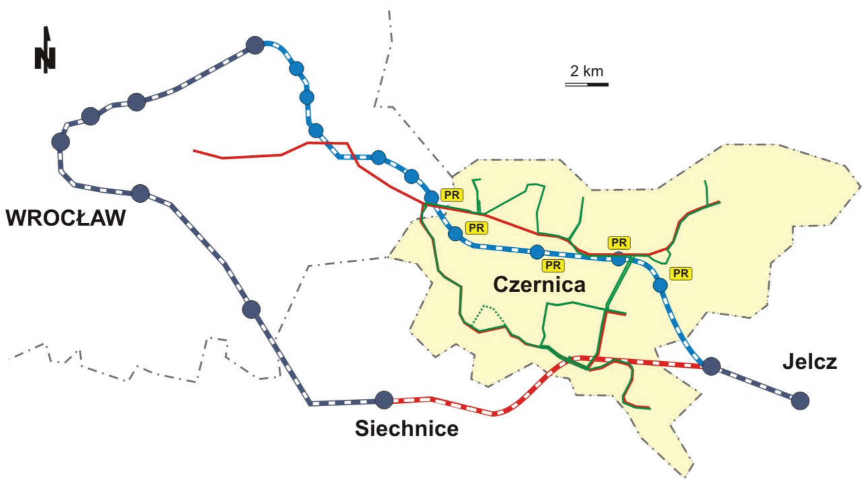


Figure 3. The map of the case study area.

4.2. Factors and Their Conversion

A set of 16 factors was used in this case study (Table 2). Factors are divided into two groups: positive (nine factors) and negative (seven factors). Rising values of positive factors increase the total number of travelers (in all modes), and increasing values of negative factors reduce this number. This is a proposal used in this research considering specific assumptions (not defining the close set of factors and their role). For example, factors F2 and F3 are classified as "positive" according to an assumption of the offer presented by the rail operator having a higher number of places than the forecasted demand. In such an assumption, the trains will not become overcrowded. The higher number of passengers or people who get on the train will increase the use of suburban rail because of the creation of "good behavior" for new passengers. Conversion into monkeys and re-conversion differ depending on which group the factor belongs to. The set of factors adopted here is not complete in terms of all possible measures of the rail system, but it does contain exemplary, representative, and easy-to-collect data.

Table 2. The factors considered in the case study.

Factors		
n	**Group**	**Description**
F_1	positive	number of departures of trains (in a day)
F_2	positive	number of passengers (in trains in a day)
F_3	positive	number of people who get on the train in the chosen stations (one course)
F_4 [%]	positive	percentage of seats taken up on the train (in a peak hour)
F_5	positive	number of stops in the characteristic distance
F_6	positive	number of residents in the "target area"
F_7	positive	parking volume on PR
F_8	positive	number of passengers who arrived at train from other forms of public transport (e.g., bus correlated in the timetable with trains)
F_9	positive	number of departures in other correlated forms (in a day)
F_{10} [PLN]	negative	cost (the price of a typical ticket, single travel, adult)
F_{11}	negative	number of departures in public transport competitive with the considered train line
F_{12} [minutes]	negative	travel time by train (in a peak hour)
F_{13} [minutes]	negative	travel time by competitive public transport (in a peak hour)
F_{14} [minutes]	negative	travel time by private cars (in a peak hour)
F_{15}	negative	number of passengers on competitive public transport (in a day)
F_{16}	negative	number of people who use private cars (in a day)

Assuming (or identifying) a range of all factors is a necessary and important element of NOAH. The minimum and maximum values of the selected factors are necessary to calculate the monkey position value (M_n). Monkey positions correspond with the factors collected in Table 2. Two experiments are carried out in this case study. The first (Section 4.3) tests the volatility of the factor values. The second (Section 4.4) takes the actual factor values and compares them with the NOAH results. The conversion from F to M only occurs in the second experiment, but the re-conversion from M to F applies to both experiments. The following conversion formulas (6)–(7) and re-conversion formulas (8)–(9) are used depending on the specificity of the positive (FP) or negative (FN) factors. The mathematical conversion formulas are used impose monkey position values in the range of 0 to 1.

$$M_n = \frac{FP_n - FP\min_n}{FP\max_n - FP\min_n} \quad (6)$$

$$M_n = \frac{FN\max_n - FN_n}{FN\max_n - FN\min_n} \quad (7)$$

$$FP_n = FP\min_n + (FP\max_n - FP\min_n) \cdot M_n \quad (8)$$

$$FN_n = FN\max_n - (FN\max_n - FN\min_n) \cdot M_n \quad (9)$$

where:

*FP*min to *FP*max is the range of positive factors;

*FN*max to *FN*min is the range of negative factors.

Data for both experiments are summarized in Table 3. The "reference value" of a factor and the corresponding monkey position value show the actual (current) data. All factor values are commented on in Section 5.

Table 3. The data for both experiments.

Factor, F_n	min	max	Reference Value	Monkey's Position
F_1	0	20	10	0.500
F_2	0	600	540	0.900
F_3	0	100	60	0.600
F_4 [%]	0	100	90	0.900

Table 3. *Cont.*

Factor, F_n	min	max	Reference Value	Monkey's Position
F_5	6	21	15	0.600
F_6	12,000	20,000	16,000	0.500
F_7	0	100	80	0.800
F_8	0	100	70	0.700
F_9	0	10	4	0.400
F_{10} [PLN]	4.6	12	10.2	0.757
F_{11}	0	20	16	0.200
F_{12} [minutes]	30	90	30	1000
F_{13} [minutes]	30	90	60	0.500
F_{14} [minutes]	30	90	45	0.750
F_{15}	0	500	200	0.600
F_{16}	2400	16,000	10,000	0.441

4.3. Experiment 1, Testing the Changeability of Factors' Values

In this experiment, the initial values of all monkey positions are midway between the minimum and maximum, which is 0.500. The followers coefficient (*L*) is 1.5, and the range of hierarchy modifiers (*R*min, *R*max) are −0.3 and 0.3. These values were selected based on testing various algorithm stop criteria. This aspect is commented on in Section 5. The effect of the NOAH algorithm after 32 steps is shown in Figure 4.

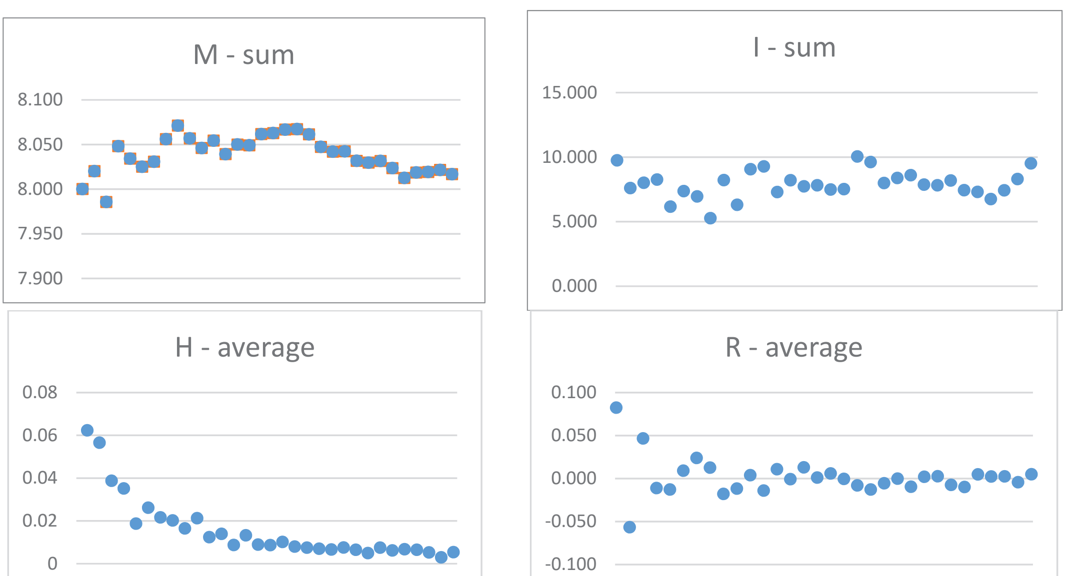


Figure 4. Changes in decision measures during the steps in Experiment 1.

Because the initial monkey position value assumption is 0.5 and the number of monkeys considered is 16, the starting value of the first decision measure (*M*) is 8.0. The value of this measure is changed in the subsequent steps of the algorithm in accordance with the procedures described in Section 3. These changes should be observed in order to formulate the algorithm stopping criteria. One such criterion could be the difference between the *M* values in the following steps. When this difference reaches a predetermined minimum, the algorithm stops. We observe "stabilization in the nest".

The second decision measure is the sum of importance values (*I*). Because each individual's value for importance is random, the measure *I* varies from step to step but fluctuates around an average of 8.0. Observing the changes in the value of *I* makes sense in order to formulate the second algorithm stopping criterion. If you change this value significantly, you can stop the algorithm or ignore this particular step. Here we see "a remarkable change of subjective meaning in the nest".

The average value of the hierarchy (*H*) is the third decision measure. This value drops to zero. Achieving the assumed minimum value may terminate the algorithm's work. A similar situation takes place in the next decision measure—the average value of the random hierarchy modifier (*R*). It is possible to use only one decision measure and only one stop criterion, but the observation of all of them increases the set of analyzed solutions. In this experiment, stabilization in the socket was achieved after 32 steps, and the algorithm was completed. The values of all NOAH parameters for all monkeys and the decision measures in the final step are presented in Table 4. This table also shows the recalculated values of the analyzed factors as a set characterizing the final step of the algorithm. The interpretation of the coefficient values is presented in Section 5

Table 4. The results of the first experiment.

M_n	I_n	H_n	R_n	F_n
0.478	0.937	0.010	−0.003	10
0.538	0.083	0.009	0.003	323
0.566	0.333	0.005	0.000	57
0.440	0.675	0.005	−0.001	44
0.460	0.834	0.008	−0.002	13
0.513	0.523	0.000	0.000	16,101
0.545	0.403	0.003	0.001	54
0.516	0.858	0.007	0.000	52
0.538	0.752	0.004	0.001	5
0.482	0.800	0.007	0.000	8.4
0.478	0.584	0.002	0.000	10
0.491	0.729	0.005	0.001	61
0.506	0.513	0.000	0.000	60
0.500	0.295	0.004	−0.001	60
0.511	0.247	0.005	0.001	244
0.455	0.938	0.010	0.003	9811
$M = 8.017$	$I = 9.504$	$H = 0.005$	$R = 0.000$	

4.4. Experiment 2, Considering the Real Data

In this experiment, the initial values of the monkeys are calculated according to actual (reference) factor values (see Table 3). The values of the followers coefficient and hierarchy modifier ranges are the same as in Experiment 1. The effect of the NOAH algorithm after 32 steps is shown in Figure 5. The same four decision measures and stopping criteria were also used as in Experiment 1. The values of all NOAH parameters for all monkeys and decision measures in the final step are presented in Table 5. This table also shows the re-converted values of the analyzed factors as a set characterizing the final step of the algorithm. The interpretation of the factor values is presented in Section 5.

Table 5. The results of the second experiment.

M_n	I_n	H_n	R_n	F_n
0.525	0.039	0.010	0.001	10
0.862	0.708	0.003	−0.001	517
0.529	0.404	0.003	0.000	53
0.948	0.654	0.006	−0.001	95
0.560	0.308	0.005	0.000	14
0.397	0.809	0.009	−0.002	15,174
0.999	0.707	0.006	−0.001	100
0.699	0.689	0.000	0.000	70

Table 5. *Cont.*

M_n	I_n	H_n	R_n	F_n
0.413	0.074	0.007	−0.002	4
0.752	0.841	0.002	0.000	6.4
0.263	0.787	0.011	0.003	15
0.925	0.730	0.004	0.000	34
0.472	0.262	0.004	−0.001	62
0.755	0.901	0.003	0.001	45
0.607	0.087	0.011	0.003	196
0.447	0.078	0.008	0.000	9926
M = 10,153	I = 8078	H = 0.006	R = 0.000	

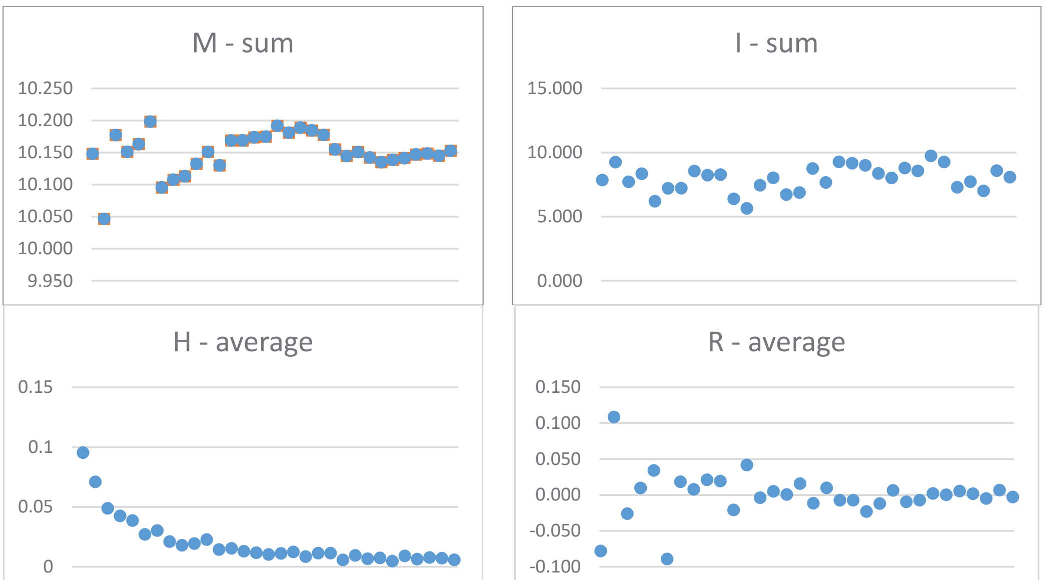


Figure 5. Changes in decision measures during the steps in Experiment 2.

5. Discussion

Table 6 summarizes the important data for all factors. The minimum, maximum, reference (actual), and final values from both experiments are shown. The reference values correspond to the observed (measured) situations. Measurements and data collection were performed in the spring of 2022. The minimum and maximum values are calculated or assumed according to physical conditions or other possibilities. For example, "percentage of spaces occupied" (F_4) can of course vary between 0 and 100%, and "parking volume on PR" (F_7) can vary between 0 and 100, the upper limit being the actual number of parking spaces in all of the considered locations. The "cost" (F_{10}) could vary from PLN 4.6 to 12.0, which results from the comparison of various fees in the considered journeys between the origin and the destination; "travel times" (F_{12}–F_{14}) oscillate between values obtained from measurements or calculated taking into account the possible speeds.

The values obtained in the experiments depend on the values of the parameters adopted in the algorithm: the followers coefficient (L) and the range of hierarchy modifiers (Rmin, Rmax). These values may vary depending on the specifics of the problem under consideration (e.g., depending on a number of factors) and should be tested in the experimental phase of the research. Finally, the values were selected—L = 1.5, Rmin = −0.3 and Rmax = 0.3—as the best according to the decision measure change process. The impact of the abovementioned parameters on the results of NOAH requires further research and will be explored in the future.

Table 6. Set of values for all factors.

			F_n			
n	**min**	**Reference**	**Exp. 1**	**Exp. 2**	**max**	**Short Description**
F_1	0	10	10	10	20	departures of trains in a day
F_2	0	540	323	517	600	passengers on trains in a day
F_3	0	60	57	53	100	people who get on the train
F_4 [%]	0	90	44	95	100	percentage of seats taken up
F_5	6	15	13	14	21	stops
F_6	12,000	16,000	16,101	15,174	20,000	residents in the "target area"
F_7	0	80	54	100	100	parking volume in PR
F_8	0	70	52	70	100	passengers arrived
F_9	0	4	5	4	10	departures in correlated forms
F_{10} [PLN]	4.6	10.2	8.4	6.4	12.0	cost
F_{11}	0	16	10	15	20	competitive departures
F_{12} [minutes]	30	30	61	34	90	travel time by train
F_{13} [minutes]	30	60	60	62	90	travel time in competitive transport
F_{14} [minutes]	30	45	60	45	90	travel time in private cars
F_{15}	0	200	244	196	500	passengers using competitive transport
F_{16}	2400	10,000	9811	9926	16,000	people who use private cars

The factors values obtained from the experiments should be analyzed as a complex set of parameters. In both experiments, sufficient numbers of trips (F_1) and stops (F_5) were identified in relation to the values of the other factors. These values led to an intuitive decrease in the number of passengers during the day (F_2). Comparing these values with the stable number of residents (F_6), there is a need to increase the role of the delivery system. The delivery system is represented here by factors including cars in PR (F_7) and passengers arriving from correlated forms of public transport (F_8). The travel cost (F_{10}) should be lower. The conditions tested above also show a lower number of journeys by means that compete with rail, both with private cars (F_{16}) and buses (F_{15}).

Some results differ in both experiments. Because the first experiment starts with the "average" values of the factors, the results are close to the middle between the minimum and the maximum. This shows the potential NOAH effect but is not of practical use. The results of the second experiment are more realistic and allow you to judge the real conditions. The maintenance of a clear difference between the travel time of rail travel and those of competitive forms is particularly visible. The results show the possibilities of further use of the constructed methodology and algorithm. For example, it is possible to test other numbers of residents (F_6) or numbers of departures (F_1). It is also possible to test different values of the minimum and maximum factors. They should allow the modeling of various conditions in the suburban rail system and the observation of correlations between all factors. Initial values of the abovementioned parameters should be carefully collected. This limitation requires further work to be overcome.

The obtained results correspond with actual topics involved in the interdisciplinary field of sustainable urban planning and transport development. Significantly, connection with heuristics used in analyses of transportation and railway systems [64,65] occurred. This aspect shows the potential of the proposed algorithm and methodology to be developed in other studies not only connected with railway systems and not only in transportation engineering.

6. Conclusions

The parameters describing a suburban rail system have different characteristics. The set of possible factors is not precisely defined, and the data collection process has specific problems. Some data are incomplete, while others contain errors. The influence of each selected factor and its importance are not fully understood. Therefore, modeling and analysis of suburban rail systems requires specific methods that also take into account human behavior. Here, heuristics as a holistic tool can help in the analysis of possible correlations between factors, as well as be helpful in the decision-making process. The novel method presented here allows using an open set of data. The factors could be different and somewhat "chaotic" at first sight (as in the presented experiments). This is the key innovation in analyses of "technical systems" like the suburban railways considered here.

The main advantage of the proposed method is the creation of the possibility to observe various sets of data and their interactions without precise knowledge about the influence of a specific factor on the result. The data (describing the transportation systems) depend partially on human decisions. For example, the choice of the mode of transport could be a reaction to the behaviors of other people (neighbors, social media groups). So, an individual can observe and copy leaders as a follower. The use of the specific transport means influencing the number of passengers or parking volume in PR has some uncertainties and could be modeled using heuristics.

NOAH, which is inspired by the behavior of groups of monkeys, especially taking into account dynamic changes in leadership, is likely to be useful in specific technical problems where physical parameters (such as the number of departures or stops) are compared with human decisions moderated by travel time, prices, etc. The basic definitions, the procedures, the algorithm, and the potential application of NOAH are illustrated in simple examples with a relatively small set of factors. The NOAH algorithm modifies the values of factors in a heuristic way and shows possible solutions that could be introduced in reality. This method created originally by the author is quite similar to swarm intelligence algorithms (like PSO and ACO) but contains new elements based on specific behaviors of monkeys which were described in Section 3.

Strict comparison of this new method with others is not possible because of the other goals of those methods. The heuristics search mainly for optimal solutions. NOAH can compare factors, not showing the best result. This is an intentional assumption representing the difficulty of evaluation of data by an individual person. Thus, the evaluation of the effectiveness of the proposed method is difficult, especially in the present stage of research. The study introduced in one of the Polish agglomerations will be continued and should formulate remarks to modify selected elements of the transport system (e.g., number of departures or cost) with the observation of changes in other factors. When the obtained results are similar to the model, NOAH will be effective.

The presented material introduces the new algorithm by showing its procedures that can allow for its use in similar problems. This could test obtained assumptions and improve procedures in the future. Future works should contain influence analyses of the parameters adopted in the algorithm (the followers coefficient and the range of hierarchy modifiers), other (broader) sets of factors, and comprised studies in other areas. The NOAH method could be also used for other problems where incomplete and different data make observations of technical systems difficult.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Not applicable.

Conflicts of Interest: The author declares no conflict of interest.

References

1. Canca, D.; De-Los-Santos, A.; Laporte, G.; Mesa, J.A. An adaptive neighborhood search metaheuristic for the integrated railway rapid transit network design and line planning problem. *Comput. Oper. Res.* **2017**, *78*, 1–14. [CrossRef]
2. Yan, F.; Goverde, R.M.P. Combined line planning and train timetabling for strongly heterogeneous railway lines with direct connections. *Transp. Res. Part B Methodol.* **2019**, *127*, 20–46. [CrossRef]

3. Hickish, B.; Fletcher, D.I.; Harrison, R.F. Investigating Bayesian Optimization for rail network optimization. *Int. J. Rail Transp.* **2020**, *8*, 307–323. [CrossRef]
4. Schlechte, T.; Borndörfer, R.; Erol, B.; Graffagnino, T.; Swarat, E. Micro–macro transformation of railway networks. *J. Rail Transp. Plan. Manag.* **2011**, *1*, 38–48. [CrossRef]
5. Weik, N.; Warg, J.; Johansson, I.; Bohlin, M.; Nießen, N. Extending UIC 406-based capacity analysis—New approaches for railway nodes and network effects. *J. Rail Transp. Plan. Manag.* **2020**, *15*, 100199. [CrossRef]
6. Ahmed, C.; Nur, K.; Ochieng, W. GIS and genetic algorithm based integrated optimization for rail transit system planning. *J. Rail Transp. Plan. Manag.* **2020**, *16*, 100222. [CrossRef]
7. Dong, X.; Li, D.; Yin, Y.; Ding, S.; Cao, Z. Integrated optimization of train stop planning and timetabling for commuter railways with an extended adaptive large neighborhood search metaheuristic approach. *Transport. Res. C Emerg. Technol.* **2020**, *117*, 102681. [CrossRef]
8. Qiannan, W.; Yang, L.; Pengrui, D. Optimization of urban rail transit station spacing for minimizing passenger travel time. *J. Rail Transp. Plan. Manag.* **2022**, *22*, 100317. [CrossRef]
9. Binder, S.; Maknoon, M.Y.; Sharif Azadeh, S.; Bierlaire, M. Passenger-centric timetable rescheduling: A user equilibrium approach. *Transport. Res. Part C Emerg. Technol.* **2021**, *132*, 103368. [CrossRef]
10. Jamili, A.; Pourseyed Aghaee, M. Robust stop-skipping patterns in urban railway operations under traffic alteration situation. *Transport. Res. Part C Emerg. Technol.* **2015**, *61*, 63–74. [CrossRef]
11. Shang, P.; Li, R.; Liu, Z.; Yang, L.; Wang, Y. Equity-oriented skip-stopping schedule optimization in an oversaturated urban rail transit network. *Transport. Res. Part C Emerg. Technol.* **2018**, *89*, 321–343. [CrossRef]
12. Wang, Y.; D'Ariano, A.; Yin, J.; Meng, L.; Tao, T.; Ning, B. Passenger demand oriented train scheduling and rolling stock circulation planning for an urban rail transit line. *Transp. Res. Part B Methodol.* **2018**, *118*, 193–227. [CrossRef]
13. Jensen, L.W.; Landex, A.; Nielsen, O.A.; Kroon, L.G.; Schmidt, M. Strategic assessment of capacity consumption in railway networks: Framework and model. *Transp. Res. Part C Emerg. Technol.* **2017**, *74*, 126–149. [CrossRef]
14. Yin, J.; D'Ariano, A.; Wang, Y.; Yang, L.; Tang, T. Timetable coordination in a rail transit network with time-dependent passenger demand. *Eur. J. Oper. Res.* **2021**, *295*, 183–202. [CrossRef]
15. Zhang, T.; Li, D.; Qiao, Y. Comprehensive optimization of urban rail transit timetable by minimizing total travel times under time-dependent passenger demand and congested conditions. *Appl. Math. Model.* **2018**, *58*, 421–446. [CrossRef]
16. Zhang, Y.; D'Ariano, A.; He, B.; Peng, Q. Microscopic optimization model and algorithm for integrating train timetabling and track maintenance task scheduling. *Transp. Res. Part B Methodol.* **2019**, *127*, 237–278. [CrossRef]
17. Zhang, Y.; Peng, Q.; Yao, Y.; Zhang, X.; Zhou, X. Solving cyclic train timetabling problem through model reformulation: Extended time-space network construct and Alternating Direction Method of Multipliers methods. *Transp. Res. Part B Methodol.* **2019**, *128*, 344–379. [CrossRef]
18. Zhang, Q.; Lusby, R.M.; Shang, P.; Zhu, X. A heuristic approach to integrate train timetabling, platforming, and railway network maintenance scheduling decisions. *Transp. Res. Part B Methodol.* **2022**, *158*, 210–238. [CrossRef]
19. Zhao, S.; Yang, H.; Wu, Y. An integrated approach of train scheduling and rolling stock circulation with skip-stopping pattern for urban rail transit lines. *Transp. Res. Part C Emerg. Technol.* **2021**, *128*, 103170. [CrossRef]
20. Whitbrook, A.; Meng, Q.; Chung, P.W.H. Reliable, Distributed Scheduling and Rescheduling for Time-Critical, Multiagent Systems. *IEEE Trans. Autom. Sci. Eng.* **2018**, *15*, 732–747. [CrossRef]
21. Zheng, Y.-J.; Ling, H.-F.; Shi, H.-H.; Chen, H.-S.; Chen, S.-Y. Emergency railway wagon scheduling by hybrid biogeography-based optimization. *Comput. Oper. Research* **2014**, *43*, 1–8. [CrossRef]
22. Satoshi, K.; Koichi, S.; Shingo, H.; Norio, T. An optimal delay management algorithm from passengers' viewpoints considering the whole railway network. *J. Rail Transp. Plan. Manag.* **2011**, *1*, 25–37. [CrossRef]
23. Samà, M.; Pellegrini, P.; D'Ariano, A.; Rodriguez, J.; Pacciarelli, D. On the tactical and operational train routing selection problem. *Transp. Res. Part C Emerg. Technol.* **2017**, *76*, 1–15. [CrossRef]
24. Oneto, L.; Fumeo, E.; Clerico, G.; Canepa, R.; Papa, F.; Dambra, C.; Mazzino, N.; Anguita, D. Dynamic Delay Predictions for Large-Scale Railway Networks: Deep and Shallow Extreme Learning Machines Tuned via Thresholdout. *IEEE Trans. Syst. Man Cybern. Systems* **2017**, *47*, 2754–2767. [CrossRef]
25. Xiao, X.; Jia, L.; Wang, Y. Correlation between heterogeneity and vulnerability of subway networks based on passenger flow. *J. Rail Transp. Plan. Manag.* **2018**, *8*, 145–157. [CrossRef]
26. Shen, W.; Xiao, W.; Wang, X. Passenger satisfaction evaluation model for Urban rail transit: A structural equation modeling based on partial least squares. *Transp. Policy* **2016**, *46*, 20–31. [CrossRef]
27. Wu, J.; Sun, H.; Wang, D.Z.W.; Zhong, M.; Han, L.; Gao, Z. Bounded-rationality based day-to-day evolution model for travel behavior analysis of urban railway network. *Transp. Res. Part C Emerg. Technol.* **2013**, *31*, 73–82. [CrossRef]
28. Liu, Y.; Liu, Z.; Jia, R. DeepPF: A deep learning based architecture for metro passenger flow prediction. *Transp. Res. Part C Emerg. Technol.* **2019**, *101*, 18–34. [CrossRef]
29. Liu, T.; Cats, O.; Gkiotsalitis, K. A review of public transport transfer coordination at the tactical planning phase. *Transp. Res. Part C Emerg. Technol.* **2021**, *133*, 103450. [CrossRef]
30. Hansson, J.; Pettersson-Löfstedt, F.; Svensson, H.; Wretstrand, A. Replacing regional bus services with rail: Changes in rural public transport patronage in and around villages. *Transp. Policy* **2021**, *101*, 89–99. [CrossRef]

31. Wei, S.; Zheng, W.; Wang, L. Understanding the configuration of bus networks in urban China from the perspective of network types and administrative division effect. *Transp. Policy* **2021**, *104*, 1–17. [CrossRef]
32. Ngo, N.S.; Götschi, T.; Clark, B.Y. The effects of ride-hailing services on bus ridership in a medium-sized urban area using micro-level data: Evidence from the Lane Transit District. *Transp. Policy* **2021**, *105*, 44–53. [CrossRef]
33. Behrends, S. Burden or opportunity for modal shift?—Embracing the urban dimension of intermodal road-rail transport. *Transp. Policy* **2017**, *59*, 10–16. [CrossRef]
34. Stead, A.D.; Wheat, P.; Smith, A.S.J.; Ojeda-Cabral, M. Competition for and in the passenger rail market: Comparing open access versus franchised train operators' costs and reliability in Britain. *J. Rail Transp. Plan. Manag.* **2019**, *12*, 100142. [CrossRef]
35. Yang, A.; Wang, B.; Huang, J.; Li, C. Service replanning in urban rail transit networks: Cross-line express trains for reducing the number of passenger transfers and travel time. *Transport. Res. Part C* **2020**, *115*, 102629. [CrossRef]
36. Lianhua, T.; Xingfang, X. Optimization for operation scheme of express and local trains in suburban rail transit lines based on station classification and bi-level programming. *J. Rail Transp. Plan. Manag.* **2022**, *21*, 100283. [CrossRef]
37. Chen, X.; Lin, X.; He, F.; Li, M. Modeling and control of automated vehicle access on dedicated bus rapid transit lanes. *Transp. Res. Part C Emerg. Technol.* **2020**, *120*, 102795. [CrossRef]
38. Tang, R.; De Donato, L.; Bešinović, N.; Flammini, F.; Goverde, R.M.P.; Lin, Z.; Liu, R.; Tang, T.; Vittorini, V.; Wang, Z. A literature review of Artificial Intelligence applications in railway systems. *Transp. Res. Part C Emerg. Technol.* **2022**, *140*, 103679. [CrossRef]
39. López, D.; Farooq, B. A multi-layered blockchain framework for smart mobility data-markets. *Transp. Res. Part C Emerg. Technol.* **2020**, *111*, 588–615. [CrossRef]
40. Khisty, C.J.; Arslan, T. Possibilities of steering the transportation planning process in the face of bounded rationality and unbounded uncertainty. *Transp. Res. Part C Emerg. Technol.* **2005**, *13*, 77–92. [CrossRef]
41. Li, H.; He, F.; Lin, X.; Wang, Y.; Li, M. Travel time reliability measure based on predictability using the Lempel–Ziv algorithm. *Transp. Res. Part C Emerg. Technol.* **2019**, *101*, 161–180. [CrossRef]
42. Kahneman, D. *Thinking Fast and Slow*; Farrar, Straus and Giroux: New York, NY, USA, 2013; ISBN -100374533555.
43. Lau, H.C.; Raidl, G.R.; Van Hentenryck, P. New developments in metaheuristics and their applications. *J. Heuristics* **2016**, *22*, 359–363. [CrossRef]
44. Xavier, E.A.; Xavier, V.L. Flying elephants: A general method for solving non-differentiable problems. *J. Heuristics* **2016**, *22*, 649–664. [CrossRef]
45. Martinelli, D.R.; Teng, H. Optimization of railway operations using neural networks. *Transp. Res. Part C Emerg. Technol.* **1996**, *4*, 33–49. [CrossRef]
46. Fischetti, M.; Monaci, M. Proximity search heuristics for wind farm optimal layout. *J. Heuristics.* **2016**, *22*, 459–474. [CrossRef]
47. Teodorović, D. Swarm intelligence systems for transportation engineering: Principles and applications. *Transp. Res. Part C Emerg. Technol.* **2008**, *16*, 651–667. [CrossRef]
48. Venter, G.; Sobieszczanski-Sobieski, J. Multidisciplinary optimization of a transport aircraft wing using particle swarm optimization. *Struct. Multidisc. Optim.* **2004**, *26*, 121–131. [CrossRef]
49. Steiger, E.; Resch, B.; de Albuquerque, J.P.; Zipf, A. Mining and correlating traffic events from human sensor observations with official transport data using self-organizing-maps. *Transp. Res. Part C Emerg. Technol.* **2016**, *73*, 91–104. [CrossRef]
50. Cesme, B.; Furth, P.G. Self-organizing traffic signals using secondary extension and dynamic coordination. *Transp. Res. Part C Emerg. Technol.* **2014**, *48*, 1–15. [CrossRef]
51. Hua, G.; Zhu, L.; Wu, J.; Shen, C.; Zhou, L.; Lin, Q. Blockchain-Based federated learning for intelligent control in heavy haul railway. *IEEE Access* **2020**, *8*, 176830–176839. [CrossRef]
52. Kawaji, H.; Takenaka, Y.; Matsuda, H. Graph-based clustering for finding distant relationships in a large set of protein sequences. *Bioinformatics* **2004**, *20*, 243–252. [CrossRef]
53. Paradis, E.; Claude, J.; Strimmer, K. APE: Analyses of phylogenetics and evolution in R language. *Bioinformatics* **2004**, *20*, 289–290. [CrossRef]
54. Simon, D. Biogeography-Based optimization. *IEEE Trans. Evol. Computation* **2008**, *12*, 702–713. [CrossRef]
55. Nakamoto, S. Bitcoin: A Peer-to-Peer Electronic Cash System; Technical Report; Bitcoin.org: 2008. Available online: https://bitcoin.org/bitcoin.pdf (accessed on 22 October 2022).
56. Decellieres, M.; Zuberbühler, K.; León, J. Habitat-dependent intergroup hostility in Diana monkeys, Cercopithecus diana. *Anim. Behav.* **2021**, *178*, 95–104. [CrossRef]
57. Gareta García, M.; Farine, D.R.; Brachotte, C.; Borgeaud, C.; Bshary, R. Wild female vervet monkeys change grooming patterns and partners when freed from feeding constraints. *Anim. Behav.* **2021**, *181*, 117–136. [CrossRef]
58. Leca, J.-B.; Gunst, N.; Thierry, B.; Petit, O. Distributed leadership in semifree-ranging white-faced capuchin Monkeys. *Anim. Behav.* **2003**, *66*, 1045–1052. [CrossRef]
59. Miller, C.M.; Snyder-Mackler, N.; Nguyen, N.; Fashing, P.J.; Tung, J.; Wroblewski, E.E.; Gustison, M.L.; Wilson, M.L. Extragroup paternity in gelada monkeys, Theropithecus gelada, at Guassa, Ethiopia and a comparison with other primates. *Anim. Behav.* **2021**, *177*, 277–301. [CrossRef]
60. Wikberg, E.C.; Christie, D.; Sicotte, P.; Ting, N. Interactions between social groups of colobus monkeys (*Colobus vellerosus*) explain similarities in their gut microbiomes. *Anim. Behav.* **2020**, *163*, 17–31. [CrossRef]

61. Scelza, B.A.; Prall, S.P.; Blumenfield, T.; Crittenden, A.N.; Gurven, M.; Kline, M.; Koster, J.; Kushnick, G.; Mattison, S.M.; Pillsworth, E.; et al. Patterns of paternal investment predict cross-cultural variation in jealous response. *Nat. Hum. Behav.* **2019**, *4*, 20–26. [CrossRef]
62. Scelza, B.A.; Prall, S.P.; Swinford, N.; Gopalan, S.; Atkinson, E.G.; Mcelreath, R. High rate of extrapair paternity in a human population demonstrates diversity in human reproductive strategies. *Sci. Adv.* **2020**, *6*, 1–7. [CrossRef]
63. Henrich, J.; Heine, S.J.; Norenzayan, A. The weirdest people in the world? *Behav. Brain Sci.* **2010**, *33*, 61–83. [CrossRef] [PubMed]
64. Li, G.; Zhang, R.; Guo, S.; Zhang, J. Analysis of ride-hailing passenger satisfaction and life satisfaction based on a MIMIC model. *Sustainability* **2022**, *14*, 10954. [CrossRef]
65. Gong, W.; Li, J.; Ng, M.K. Deciphering property development around high-speed railway stations through land value capture: Case studies in Shenzhen and Hong Kong. *Sustainability* **2021**, *13*, 12605. [CrossRef]

sustainability

MDPI

Article

Users' Preferences in Selecting Transportation Modes for Leisure Trips in the Digital Era: Evidence from Bandung, Indonesia

Tri Basuki Joewono [1,*], Mohamed Yusuf Faridian Wirayat [2], Prawira Fajarindra Belgiawan [2], I Gusti Ayu Andani [3] and Clint Gunawijaya [2]

[1] Department of Civil Engineering, Faculty of Engineering, Universitas Katolik Parahyangan, Bandung 40141, Indonesia
[2] School of Business and Management, Institut Teknologi Bandung, Bandung 40132, Indonesia
[3] School of Architecture, Planning and Policy Development, Institut Teknologi Bandung, Bandung 40132, Indonesia
* Correspondence: vftribas@unpar.ac.id; Tel.: +62-22-203-2655

Abstract: Leisure trips have become more important in an era where people are increasingly concerned with quality of life. Leisure trips are unique in that they are not as strict as mandatory trips, while, at the same time, they have wider characteristics because of their flexibility. Research on leisure trips from developing countries is still under-represented as there is still a focus on commuting trips. This study aims to identify factors that influence the mode of transportation choice for leisure trips by domestic travelers who live in cities surrounding Bandung, Indonesia. Data were collected using stated-preference self-report questionnaires distributed to locals who have the intention to travel for leisure in Bandung in the future. Based on responses from 305 respondents with a total number of 1220 observations, a multinomial logit model was estimated. It was found that trains and buses were selected more often by locals than other modes of transportation, including private cars, for leisure trips. Our model showed that locals considered travel time and travel costs as the most significant factors in selecting the mode of transportation for their leisure trips. Besides the existence of online transportation—hailing rides through mobile apps—as an alternative, this study also reveals payment method to be a unique consideration of locals when travelling leisurely in this digital era.

Keywords: leisure trip; transportation mode choice; attributes of alternatives; stated preference; multinomial logit; cashless payment

Citation: Joewono, T.B.; Wirayat, M.Y.F.; Belgiawan, P.F.; Andani, I.G.A.; Gunawijaya, C. Users' Preferences in Selecting Transportation Modes for Leisure Trips in the Digital Era: Evidence from Bandung, Indonesia. *Sustainability* **2023**, *15*, 2503. https://doi.org/10.3390/su15032503

Academic Editors: Mengqiu Cao, Claire Papaix, Tianren Yang and Benjamin Büttner

Received: 29 December 2022
Revised: 23 January 2023
Accepted: 26 January 2023
Published: 30 January 2023

1. Introduction

People are becoming more concerned about their quality of life. The understanding and measurement of quality of life have grown from focusing on fulfilling material and physical needs to incorporating subjective factors [1]. Happiness and well-being have been used as important indicators to measure the impact of development or policy [2]. Thus, investigators can glimpse the rationale behind the growing popularity of leisure activities.

Leisure includes freely chosen activities that bring satisfaction or enjoyment and provide opportunities to strengthen social contacts and realize certain personal goals [3–5]. Leisure includes activities for humans to find refreshment after their daily routines; leisure is often engaged in outside normal working hours or domestic activities. It includes recreation, cultural events, sports, and social visits [6]. Cumulative satisfaction with leisure activities (*hedonic well-being*) can, therefore, impact both eudaimonic well-being and life satisfaction [5].

Leisure is broader than *recreation*, which refers to the activities that occur during leisure. Tourism is considered to be a subset of recreation with an addition of time and distance factors [6]. *Tourism* denotes sightseeing, travel, or exploration, especially outside of one's homeland. Tourism-related travel is a subset of recreational travel. However, as argued by Carr [7], tourism and leisure behavior are inextricably linked and should not be studied separately. Finally, the theories and concepts derived from leisure studies can be utilized to better comprehend tourist behavior and vice versa.

As leisure activities become more important in the digital era, it is understandable that trips during leisure time are growing in popularity. Leisure trips have become more important, in part, as a result of studies that have accumulated knowledge around how travel experiences have consequential implications for well-being [8]. Furthermore, De Vos [2] explained that the life satisfaction that comes from short-term episodes, such as brief leisure trips and activities, influences people's overall life satisfaction. De Vos [9] also emphasized that travel satisfaction mainly has an indirect effect on life satisfaction, through participation in—and satisfaction with—leisure activities.

Huang et al. [10] explained that leisure activities provide an opportunity to stimulate an individual's creative potential, making positive contributions to health and well-being. Thus, it is understandable that leisure becomes the most important reason for travel and accounts for a substantial part of the increase in kilometers travelled in recent times [11,12]. The importance of leisure activities has increased steadily over the last 40 years, compared with other activities [11]. As economic prosperity continues to rise worldwide, it can be expected that the demand for discretionary activities and associated travel—including leisure trips [13]—will continue to rise too.

Tarigan and Kitamura [14] have reported that the more choices for leisure activity types and locations that individuals have seems likely to encourage them to pursue a variety of leisure locations and leisure activity types. Leisure trips are closely related to tourism activities in local, regional, and international settings. Tourism is globally recognized as one of the largest and fastest-growing economic sectors, while in developing countries, tourism is specifically seen as a tool to promote economic development [15]. In Switzerland from 1984 to 2005, there was a 15% increase in person-kilometers travelled in leisure time [16]. Indonesia has seen a growing number of domestic tourism trips from 2018, with as many as 303 million trips to 722 million trips in 2019 [17]. Although in 2020 the number declined to 518 million trips due to COVID-19 restrictions, this figure is still higher than the 2018 level. A study by Dubois and Ceron [18] has projected that French leisure travelers will increase their passenger-kilometers 200% by 2050, using business-as-usual scenarios.

Despite its importance and flexibility in terms of specific locations and times, leisure travel is the most difficult kind of travel to analyze [16]. Even though it is a complex topic, a substantial number of studies have been conducted by researchers who have mainly gathered empirical evidence from developed countries. In his dissertation, Nawijn [19] explored the potential effects of leisure travel on individuals' happiness; he studied which leisure activities increase happiness and who receives the benefit from these activities. Nawijn and Veenhoven [20] disentangled cause and effect in the relationship between happiness and leisure activity, using data from Germany. Ohnmacht et al. [16] researched leisure travel behavior with regard to interrelationships between lifestyles, social networks, and social influence. De Vos et al. [5] studied the effect of satisfaction with leisure trips on the satisfaction with the leisure activity at the trip's destination. They employed data from Ghent, Belgium, and found that spill-over effects exist from trip satisfaction on leisure activity satisfaction and that both these short-term satisfactions affect eudaimonic well-being and life satisfaction, whether directly or indirectly.

Several other topics related to leisure trips have been studied. For example, Almlöf et al. [21] conducted a study in Stockholm regarding the impact of autonomous technology on leisure and work trips. They found that the impacts of self-driving technology may have varied societal impacts even within a region and may lead to increased car travel, especially during off-peak travel periods. Kim and Mokhtarian [22] examined long-distance (overnight) leisure trips by residents of the state of Georgia based on a survey conducted in 2017–2018. Große et al. [23] compared the leisure travel patterns of people living in a central urban district in Copenhagen, Denmark, with those of people living in a small town in the commuter belt. Priya et al. [24] attempted to analyze the trips undertaken by senior citizens for leisure activities. Dubois and Ceron [18] investigated the impact of French tourism/leisure trips on greenhouse gas (GHG) emissions and found a projected increase in GHG emissions by 90% in 2050, using business-as-usual scenarios. Meyer and Meyer [15] investigated the role of tourism in South Africa in the economic development of local regions. Laroche et al. [25] examined the role of tourists' holiday preferences in shaping the carbon footprint of leisure travel within the EU by calculating demand and impact indicators associated with eight holiday styles. A study by Wicker et al. [26] in 2020 examined the economic impact (measured by visitor spending) and environmental impact (measured by carbon footprint) of leisure trips on the natural environment. Chincholkar [27] explored Indian consumers' behavior towards tourism and identified their preferences when planning leisure trips.

Studies on leisure trips are mostly carried out in the context of travel behavior. Tarigan and Kitamura [14] examined the effect of the frequency of leisure trips per week on the variability in the number of such trips over weeks, and found that the effects varied substantially across activity types, using data from Germany. Using data from households in Bristol and Greater Manchester, England, Farag and Lyons [28] studied the relative strength of various factors affecting the use and non-use of pre-trip public transportation information for business and leisure trips. Mokhtarian et al. [13] conceptually explored the potential impacts of information communication technology (ICT) on leisure activities and associated travel. Using Mobidrive data based on interviews in the cities of Karlsruhe and Halle, Germany, Schlich et al. [11] answered the questions of how repetitious leisure traffic is, how much does one day resemble another in terms of what people do in their free time, and how many different places are visited. Cai [29] examined U.S. household lodging expenditure patterns on vacation. Duffell and Harman [30] examined the factors influencing and inducing leisure travel by focusing on leisure marketing by Britain's national railway corporation. The mobility of senior citizens with respect to various leisure activities was analyzed using data from the Dutch National Travel Survey [31]. Simma et al. [32] studied the destination choice within Switzerland for different activity types. A study on the characteristics of everyday leisure trips for social and recreational purposes was conducted by Strömblad et al. [33]. Sener et al. [34] studied discretionary leisure activity engagement by children in detail, using data from the United States. Strömblad et al. [35] conducted a study with a focus on everyday leisure trips for social and recreational purposes to cope with COVID-19 in Sweden. The "value of leisure" (VoL) for different population segments has been estimated by Hössinger et al. [36].

Studies on transportation mode choice for specific trips, for instance leisure trips, have been widely conducted. Limtanakool et al. [37] investigated the influence of spatial configuration of land use and transport systems on mode choice for medium- and longer-distance travel across the trip purposes of commuting, business, and leisure by employing data from the Netherlands. Acker et al. [38] built a modal choice model for leisure trips, using data on personal lifestyles and attitudes from Ghent, Belgium. Wardman et al. [39] examined the degree of interaction between rail and car modes in the interurban leisure travel market in Great Britain. Anable and Gatersleben [40] examined the relative importance that people attach to various instrumental and affective journey attributes when travelling either for work or for a leisurely day trip. Strömblad et al. [41] analyzed factors affecting mode choice for everyday leisure purposes and reasons for reducing car mileage for leisure trips by conducting an interview study among residents of Gävle, Sweden.

In terms of variables in investigations of transportation mode choice, the impact of travel time, cost, and transit burdens on mode of commuting choice have been examined based on the binomial logistic regression model in a transit-oriented mega city: Seoul, Korea [42]. Attributes of the elderly's demographic characteristics, latent variables, and heterogeneity were employed to evaluate the accessibility of public transit in China; the investigators used confirmatory factor analysis and a latent-class logit model (LCM) [43].

A study using data from households surveyed in Budapest examined travel-time variables and travel characteristics, such as travel time, travel cost, age, gender, income, and car ownership, which were analyzed using a multinomial logit (MNL) model [44]. Different leisure travel types among urbanites were analyzed using an LCM on data from Berlin and Munich, Germany; the researchers analyzed everyday travel, norms and attitudes, socio-demographic characteristics, spatial aspects, and mode choice [45]. The linkage between the built environment and travel behavior was investigated by employing a path model to evaluate objective and subjective influences on mode choice for leisure trips, using data from Ghent [38]. Baumgartner et al. [46] reported an online choice experiment in Switzerland to test the effectiveness of two financial and three non-financial treatments to reduce car-based leisure travel control for a wide range of determinants proven to be relevant for mode choice using an MNL model. Schwanen et al. [31] investigated the link between the choice of travel mode for leisure trips to personal characteristics, car ownership, and residential environment, using an MNL model with data from The Netherlands.

A review of the literature has shown that a large number of studies have been conducted using empirical data from developed countries. Less common is literature regarding leisure trips in developing countries, keeping in mind that there is a close relationship between tourism efficiency and transportation accessibility [47], thus the present authors' motivation to study transportation-mode choice behavior specifically for leisure trips.

Some shared features of tourism and leisure include voluntary activities and activities conducted during free time. Although both terms share a common feature, tourism emphasizes a more substantial break in routine [48]. Moreover, the effect of ICT exists in the form of the service of *online transportation*—car- and motorcycle-based ride-hailing through mobile applications.

Thus, the results of this study intend to enrich the body of knowledge regarding travel behavior for leisure trips, using data from a developing country in the digital era. The aims of this study are to identify the significant attributes that influence the decisions of people outside Bandung in choosing transportation modes for leisure trips to Bandung. For this research, we ran four different MNL models. In the first one, we inputted all travelers, whereas for the others, we employed car users, motorcycle users, and public transport users, respectively.

This remainder of this article is organized as follows. Section 2 describes the materials and methods used in this study. Section 3 presents the results, which is followed by the discussion in Section 4. The final section provides conclusions, policy implications, study limitations, and ideas for future research.

2. Materials and Methods

2.1. Study Area

The study area in this research was Bandung (Figure 1), the capital city of West Java, Indonesia. Bandung is located about 150 km southeast of Jakarta. It can be reached in around 2.5 h by road from Jakarta. There are many available modes of transportation in Bandung City, from the motorcycle, paratransit (*Angkot*), taxi, and bus, up to online transportation (Figure 2). In fact, the Government of Indonesia proposed several economic development plans where tourism activity is the main driver. Several new tourism destinations have been recently built to attract visitors. Each local government also strives to improve their city's amenities, including the City of Bandung.

Bandung has grown to become an important center in Indonesia, demonstrating a higher economic growth rate than the national average [49]. Bandung has become a major tourism destination with its proximity to the Indonesian capital city of Jakarta. Bandung has diverse tourism potential with its unique natural sites, culture, heritage buildings, culinary attractions, fashion, recreation, and entertainment options [50], as well as the geo-tourism possibilities in the Bandung Basin [51]. Bandung attracts not only visitors from faraway cities, but also visitors from surrounding cities, such as Cimahi City, Bandung Regency, and West Bandung Regency.

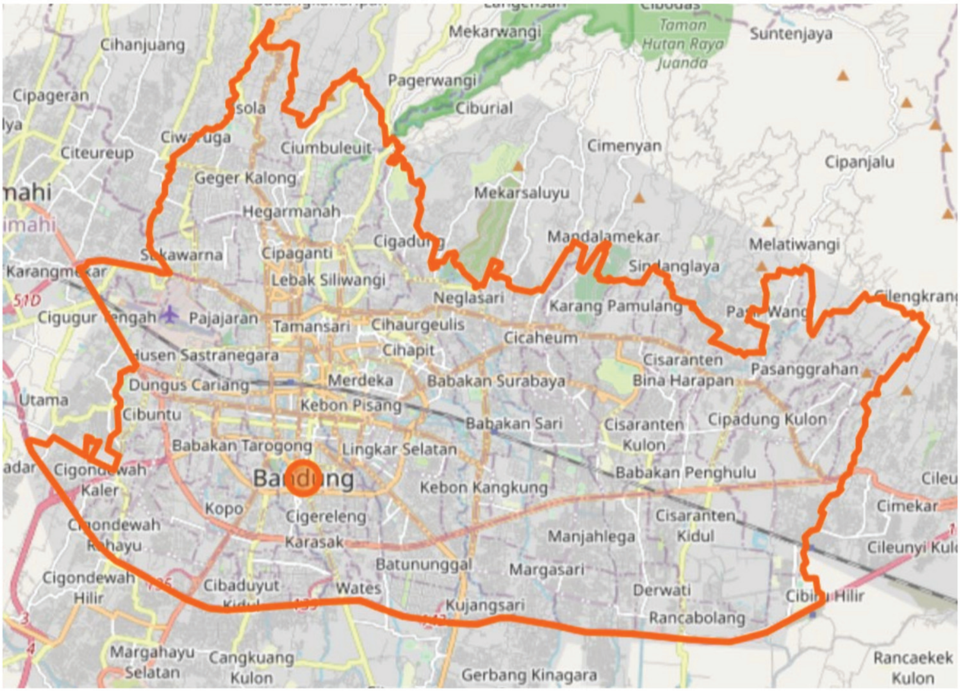


Figure 1. Map of Bandung City [52].

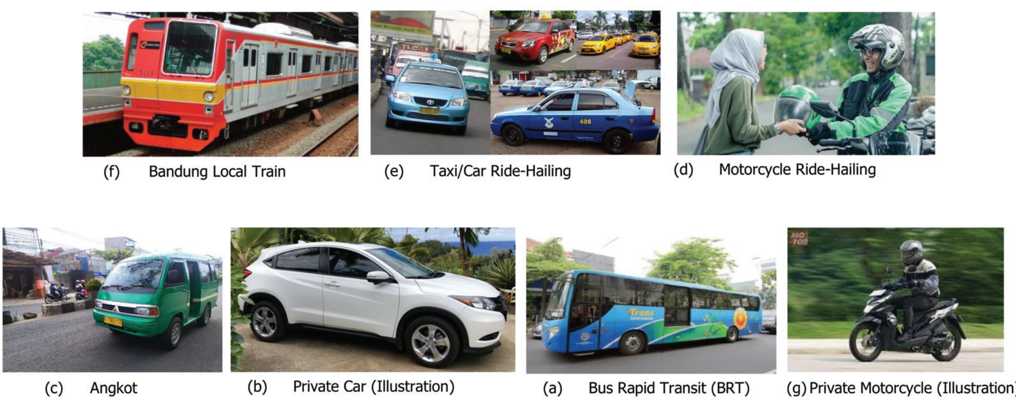


Figure 2. Available Modes of Transportation in Bandung City [53–58].

2.2. Data and Survey Implementation

A key element of the survey used in this study is the prospective travel choices based on stated preferences in the choice experiment. Stated-preference (SP) surveys have been widely used in the field of transportation to analyze people's travel behavior [43]. SP surveys can be designed to capture people's preferences for a set of hypothetical scenarios, such as alternate kinds of transportation that are not yet available or a change in the value of a given alternative. In the SP survey, various hypothetical scenarios are presented to respondents, who then select their preferred choice(s) regarding each scenario from a finite set of attributes and alternatives [59,60].

In this study, seven choice alternatives of transportation mode were provided to respondents, including train, privately owned car, privately owned motorcycle, *angkot* (a kind of paratransit that drives a fixed route. It is a small four-wheeled vehicle (e.g., a minibus) that has been modified for use as public transportation. They are mostly operated by private organizations or individuals.), motorcycle ride-hailing (MRH), car ride-hailing (CRH) (which also includes conventional taxis), and bus rapid transit. The choice alternatives in this study are the existing modes in Bandung; more detailed information regarding the mode services there can be found in [61,62].

The five attributes to describe the services available in each mode included travel time, waiting time, travel cost, access time, and payment method, which were presented in the SP questionnaire to respondents. These attributes were drawn from prior studies that found they were the most popular in describing each mode choice for an Indonesian context, for example travel time and travel cost [63–67]. Some consider waiting time [63,64,66,67] for public transport, and some also consider access egress [64]. However, payment method is seldom considered, especially the cashless method; therefore, we have added that attribute to our SP experiment.

To increase the realism of the choices, the distance provided in this survey is the same route for each scenario. A preliminary study was conducted to identify the real range of values characteristic of each mode. The travel-time value of the alternatives was collected using Google Maps applications for two conditions—during a *peak period* with heavy traffic and during normal conditions on the weekend. The peak period usually lasts over the lunch and dinner hours, while normal conditions are experienced outside peak periods during weekends. For more on the value of the waiting time and *access-egress time* see Rizki et al. [62]. The travel costs of a private car and motorcycle were calculated by including fuel and parking costs, while the private car mode included the cost of tolls. The travel costs of the bus rapid transit, train, angkot, MRH, and taxi were calculated from existing fares, using the available apps. The payment methods for this study were divided into cash and cashless. After conducting several runs of preliminary data collection to simulate the real services, a list of the range values was able to be gathered. Based on the range values for each attribute, the values for each attribute were selected for each choice alternative. The levels' values for each alternative are presented in Table 1.

Table 1. Levels of the attributes for each alternative.

Attributes	Private Car	Private Motorcycle	Angkot	Train	Bus Rapid Transit	Motorcycle Ride- Hailing (MRH)	Car Ride-Hailing (CRH)
Travel Time (min.)	40, 60, 80	40, 50, 60	60, 75, 90	25, 35, 45	60, 75, 90	40, 50, 60	40, 60, 80
Waiting Time (min.)	NA	NA	5, 10, 15	5, 10, 15	5, 10, 15	5, 10, 15	5, 10, 15
Travel Cost (IDR) [a]	45,000, 55,000, 75,000	25,000, 30,000, 40,000	2000, 5000, 7000	5000, 7000	10,000, 12,000, 15,000	50,000, 60,000, 70,000	90,000, 120,000, 150,000
Access Egress (minutes)	NA	NA	5, 10, 15	5, 10, 15	5, 10, 15	5, 10, 15	5, 10, 15
Payment Method	Cash, Cashless	Cash, Cashless	Cash, Cashless	Cash, Cashless	Cash, Cashless	Cash, Cashless	Cash, Cashless

[a] USD 1 equaled IDR 15,729.37. https://www.xe.com/currencyconverter/convert/?Amount=1&From=USD&To=IDR, accessed 5 November 2022.

With seven choice alternatives and five attributes with two or three levels, a total of 32 scenarios were obtained. The scenario arrangements were conducted using NGENE software for generating experimental designs that are used in stated-choice experiments for the purpose of estimating choice models, particularly of the logit type [68]. The 32 scenarios were segmented into eight blocks with four scenarios each. Each block was later assigned to each set of questionnaires. The questionnaire was divided into three parts. The first part asked respondents to report their daily mode of transportation and also their preferred mode of transportation during holidays. The second part presented the scenarios, and the last part asked respondents to report their demographics. The English version of the distributed questionnaire is provided in Appendix B.

In this study, data were collected from respondents who lived outside Bandung City. Residents from outside Bandung City who visited Bandung during weekends or holidays for leisure were chosen as respondents. The data for analyses were collected from 5 August 2022 to 27 August 2022. A convenience sampling method with snowball distribution was used, and the team collected responses from 305 participants. As each respondent received four scenarios, the total number of observations collected added up to 1220.

2.3. Multinomial Logit Model

The MNL model is frequently used to interpret and calibrate mode-choice data [69]. In MNL models, the probability of a decision-maker (n) choosing an alternative (i) over a set of alternatives (j) is when the utility of an alternative (i) is bigger than other alternatives, as can be seen in Equation (1), where C_n stands for the available set of alternatives.

$$P_{in} = Pr(U_{in} > U_{jn},\ \forall\, j \in C_n, j \neq i) \quad (1)$$

where P_{in} is the probability of individual or decision-maker (n) choosing an alternative (i) over a set of alternatives (j). U_{in} is the utility of the alternative (i) chosen by the decision-maker (n). U_{jn} is the the utility of non-chosen alternatives for a set of alternatives (j) by the decision-maker (n). In this study, the alternatives were private car ($i = 1$), private motorcycle ($i = 2$), angkot ($i = 3$), train ($i = 4$), bus rapid transit ($i = 5$), MRH ($i = 6$), and CRH ($i = 7$). The utility (U_{in}) is then decomposed into systematic (V_{in}) and random utility (ε_{in}), as can be seen in Equation (2).

$$U_{in} = V_{in} + \varepsilon_{in} \quad (2)$$

The systematic utility function (V_{in}) is further decomposed, as can be seen in Equation (3). The random utility (ε_{in}) is assumed to be an extreme value (i.e., Gumbel-distributed) with a variance of $\frac{\pi^2}{6}$ and identically and independently distributed across observations.

$$V_{in} = \alpha_i + \sum_k \beta_{ki} X_{kin} + \sum_k \gamma_{ki} S_{kin} \quad (3)$$

where α_i is the alternative-specific constant with paratransit as the reference alternative, and β_{ki} provides the alternative (i) specific parameters related to attribute X_{kin}. These attributes are travel time, travel cost, waiting time, access egress, and payment method. γ_{ki} describes the alternative-specific (i) parameters related to the socio-demographic characteristics of participant S_{kin}, where the characteristics included age, education, gender, domicile, and income.

The utility function of the first alternative, car, can be seen in Equation (4). We estimated the alternative-specific constant of car against the reference alternative, which is angkot. Attributes are travel time, travel cost, and payment method. There is no waiting time and access egress, since we assumed that the decision-maker could directly use the car. Payment method in this context is for buying fuel. Regarding socio-demographic characteristics, we estimated them against the reference alternative, angkot.

$$\begin{aligned} V_{Car_n} = {} & ASC_{Car_n} + \beta_{TravelTimeCar_n} TravelTimeCar_n + \beta_{TravelCostCar_n} TravelCostCar_n \\ & + \beta_{PaymentMethodCar_n} PaymentMethodCar_n + \sum_k \gamma_{ki} S_{kin} \end{aligned} \quad (4)$$

The utility function of the second alternative, motorcycle, can be seen in Equation (5). The attributes are mostly similar to the car alternative, since we assumed that the decision-maker could use their motorcycle directly.

$$\begin{aligned} V_{motorcycle_n} = {} & ASC_{motorcycle_n} + \beta_{TravelTimeMotorcycle_n} TravelTimeMotorcycle_n \\ & + \beta_{TravelCostMotorcycle_n} TravelCostMotorcycle_n \\ & + \beta_{PaymentMethodMotorcycle_n} PaymentMethodMotorcycle_n + \sum_k \gamma_{ki} S_{kin} \end{aligned} \quad (5)$$

The third alternative's utility function can be seen in Equation (6). For this alternative, we did not estimate the alternative-specific constant as well as socio-demographic characteristics since this alternative is the reference alternative. The attributes are travel time, travel cost, waiting time, access egress, and payment method. Waiting time and access egress become relevant for public transport since the decision-maker cannot access it directly.

$$\begin{aligned} V_{Angkot_n} = {} & \beta_{TravelTimeAngkot_n} TravelTimeAngkot_n + \beta_{TravelCostAngkot_n} TravelCostAngkot_n \\ & + \beta_{WaitingTimeAngkot_n} WaitingTimeAngkot_n + \beta_{AccessEgressAngkot_n} AccessEgressAngkot_n \\ & + \beta_{PaymentMethodAngkot_n} PaymentMethodAngkot_n \end{aligned} \quad (6)$$

The fourth alternative's utility model can be seen in Equation (7). The attributes for this alternative, train, are almost similar to angkot. However, we added an alternative-specific constant and we also estimated the socio-demographic characteristic parameters.

$$\begin{aligned} V_{Train_n} = {} & ASC_{Train_n} + \beta_{TravelTimeTrain_n} TravelTimeTrain_n + \beta_{TravelCostTrain_n} TravelCostTrain_n \\ & + \beta_{WaitingTimeTrain_n} WaitingTimeTrain_n + \beta_{AccessEgressTrain_n} AccessEgressTrain_n \\ & + \beta_{PaymentMethodTrain_n} PaymentMethodTrain_n + \sum_k \gamma_{ki} S_{kin} \end{aligned} \quad (7)$$

For the fifth alternative, we can see the utility function in Equation (8). For bus, the attributes are travel time, travel cost, waiting time, access egress, and payment method. For this alternative, we also estimated an alternative-specific constant and the socio-demographic parameters.

$$\begin{aligned} V_{Bus_n} = {} & ASC_{Bus_n} + \beta_{TravelTimeBus_n} TravelTimeBus_n + \beta_{TravelCostBus_n} TravelCostBus_n \\ & + \beta_{WaitingTimeBus_n} WaitingTimeBus_n + \beta_{AccessEgressBus_n} AccessEgressBus_n \\ & + \beta_{PaymentMethodBus_n} PaymentMethodBus_n + \sum_k \gamma_{ki} S_{kin} \end{aligned} \quad (8)$$

The sixth alternative is motorcycle-based ride-hailing. We can see the utility function in Equation (9). Other than the alternative-specific constant and socio-demographic parameters that we estimated, we also have attributes similar to other public transport alternatives.

$$\begin{aligned} V_{MRH_n} = {} & ASC_{MRH_n} + \beta_{TravelTimeMRH_n} TravelTimeMRH_n + \beta_{TravelCostMRH_n} TravelCostMRH_n \\ & + \beta_{WaitingTimeMRH_n} WaitingTimeMRH_n + \beta_{AccessEgressMRH_n} AccessEgressMRH_n \\ & + \beta_{PaymentMethodMRH_n} PaymentMethodMRH_n + \sum_k \gamma_{ki} S_{kin} \end{aligned} \quad (9)$$

Finally, the last alternative utility function can be seen in Equation (10). We can see that the estimated parameters are the alternative-specific constant for car-based ride-hailing, travel time, travel cost, waiting time, access egress, and payment method.

$$\begin{aligned} V_{CRH_n} = {} & ASC_{CRH_n} + \beta_{TravelTimeCRH_n} TravelTimeCRH_n + \beta_{TravelCostCRH_n} TravelCostCRH_n \\ & + \beta_{WaitingTimeCRH_n} WaitingTimeCRH_n + \beta_{AccessEgressCRH_n} AccessEgressCRH_n \\ & + \beta_{PaymentMethodCRH_n} PaymentMethodCRH_n + \sum_k \gamma_{ki} S_{kin} \end{aligned} \quad (10)$$

The probability (P_{in}) of each individual n choosing alternative i from a set of alternatives j (j = 1, 2, . . . , J) can be estimated as follows in Equation (11).

$$P_{in} = \frac{\exp(V_{in})}{\sum_{j=1}^{J} \exp(V_{jn})} \tag{11}$$

A summary of the model framework can be seen in Figure 3. Rectangles represent the observed variables, which consist of socio-demographic characteristics and five attributes of alternatives. The ellipse represents one latent factor utility of alternatives, for which the equations can be found in Equations (4)–(10). The solid arrows denote the regression relationship, while dashed arrows represent the indicator measurement relationship. Epsilon represents the random utility, while the utility maximization is as expressed in Equation (12).

$$y_i = \begin{cases} 1 \; if \; U_{in} > U_{jn}, \forall \, j \neq i \\ 0 \; otherwise \end{cases} \tag{12}$$

where y_i is 1 if the alternative i is chosen, and 0 otherwise.

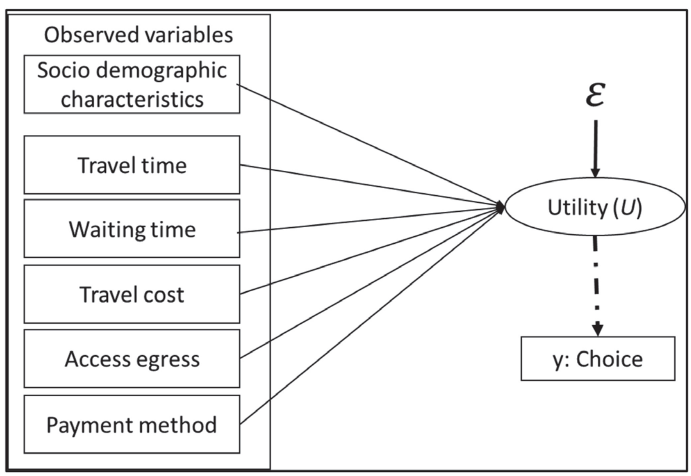


Figure 3. Multinomial logit model framework.

We estimated the MNL model parameters with maximum likelihood estimation using Biogeme, an open-source freeware. By using Biogeme, we were able to estimate the parameters of a model, test hypotheses about those parameters, and estimate by maximum likelihood a broad range of random utility models. In the end, simulations results will provide a number of estimates and robust *t*-tests [70].

3. Results

3.1. Characteristics of Respondents

A total 305 respondents who travelled to Bandung City were recruited. All of them lived outside Bandung City. Table 2 shows that most respondents were female (72%). Most respondents were either high school- or undergraduate-educated (93%). Respondents working at private companies made up the majority (60%), whereas civil servants comprised only 3% of the sample.

Table 2. Respondent characteristics.

Variables		n		Proportion (%)	
Gender	Male	87		28	
	Female	218		72	
Age	Students	147		48	
	Young adult	113		37	
	Senior	46		15	
Education	High school	94		30	
	Undergraduate	194		63	
	Graduate	17		7	
Occupation	Student	39		12	
	Civil servant	12		3	
	Private officer	182		60	
	Other	73		25	
Monthly income (IDR)	1–6 million	234		76	
	6–12 million	49		16	
	>12 million	13		8	
Existing mode of transport for leisure	Privately owned car	210		69	
	Privately owned motorcycle	50		16	
	Bus	18		6	
	Taxi	13		4	
	Bandung local train	7		2	
	Angkot	3		1	
	Microbus	1		1	
	Rent-a-Car	3		1	
Ownership (units)		MC	Car	MC	Car
	0	12	191	4	62
	1	153	94	50	30
	2	104	19	34	6
	3	30	0	10	0
	4+	6	1	2	0.3

Travelers in this study with a monthly income ranging from IDR one to six million comprised 76% of the sample, while travelers with a monthly income more than IDR twelve million comprised 8% (IDR three million is the monthly minimum wage in the Bandung area). Most travelling respondents, therefore, fell into the medium range of income. Most of the respondents used private cars for leisure trips to Bandung City, while the choice of using public transportation added up to 15% of the sample. This fact is in line with the number of cars or motorcycles owned by respondents in their households. Data show that 93% of respondents owned at least one motorcycle (MC), and 63% owned at least one car.

3.2. Model Estimation

The estimation results are presented in Table 3, while the results of the respondent demographic analysis are presented in Table A1. There are four models: (1) general respondents, (2) car users, (3) motorcycle users, and (4) public transport users. General respondents included all respondents in the sample by existing mode use. From the model fit, we can see that the rho-square is between 0.2 and 0.5; therefore, we can say these models were acceptable.

Table 3. Estimation results.

Alternative/Attribute	General Respondents		Car Users		Motorcycle Users		Public Transport Users	
	Estimate	Robust *t*-Test	Estimate	Robust *t*-Test	Estimate	Robust *t*-Test	Estimate	Robust *t*-Test
Private Car	0.0731	0.0986	4.35	4	0.513	0.422	2.19	1.72
Private Motorcycle	0.782	1.12	4.9	4.48	1.21	1.17	−0.395	−0.334
Ride-hailing	1.62	1.42	1.99	1.29	3.82	1.72	6.31	2.97
Taxi	1.19	1.1	5.79	4.07	−9.7	−3.39	1.82	0.655
Train	2.56	2.87	6.97	5.42	−0.527	−0.416	2.60	1.69
Bus	6.1	4.65	7.09	3.66	3.44	1.19	3.59	1.58
Travel Time_Car	−0.00468	−0.351	−0.015	−0.915	−0.00562	−0.167	0.0218	0.575
Travel Cost_Car	0.00261	0.294	−0.00557	−0.516	−0.0014	−0.0617	0.0366	1.48
Payment Method_Car	0.0612	0.906	0.0892	1.12	−0.288	−1.53	0.213	1.03
Travel Time_Motorcycle	−0.0146	−1.7	−0.0224	−1.91	−0.0123	−0.653	0.000605	−0.0248
Travel Cost_Motorcycle	−0.0166	−1.88	−0.035	−2.82	0.000164	0.00908	0.0454	1.66
Payment Method_Motorcycle	0.0496	0.0971	0.11	1.56	−0.0623	−0.594	0.0322	0.218
Travel Time_MRH	−0.0186	−0.718	0.00468	0.141	−0.103	−1.72	−0.0784	−1.14
Waiting Time_MRH	−0.0186	−0.718	−0.00553	−0.137	−0.0842	−1.08	−0.0828	−0.899
Travel Cost_MRH	−0.0591	−2.37	−0.0473	−1.46	−0.114	−1.86	−0.213	−2.02
Payment Method_MRH	−0.292	−2.93	−0.24	−1.9	−0.46	−1.71	−0.644	−2.63
Travel Time_CRH	−0.0295	−1.84	−0.0292	−1.48	0.0186	0.265	−0.128	−2.38
Waiting Time_CRH	−0.0502	−0.927	−0.0593	−0.936	−0.00146	−0.00532	0.00255	0.0109
Travel Cost_CRH	−0.00994	−0.896	−0.0132	−0.986	0.0812	1.91	−0.0551	−1.39
Payment Method_CRH	−0.057	−0.576	−0.0711	−0.604	0.342	0.744	−0.108	−0.377
Travel Time_Angkot	−0.00181	−0.115	0.00241	0.0726	0.0108	0.455	−0.0176	−0.546
Waiting Time_Angkot	−0.000329	−0.00979	0.0521	0.803	0.00912	0.166	−0.0523	−0.664
Travel Cost_Angkot	−0.0429	−0.553	−0.106	−0.637	0.0312	0.254	−0.107	−0.683
Access Egress_Angkot	0.00548	0.15	−0.00751	−0.109	0.0258	0.424	−0.0271	−0.371
Payment Method_Angkot	0.192	1.45	0.252	0.995	0.146	0.72	0.0464	0.189
Travel Time_Bus	−0.0455	−2.51	−0.0559	−2.16	−0.0448	−0.862	−0.0275	−0.747
Waiting Time_Bus	−0.0621	−2.09	−0.0656	−1.57	−0.0988	−1.23	−0.0432	−0.732
Travel Cost_Bus	−0.175	−1.63	−0.264	−1.58	−0.112	−0.374	−0.0732	−0.335
Access Egress_Bus	−0.0247	−0.595	−0.0762	−1.08	−0.0202	−0.195	0.0612	0.722
Payment Method_Bus	−0.0739	−0.821	−0.144	−1.01	0.0059	0.0264	−0.0195	−0.105
Travel Time_Train	0.0258	1.53	0.0209	0.891	0.032	0.926	0.0298	0.321
Waiting Time_Train	−0.00203	−0.0725	−0.0224	−0.564	0.0102	0.192	0.0235	0.321
Travel Cost_Train	0.0929	0.673	−0.027	−0.139	0.288	1.04	0.116	0.31
Access Egress_Train	0.00327	0.149	−0.00803	−0.263	−0.00245	−0.0561	0.0496	0.782
Payment Method_Train	0.0352	0.64	−0.134	−1.76	0.318	2.76	0.0725	0.423
Model Fit								
Number of estimated parameters:	149		149		149		149	
Observation:	1376		800		356		220	
Init. log likelihood:	−2677.572		−1556.728		−692.744		−428.1002	
Final log likelihood:	−2144.414		−1193.522		−420.4835		−296.1037	
Rho-square for the init. model:	0.199		0.233		0.393		0.308	
Rho-square-bar for the init. model:	0.143		0.138		0.178		−0.0397	

The first column in Table 3 displays the general respondents' model. By achieving a robust *t*-test, the model shows that train and bus results were significant. The results indicate that, all else being equal, respondents would rather choose to take a train or bus (with the latter being most preferred) than an angkot for leisure trips. The model also shows that seven attributes were found to be significant in influencing leisure mode. Travel time and travel costs for private motorcycles, travel costs and payment method for ride-hailing, travel time for CRH, and travel time and waiting time for the bus were found to be negatively significant.

The second column in Table 3 presents the results of the car-users model. This model used data from respondents who mainly used a car as their preferred mode for leisure travel. There were 200 respondents in this category; therefore, we gathered a total of 800 observations. The two alternatives, train and bus, were significant. The results indicate that, all else being equal, people were more likely to choose to take a train or a bus over using the angkot, ride-hailing, CRH, or private car modes. The model also shows four significant attributes. Travel time for motorcycle mode, travel costs for motorcycle mode, and travel time for bus mode were negatively significant. In the payment method for the train, the results were significant with a negative value, which indicated that people were more likely to choose the train if the payment was using cash.

The third column in Table 3 shows the results of the motorcycle-users model. This model used data from respondents who preferred to use a motorcycle in their leisure activities. It can be seen that ride-hailing is the alternative which was significant. It also can be concluded that, all else being equal, people were more likely to choose ride-hailing than using a private motorcycle. The model also shows four attributes that were additionally significant; they were travel time with ride-hailing and travel cost with ride-hailing, but the result was negative for MRH, which indicates it was negatively significant. However, for CRH, the travel-cost attribute was positively significant. In the case of payment method, a positive significant result means that our respondents preferred to pay for their tickets using a cash method.

The last column presents model results from respondents who did not own any vehicles and currently used public transport as their preferred mode for leisure travel. Two alternatives were found to be significant: private cars and trains. Therefore, all else being equal, respondents who did not have private transport still preferred taking a private car or train for leisure travel.

The model also shows four significant attributes: travel costs of the motorcycle mode, travel costs and payment method for MRH, and travel time for CRH. Motorcycle travel costs were positively high, contrasting findings with the travel costs associated with ride-hailing, which is reflected in the result being negatively significant. Users of ride-hailing had a higher preference for low costs when they used those modes.

For the findings from the socio-demographic investigation, see Appendix A. For the socio-demographic characteristics, we grouped them into three categories: students (18–25 years old), young adults (26–41 years old), and seniors (42–56 years old). From the *t*-test results, students who used the bus had a significantly positive value. This means that students preferred the bus over the angkot. For the young adults, their result shows that they preferred the bus for their leisure trips. Last, for the seniors, all the mode alternatives were found to be significant except for the private car mode; those respondents were more likely to use the motorcycle, ride-hailing, CRH, bus, or train modes than the angkot.

As per the demographic of gender, the results show that males preferred to use the train or take the bus over the angkot. Furthermore, motorcycle, ride-hailing, train, and bus show positive results for females. Female respondents preferred to use a motorcycle, ride-hailing, train, or bus over an angkot.

The educational backgrounds of the respondents were also examined. High school, undergraduate, and graduate degrees comprised our three divisions. For their leisure trips, the respondents with those three backgrounds were more likely to use private cars, private motorcycles, or ride-hailing than they were to use angkots. The negative findings, however, indicate that angkots were more frequently utilized than ride-hailing, trains, or buses by respondents with those three backgrounds.

Respondents' domiciles were separated into two groups, West Java and outside West Java. With trains and buses, significant values were found from respondents who lived in West Java. According to this, commuters from West Java and outside West Java might be more likely to take the train or bus than the angkot.

We also surveyed respondents' incomes and divided them into three categories: Income A: IDR 1,000,000–IDR 6,000,000; Income B: IDR 6,000,001–IDR 12,000,000; and Income C: >IDR 12,000,000). First, respondents categorized into Income A and Income B were more likely to use CRH services over angkots for commuting. Furthermore, the results for respondents with incomes above IDR 12,000,000 differed, which shows that they were less likely to choose buses for their leisure trips than angkots. However, respondents in the Income C group preferred cars, motorcycles, ride-hailing, CRH, and trains over angkots.

1. Car users

Similar to before, we divided respondents' age into the same three groups. The outcomes of all the alternatives in car-user respondents were significantly positive. In order to avoid using angkots, respondents in the student age group were more likely to use a car, motorcycle, ride-hailing service, CRH service, train, or bus. It is clear from the results for both young adults and older adults that individuals preferred utilizing angkots over ride-hailing, since the ride-hailing result was negatively significant. However, because some of the alternatives—such as a private vehicle, motorcycle, ride-hailing service, train, and bus—are also favorably significant, some respondents were less likely to use angkots.

Furthermore, the respondents with high school and undergraduate backgrounds preferred to use a car for their leisure travel. Motorcycle and ride-hailing users were positively significant too, indicating that high school and undergraduate respondents were more likely to choose a car, motorcycle, or ride-hailing than use an angkot. However, the results from respondents with a high school and undergraduate background were different from respondents with a graduate school background. They were more likely to choose to use a private car or motorcycle than an angkot.

In terms of gender, male respondents were less likely to use ride-hailing, as the ride-hailing results were negatively significant. However, for female respondents, the results show that all the alternatives were positively significant. Therefore, female respondents were less likely to use angkots.

Based on respondents' domiciles, respondents came from either West Java or outside of West Java. The results from respondents from both West Java and outside West Java were mostly similar. However, respondents living outside West Java were less likely to use ride-hailing, since ride-hailing was insignificant.

As per respondents' income, data from those with Income A revealed that the bus result was positively significant, indicating that those individuals were more likely to use buses than angkots. Along with strong negative results, there were also significant positive results for the use of cars, motorcycles, and trains, indicating that respondents with Income A were more likely to use angkots than other modes of transportation. Similar findings are shown for Income B respondents. Those with incomes between IDR 6,000,001 and IDR 12,000,000 were more likely to use ride-hailing and to take the train than use an angkot for leisure travel. Finally, Income C respondents provided positively significant results for ride-hailing and CRH, indicating that they were more likely to utilize e modes than angkots.

2. Motorcycle users

By age, especially for students, the results for bus use were significant. Students preferred to use buses over angkots. Young adults preferred ride-hailing and bus trips over motorcycle trips for leisure travel. Results for young adults also show a significant value, but results were negative for CRH; therefore, it can be concluded that young adult respondents preferred to use angkots rather than CRH services. However, for senior respondents, the results were positively significant for motorcycle use and ride-hailing.

For males, only one alternative was significant with a negative result and that was for CRH; therefore, male respondents preferred to use CRH rather than angkots. However, the results for females were different from those for male respondents, which shows that females were more likely to use motorcycles or ride-hailing than angkots.

Respondents with a high school or undergraduate education provided significant results for train use. Respondents with a high school or undergraduate educational background were more likely to choose to use a train rather than an angkot for their leisure travel. Respondents with a graduate education background showed only positive significant results for CRH, meaning graduate respondents preferred to use CRH over angkots.

As per incomes, as depicted in Table A1 below, CRH characteristics for Income A respondents show significant results. It can be concluded that CRH for respondents with incomes between IDR 1,000,000 and IDR 6,000,000 were more likely to use CRH than angkots. However, Income B respondents preferred to use angkots over ride-hailing, trains, or buses; ride-hailing, train, and bus use for leisure were negatively significant. Last, Income C respondents reported positively significant car and motorcycle use, which indicates that respondents with incomes above IDR 12,000,000 were less likely to use angkots than cars or motorcycles.

3. Public transportation users

We also analyzed data from respondents with no private vehicle at their disposal. First, according to the results by students' ages, it can be seen in Table A1 that mostly negatively significant results were found with cars, motorcycles, and trains. Therefore, students were more likely to choose an angkot than a car, motorcycle, or train for leisure travel. For the young adult age group, the results of all transportation mode alternatives were significant but negative; this means that angkots were still the preferred choice for young adult respondents. Young adults reported entirely different results from seniors. They were most likely not to choose angkots, as all other alternatives, including car, motorcycle, ride-hailing, CRH, bus, and train results were positively significant for senior respondents.

Based on educational background, respondents educated to the high-school level were more likely to choose a car, train, or bus over an angkot, as the *t*-test value was positive and significant. However, according to respondents with undergraduate backgrounds, the results show that the ride-hailing and CRH choices were positively significant. Therefore, people with undergraduate backgrounds preferred ride-hailing or CRH for their leisure commuting.

Regarding respondents' gender, as seen in Table A1, for males, ride-hailing and motorcycle use show a significant value. However, ride-hailing shows a positive significance, meaning male respondents (who do not own any vehicle) were likely to choose ride-hailing over angkots. The results differed with motorcycle use, showing negatively significant results, meaning that respondents were more likely to use angkots than motorcycles.

Next, we analyzed the socio-demographic characteristic of respondents' domicile. Regarding respondents from West Java, the results show that four significant alternatives were car, ride-hailing, train, and bus use. The results of the four alternatives were positively significant, so it can be concluded that people travelling from the West Java area for leisure were more likely to use a car, ride-hailing, train, or bus than an angkot. However, respondents who lived outside West Java were more likely to use ride-hailing for commuting than angkots (i.e., ride-hailing was positively significant).

Finally, with respect to respondents' income, as can be seen in Table A1 below, motorcycle is the transportation alternative that was positively significant, which indicates that respondents with incomes between IDR 1,000,000 and IDR 6,000,000 were more likely to choose motorcycles over angkots. However, respondents with Income B were more likely to choose angkots versus alternatives that had negatively significant results.

4. Discussion and Conclusions

Using an SP questionnaire, this research aimed to identify the significant factors that influenced the decision of people living outside Bandung to choose leisure transportation modes to the City of Bandung. From the answers of 305 respondents, from which 1220 observations were garnered, four MNL models were estimated: (1) general respondents, (2) car users, (3) motorcycle users, and (4) public transportation users.

Each MNL revealed distinct findings that complement each other. First, from the general model, the train and bus mode were most popular for leisure trips to Bandung. This finding contradicts previous studies on leisure travel mode preferences in developing countries, such as from Sabogal-Cardona et al. [71] in Mexico and Acheampong et al. [72] in Ghana, who found that ride-hailing was mostly used for occasional trips. This can be explained by the fact that not only were the journeys in the present study long distance—originating outside of Bandung—but they were also typically conducted in groups of more than two people. Thus, trains or buses would be an appropriate transportation mode choice for parties involving more than two people. As also indicated by Bhat and Gossen [73], based on respondents in San Francisco, California, individuals with children or who live together with other households preferred outdoor recreation for leisure.

For the second model, the results showed that ride-hailing was less likely to be chosen by car-use respondents. However, the third model—where respondents currently used a motorcycle—shows that ride-hailing was preferred over an angkot. Last, the fourth model shows that car, ride-hailing, and train were the preferred modes. Moreover, the estimation results of the socio-demographics show that age, income, gender, educational background, and domicile influenced respondents' decision in choosing their transportation mode for leisure trips. This finding emphasized the effect of ICT on the decisions of people in developing countries, such as those in Bandung, in finding mobility for leisure travel in the digital era.

Our findings are also partly explained by the fact that our sample was dominated by females (71%). As Alemi et al. [74] pointed out in their study in California, women were more likely to use ride-hailing services than men, and the women were more inclined to use on-demand services. Additionally, our sample was dominated by productive-age respondents (19% students versus 71% workers) and educated individuals (64% with a bachelor's degree). Educated users tend to utilize ride-hailing services more frequently because they are more familiar with technology.

Payment methods also influenced preferences of travel modes for leisure trips. Interestingly, we found that when a cashless payment method was available (as in ride-hailing services), the respondents tended to choose paying with cash. On the contrary, when a cashless payment method was not available yet (as in the case of angkots), the respondents preferred paying with a cashless method. This finding implies that users should have access to a variety of payment options, including cashless and cash payments, as also suggested by Sikder [75] and Phuong and Tran [76]. Again, this study revealed an interesting finding regarding travel behavior in the digital era in fulfilling mobility needs for leisure trips, namely that flexibility—in terms of payment and mobility options—is valued more highly by Indonesians when travelling for leisure.

Travel time and travel costs have a significant effect, but the results are negative, which means that if the travel time is long, respondents will choose other modes of transportation. This finding is in line with the study by Mahdi et al. [44]. Travel time became significant for private motorbike users because they must drive their own vehicle, and it is different from using ride-hailing, where individuals do not need to steer their own motorbikes. Additionally, high travel time will also impact costs incurred by private motorbike users. This result is supported by the findings from Ha et al. [42], who found that individuals behave rationally when choosing transportation modes by taking into account both the travel-time gap and ratio. In tandem with travel-time factors, people also made mode choices based on travel-cost considerations.

The preference for using public transportation (e.g., ride-hailing services, taxis, and buses) for leisure trips is also found to be sensitive to travel time and travel cost, with bus users being the most sensitive. To alleviate the severe congestion that occurs in Bandung every weekend as a result of the high volume of recreational trips, public transportation should be promoted. A reliable service that guarantees efficient travel times with reasonable fares should be offered to encourage people to use public transportation.

5. Recommendations and Future Research

Based on the findings from this study, some recommendations can be made. The findings from the estimated model show that the local travelers who take leisure trips have a variety of transport mode preferences, but their previous or daily mode has a strong influence. The findings from the experiment using the SP questionnaire in this study show the effect of including the sensitivity of the common variables in mode choice. Moreover, our study also employed online transportation as a possible mode choice, in the form of motorcycle- and car-based ride-hailing. Our study also involved a variety of payment methods, from cash to cashless. These ride-hailing modes as well as cashless payment are the manifestation of the effect of digitalization, especially in leisure trips for local travelers. These findings motivate the first recommendation, namely the need to better understand the travel behavior or travel patterns of people who take leisure trips by considering the possible effects of digitalization. This information may provide a broader view of the effective potential of leisure trips, even if there is complexity surrounding this topic and high car dependence [33]. This understanding will also possibly mitigate tourism's externalities and implications for inequality and sustainability issues [77]. In fact, leisure trips are uniquely flexible and provide unusual independence. This uniqueness may differentiate the pattern or behavior of users in travelling leisurely from taking mandatory trips, such as commuting to work. Leisure trips often involve cars [46], especially in the case of domestic leisure trips that are short to medium in duration. This explains why CRH has become a popular choice, as ride-hailing provides flexibility as well as independence. It is a challenge for city governments to provide a series of mode choices that resonate with the city populace by utilizing positive features of ICT in this digital era. Mokhtarian et al. [13] suggested 13 dimensions of leisure activities to integrate ICT into the urban transportation system. Moreover, a study by Nawijn [19] found that people who took one or more holiday trips appeared to be significantly happier, even when income, health, and personality were controlled for. This finding implies a need to understand what aspects of leisure trips contribute most to happiness in both the present and future, especially in the face of increasing digitalization.

In the field of transportation, the accessibility of transportation is key [78]. As accessibility can be explained by several attributes, this study highlights the importance of travel cost, travel time, waiting time, access egress, and payment method. This study also highlights the sensitivity of those attributes, since travelers can be quite familiar with the urban transportation system at their destination (i.e., the travelers in this study from surrounding cities who visited Bandung City for leisure). Travelers showed sensitivity to price, time, and payment method, and these aspects might become more crucial as the features of ICT in transportation services may be employed to support the flexibility of leisure trips.

It is widely acknowledged that domestic tourism can provide an impetus to further economic growth in holiday regions and that domestic tourism may assist in solving some of the problems facing a country's international tourism industry [79,80]. This study investigated leisure trips by local travelers in Bandung City. The estimated models revealed the detailed characteristics of travelers based on their socio-demographic characteristics in selecting mode choice. The understanding of the individual characteristics of travelers is beneficial to developing a suitable marketing strategy for local governments to support tourism campaigns. Thus, the second recommendation is that city governments should define the characteristics of leisure-tourism trips in their cities. This will depend on the wide variety of possible leisure destinations and activities in the city. Tourists' actual choices were influenced by past experiences and by regional differences in the qualities of the wider environment [81]. In the case of Bandung City, which has a wide variety of tourist attractions, such as natural sites, cultural attractions, heritage buildings, culinary options, fashion outlets, recreation options, and entertainment venues [50], as well as geo-tourism possibilities in the Bandung Basin [51], the city will need a comprehensive plan regarding tourism transportation. Based on this plan, the city government will be able to provide concise and comprehensive information to travelers.

Comprehensive information will influence the experience of travelers. Related to our first recommendation, the third recommendation is to provide information to tourists regarding transportation services, which should carefully leverage scientific findings on travel behavior and socio-demographics, including travel attitudes, information factors, and social surroundings, as suggested by Farag and Lyons [28]. By referring to the findings from this study in terms of the mode characteristics, the basic information that needs to be provided concerns the possible transportation modes in the city, combined with each service's attributes; the value of this resource will be increased with additional information on connectivity, places of attraction, and other local features and characteristics. Again, the possible benefits of ICT may be utilized in supporting information provision to bolster and improve tourism-related transportation services.

This research has some limitations that could be addressed in future research. First, this study sampled only people from outside Bandung City, and different results may be obtained if respondents actually live and work in Bandung. Second, after the collection period for this study, the city governor provided new rules for ride-hailing payments; therefore, the results pertaining to ride-hailing significance in this study might change in future research just based on that fact alone. Last, the mayor of Bandung City introduced an initiative called the Bandung Urban Mobility Project, which is meant to provide new mobility options available soon in Bandung. A future study might measure people's choices regarding these new mobility alternatives to determine whether there are any differences between the existing modes of transportation and the new options.

Author Contributions: Conceptualization, T.B.J., P.F.B. and I.G.A.A.; methodology, T.B.J., P.F.B. and I.G.A.A.; software, M.Y.F.W. and P.F.B.; validation, T.B.J., P.F.B. and I.G.A.A.; formal analysis, M.Y.F.W., C.G.; data curation, M.Y.F.W. and C.G.; writing—original draft preparation, M.Y.F.W. and C.G.; writing—review and editing, T.B.J., P.F.B. and I.G.A.A.; supervision, T.B.J., P.F.B. and I.G.A.A.; project administration, M.Y.F.W. and C.G.; funding acquisition, T.B.J. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by the Directorate of Research and Community Services, the Directorate General of Research and Development Strengthening, and the Ministry of Research, Technology and Higher Education of the Republic of Indonesia, according to decision number 018/E5/PG.02.00/2022 and contract number (070/E5/PG.02.00.PT/2022; 009/SP2H/RT-JAMAK/LL4/2022; III/R/2022-06/1806-I; III/LPPM/2022-06/110-PE).

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: Not applicable.

Acknowledgments: The authors thank the editor and reviewers. The authors also thank Iwan Suwandana for managing the project and all parties who participated in this study.

Conflicts of Interest: The authors declare no conflict of interest.

Appendix A

Table A1. Estimation results by socio-demographics.

Attribute/Alternatives		General		Car User		Motorcycle User		Public Transport User	
		Estimate	Robust *t*-Test	Estimate	Robust *t*-Test	Estimate	Robust *t*-Test	Estimate	Robust *t*-Test
Age	Students–Car	−0.191	−0.501	1.84	3.87	−0.372	−0.514	−1.72	−2.47
	Students–Motorcycle	0.177	0.482	2.21	4.6	−0.668	−1.07	−1.99	−3.25
	Students–Ride-hailing	0.207	0.426	1.04	1.69	−0.361	−0.392	−0.263	−0.252
	Students–Car Ride-hailing	0.21	0.414	2.15	3.55	0.707	0.276	1.58	1.17
	Students–Train	0.212	0.513	2.39	4.4	−1.72	−2.65	−2.42	−3.49

Table A1. *Cont.*

Attribute/Alternatives		General		Car User		Motorcycle User		Public Transport User	
		Estimate	Robust *t*-Test	Estimate	Robust *t*-Test	Estimate	Robust *t*-Test	Estimate	Robust *t*-Test
	Students–Bus	1.89	3.55	2.51	3.34	3.5	3.26	−0.621	−0.704
	Young Adult–Car	−0.259	−0.744	1.46	2.94	−0.571	−0.815	−2.74	−4.75
	Young Adult–Motorcycle	−0.183	−0.541	1.54	3.06	−0.00279	−0.00473	−3.94	−6.3
	Young Adult–Ride-hailing	0.178	0.379	0.624	0.981	1.66	1.65	−4.07	−4.17
	Young Adult–Car Ride-hailing	−0.315	−0.688	1.79	2.93	−13.4	−3.94	−10.2	−9.59
	Young Adult–Train	0.604	1.58	2.45	4.44	−0.375	−0.601	−2.4	−3.72
	Young Adult–Bus	1.9	3.67	2.48	3.3	4.73	4.1	−2.22	−2.62
	Senior–Car	0.524	1.18	1.05	1.73	1.46	1.35	6.64	8.92
	Senior–Motorcycle	0.788	1.83	1.16	1.93	1.88	1.87	5.53	7.48
	Senior–Ride-hailing	1.23	2.28	0.322	0.443	2.52	2.03	10.6	8.4
	Senior–Car Ride-hailing	1.3	2.37	1.86	2.61	2.96	0.393	10.4	7.73
	Senior–Train	1.75	3.73	2.13	3.26	1.57	1.56	7.51	9.79
	Senior–Bus	2.31	4	2.09	2.54	−4.79	−3.66	6.43	6.42
Education	High school–Car	2.96	3.98	3.67	2.87	0.131	0.182	1.59	2.02
	High school–Motorcycle	2.54	3.46	2.88	2.27	−0.12	−0.203	0.802	1.13
	High school–Ride-hailing	2.61	3.21	3.97	2.98	0.885	0.949	1.37	1.29
	High school–Car Ride-hailing	−5.84	−4.16	−5.76	−3.45	−12.5	−7.63	−5.06	−3.54
	High school–Train	−4.61	−3.67	−4.71	−2.78	3.55	5.64	1.61	1.79
	High school–Bus	−7.36	−7.17	−6.83	−4.5	0.958	0.868	2.26	1.92
	Undergraduate–Car	3.33	4.57	4.32	3.18	0.607	0.765	0.597	0.759
	Undergraduate–Motorcycle	2.52	3.45	2.89	2.13	0.547	0.795	−1.2	−1.58
	Undergraduate–Ride-hailing	3.21	4.08	4.57	3.27	1.12	0.961	4.94	3.55
	Undergraduate–Car Ride-hailing	−4.91	−3.55	−5.07	−2.91	−1.29	−0.826	6.89	4.12
	Undergraduate–Train	−4.58	−3.66	−4.88	−2.77	4.42	6.22	1.08	1.18
	Undergraduate–Bus	−7.59	−7.58	−7.15	−4.58	0.364	0.305	1.33	1.04
	Graduate–Car	3.69	3.9	3.75	3.39	−0.225	−0.184	-	-
	Graduate–Motorcycle	2.29	2.35	1.27	1.06	0.783	0.714	-	-
	Graduate–Ride-hailing	1.68	1.35	−7.77	−6.5	1.81	1.42	-	-
	Graduate–Car Ride-hailing	−5.03	−3.09	−16.5	−10.2	4.06	1.72	-	-
	Graduate–Train	−5.24	−3.69	−5.95	−3.78	−8.5	−7.69	-	-
	Graduate–Bus	−7.26	−5.87	−7.31	−5.28	2.12	1.17	-	-
Gender	Male–Car	−0.216	−0.528	1.67	2.56	0.0658	0.0967	0.55	0.717
	Male–Motorcycle	0.0714	0.184	2.13	3.24	−0.138	−0.249	−1.26	−1.72
	Male–Ride-hailing	0.472	0.781	0.522	0.6	0.835	0.673	2.5	2.23
	Male–Car Ride-hailing	0.447	0.772	2.18	2.71	−4.7	−4.29	1.69	1.08
	Male–Train	1.04	2.18	2.95	4	−0.559	−0.838	0.723	0.814
	Male–Bus	3.15	4.59	3.6	3.45	1.93	1.27	1.42	1.18
	Female–Car	−0.528	0.746	2.68	4.57	0.448	0.641	1.64	2.3
	Female–Motorcycle	0.184	1.92	2.77	4.75	1.35	2.19	0.867	1.24
	Female–Ride-hailing	0.781	1.95	1.47	1.8	2.98	2.65	3.81	3.27
	Female–Car Ride-hailing	0.772	1.31	3.61	4.62	−5.01	−2.5	0.135	0.0972
	Female–Train	2.18	3.3	4.02	5.9	0.0319	0.0465	1.97	2.27
	Female–Bus	4.59	4.43	3.48	3.48	1.51	1.03	2.17	1.81

Table A1. *Cont.*

Attribute/Alternatives		General		Car User		Motorcycle User		Public Transport User	
		Estimate	Robust *t*-Test	Estimate	Robust *t*-Test	Estimate	Robust *t*-Test	Estimate	Robust *t*-Test
Domicile	West Java–Car	0.369	0.369	2.64	3.93	0.965	1.35	1.47	1.9
	West Java–Motorcycle	0.875	0.875	2.87	4.23	2.06	3.56	0.441	0.589
	West Java–Ride-hailing	1.06	1.06	1.29	1.46	3.22	2.65	2.59	2.32
	West Java–Car Ride-hailing	0.597	0.597	3.21	3.88	−3.97	−3.04	0.831	0.537
	West Java –Train	1.78	1.78	4.15	5.49	0.604	0.903	1.97	2.24
	West Java–Bus	3.24	3.24	3.76	3.45	2.54	1.68	2.06	1.66
	Outside West Java–Car	−0.296	−0.78	1.71	3.53	−0.452	−0.692	0.719	0.966
	Outside West Java–Motorcycle	−0.0936	−0.263	2.03	4.2	−0.847	−1.43	−0.836	−1.24
	Outside West Java–Ride-hailing	0.554	0.984	0.704	0.965	0.592	0.536	3.72	2.99
	Outside West Java–Car Ride-hailing	0.596	1.05	2.59	3.74	−5.73	−3.48	0.994	0.651
	Outside West Java Train	0.781	1.71	2.82	4.72	−1.13	−1.64	0.721	0.791
	Outside West Java–Bus	2.86	4.39	3.33	3.66	0.9	0.62	1.53	1.31
Income	Income_A–Car	−0.334	−0.266	−6.53	−5.34	−0.7	−0.466	−7.5	−5.94
	Income_A–Motorcycle	−0.312	−0.256	−5.84	−4.25	0.934	0.712	3.39	2.88
	Income_A–Ride-hailing	−0.917	−0.724	1.72	1.46	1.06	0.714	−11.4	−6.99
	Income_A–Car Ride-hailing	6.22	5.35	0.222	0.183	13.2	4.15	−6.07	−3.25
	Income_A–Train	−0.795	−0.682	−6.29	−5.41	0.159	0.134	−7.61	−5.98
	Income_A–Bus	−2.29	−2.02	3.62	3.11	−2.45	−2	−9.86	−9.52
	Income_B–Car	−0.279	−0.208	−5.76	−3.67	−1.67	−0.98	−9.14	−6.41
	Income_B–Motorcycle	−1.43	−1.09	−6.36	−3.75	−1.21	−0.819	0.788	0.538
	Income_B–Ride-hailing	−1.12	−0.824	2.62	1.7	−12	−7.3	−12	−6.98
	Income_B–Car Ride-hailing	6.37	5.05	1.05	0.653	1.22	0.385	−4.54	−1.72
	Income_B–Train	−1.39	−1.1	−5.59	−3.67	−2.52	−1.79	−11	−6.89
	Income_B–Bus	−2.35	−1.9	4.28	2.74	−3.25	−2.3	−11.4	−8.87
	Income_C–Car	6.58	4.75	1.11	0.876	8.27	2.92	-	-
	Income_C–Motorcycle	6.04	4.47	1.44	1.01	7.83	3.04	-	-
	Income_C–Ride-hailing	6.58	4.64	10.6	8.65	−2.86	−1.02	-	-
	Income_C–Car Ride-hailing	14.3	10.7	9.51	7.54	2.9	1.18	-	-
	Income_C–Train	4.94	3.76	0.315	0.258	4.55	1.4	-	-
	Income_C–Bus	−3.25	−2.55	−0.318	−0.259	−5.37	−1.69	-	-
Model Fit									
Number of estimated parameters		149		149		149		149	
Observations		1376		800		356		220	
Init. log likelihood		−2677.572		−1556.728		−692.744		−428.1002	
Final log likelihood		−2144.414		−1193.522		−420.4835		−296.1037	
Rho-square for the init. model		0.199		0.233		0.393		0.308	
Rho-square bar for the init. model		0.143		0.138		0.178		−0.0397	

Appendix B

[Introduction]

We from the Universitas Katolik Parahyangan Research Team would like to introduce ourselves. Currently we are conducting research on the selection of modes of transportation in the City of Bandung.

There are several provisions in filling out this questionnaire:

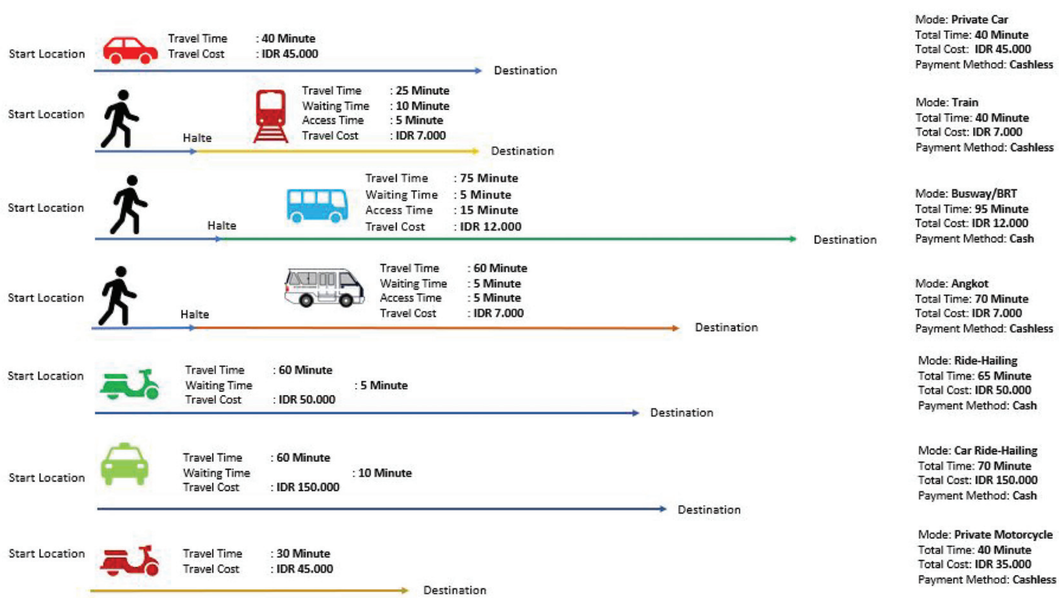
1. Completing of the questionnaire will take 5–10 min

2. There are no right or wrong answers.
3. It is expected that the respondent will fill in the answers honestly and thoroughly.
4. The information obtained from this questionnaire is CONFIDENTIAL. It will not be misused and is only for research and publication purposes.

Thank you
[Respondent Categorisation]

1. Respondent Domicile (Please fill in)
2. Birth Date
    (a) 1–8
    (b) 9–16
    (c) 17–25
    (d) 26–31

[Selection of Scenario]
Scenario (Example 1 out of 32 scenarios)



From Scenario 1, which mode of transportation fits your criteria?

(a) Private Car
(b) Train
(c) Busway/BRT
(d) Angkot
(e) Ride-Hailing
(f) Car Ride-Hailing
(g) Private Motorcycle

[Demographic Profile]

1. Gender
    (a) Male
    (b) Female
2. Age (Please fill in)
3. Educational Background

   (a) High school
   (b) Undergraduate
   (c) Graduate
4. Current Job
   (a) Student
   (b) Private Employee
   (c) Civil Servant
   (d) Self-Employed
   (e) Other: Please fill in
5. Monthy Income (1 USD = IDR 15,114)
   (a) <IDR 1 Million
   (b) IDR 1–3 Million
   (c) IDR 3–6 Million
   (d) IDR 6–9 Million
   (e) IDR 9–12 Million
   (f) >IDR 12 Million
6. Estimated Travel Time from Home to Office (Please fill in)
7. Estimated Distance from Home to Office (Please fill in)
8. Car Ownership (Please fill in)
9. Motorcycle Ownership (Please fill in)

References

1. OECD. *OECD Guidelines on Measuring Subjective Well-Being*; OECD: Paris, France, 2013.
2. Vos, J.D. Satisfaction with leisure trips: Findings from Ghent, Belgium. In *Quality of Life and Daily Travel*; Friman, M., Ettema, D., Olsson, L.E., Eds.; Springer International Publishing: New York, NY, USA, 2018; pp. 139–155.
3. Passmore, A.; French, D. Development and administration of a measure to assess adolescents' participation in leisure activities. *Adolescence* **2001**, *36*, 67–75. [PubMed]
4. Tinsley, H.E.; Hinson, J.A.; Tinsley, D.J.; Holt, M.S. Attributes of leisure and work experiences. *J. Couns. Psychol.* **1993**, *40*, 447–455. [CrossRef]
5. Vos, J.D.; Schwanen, T.; Witlox, F. The road to happiness: From obtained mood during leisure trips and activities to satisfaction with life. In Proceedings of the World Symposium on Transport and Land Use Research, Brisbane, QLD, Australia, 3–6 July 2017.
6. Mill, R.C. *The Inter-Relationships between Leisure, Recreation, Tourism, and Hospitality*; SAGE Publications Ltd.: Thousand Oaks, CA, USA, 2008.
7. Carr, N. The tourism-leisure behavioural continuum. *Ann. Tour. Res.* **2002**, *29*, 972–986. [CrossRef]
8. Mokhtarian, P.L.; Pendyala, R.M. Travel satisfaction and well-being. In *Quality of Life and Daily Travel*; Springer International Publishing: New York, NY, USA, 2018; pp. 17–39.
9. De Vos, J. Analysing the effect of trip satisfaction on satisfaction with the leisure activity at the destination of the trip, in relationship with life satisfaction. *Transportation* **2019**, *46*, 623–645. [CrossRef]
10. Huang, Y.C.; Cheng, J.S.; Chang, L.L. Understanding leisure trip experience and subjective well-being: An illustration of creative travel experience. *Appl. Res. Qual. Life* **2020**, *15*, 1161–1182. [CrossRef]
11. Schlich, R.; Schönfelder, S.; Hanson, S.; Axhausen, K.W. Structures of leisure travel: Temporal and spatial variability. *Transp. Rev.* **2004**, *24*, 219–237. [CrossRef]
12. Timo, O.; Konrad, G.; Ueli, H.; Jutta, D.; Daniel, M.; Jürg, S.; Jobst, G. *Freizeitverkehr Innerhalb von Agglomerationen*; Swiss Association of Transportation Engineers: St. Gallen, Switzerland, 2008.
13. Mokhtarian, P.L.; Salomon, I.; Handy, S.L. The impacts of ICT on leisure activities and travel: A conceptual exploration. *Transportation* **2006**, *33*, 263–289. [CrossRef]
14. Tarigan, A.K.M.; Kitamura, R. Week-to-week leisure trip frequency and its variability. *Transp. Res. Rec.* **2009**, *2135*, 43–51. [CrossRef]
15. Meyer, D.F.; Meyer, N. The role and impact of tourism on local economic development: A comparative study. *Afr. J. Phys. Health Educ. Recreat. Danc.* **2015**, *21*, 197–214.
16. Ohnmacht, T.; Götz, K.; Schad, H. Leisure mobility styles in Swiss conurbations: Construction and empirical analysis. *Transportation* **2009**, *36*, 243–265. [CrossRef]
17. BPS-Statistics Indonesia. *Jumlah Perjalanan Wisatawan Nusantara (Orang) 2018–2020*; BPS-Statistics Indonesia: Jakarta, Indonesia, 2022.
18. Dubois, G.; Ceron, J.P. Tourism/leisure greenhouse gas emissions forecasts for 2050: Factors for change in France. *J. Sustain. Tour.* **2006**, *14*, 172–191. [CrossRef]

19. Nawijn, J. *Leisure Travel and Happiness: An Empirical Study into the Effect of Holiday Trips on Individuals' Subjective Wellbeing*; Erasmus Universiteit: Rotterdam, The Netherlands, 2012.
20. Nawijn, J.; Veenhoven, R. The effect of leisure activities on life satisfaction: The importance of holiday trips. In *The Human Pursuit of Well-Being*; Springer: Dordrecht, The Netherlands, 2011; pp. 39–53.
21. Almlöf, E.; Nybacka, M.; Pernestål, A.; Jenelius, E. Will leisure trips be more affected than work trips by autonomous technology? Modelling self-driving public transport and cars in Stockholm, Sweden. *Transp. Res. Part A Policy Pract.* **2022**, *165*, 1–19. [CrossRef]
22. Kim, S.H.; Mokhtarian, P.L. Who (never) makes overnight leisure trips? Disentangling structurally zero trips from usual trip generation processes. *Travel Behav. Soc.* **2021**, *25*, 78–91.
23. Große, J.; Fertner, C.; Carstensen, T.A. Compensatory leisure travel? The role of urban structure and lifestyle in weekend and holiday trips in Greater Copenhagen. *Case Stud. Transp. Policy* **2019**, *7*, 108–117.
24. Priya, G.; Mathew, S.; Subbaiyan, G. Household structure and the travel pattern of senior citizens for leisure trips. In *Transportation Research: Lecture Notes in Civil Engineering*; Springer: Singapore, 2020.
25. Laroche, P.C.; Schulp, C.J.; Kastner, T.; Verburg, P.H. The role of holiday styles in shaping the carbon footprint of leisure travel within the European Union. *Tour. Manag.* **2023**, *94*, 104630. [CrossRef]
26. Wicker, P.; Downward, P.; Rasciute, S. Leisure trips to the natural environment: Examining the tradeoff between economic and environmental impact. *Leis. Sci.* **2020**. [CrossRef]
27. Chincholkar, S. How do Indian consumers behave when planning a leisure trip? *Worldw. Hosp. Tour. Themes* **2019**, *11*, 173–184. [CrossRef]
28. Farag, S.; Lyons, G. To use or not to use? An empirical study of pre-trip public transport information for business and leisure trips and comparison with car travel. *Transp. Policy* **2012**, *20*, 82–92.
29. Cai, L.A. Relationship of household characteristics and lodging expenditure on leisure trips. *J. Hosp. Leis. Mark.* **1999**, *6*, 5–18. [CrossRef]
30. Duffell, R.; Harman, R. Rail travel and the leisure market in Great Britain. *Transp. Plan. Technol.* **1992**, *16*, 291–304. [CrossRef]
31. Schwanen, T.; Dijst, M.; Dieleman, F.M. Leisure trips of senior citizens: Determinants of modal choice. *Tijdschr. Econ. Soc. Geogr.* **2001**, *92*, 347–360. [CrossRef]
32. Simma, A.; Schlich, R.; Axhausen, K.W. Destination choice modelling of leisure trips: The case of Switzerland. In *Monitoring and Management of Visitor Flows in Recreational and Protected Areas*; ETH Zurich: Laussane, Switzerland, 2002; pp. 150–158.
33. Strömblad, E.; Hiselius, L.W.; Rosqvist, L.S.; Svensson, H. Adaptive travel behaviors to cope with COVID-19: A Swedish qualitative study focusing on everyday leisure trips. *Sustainability* **2021**, *13*, 12979. [CrossRef]
34. Sener, I.N.; Copperman, R.B.; Pendyala, R.M.; Bhat, C.R. An analysis of children's leisure activity engagement: Examining the day of week, location, physical activity level, and fixity dimensions. *Transportation* **2008**, *35*, 673–696. [CrossRef]
35. Strömblad, E.; Hiselius, L.W.; Rosqvist, L.S.; Svensson, H. Characteristics of everyday leisure trips by car in Sweden—Implications for sustainability measures. *Promet* **2022**, *34*, 657–672. [CrossRef]
36. Hössinger, R.; Aschauer, F.; Jara-Díaz, S.; Jokubauskaite, S.; Schmid, B.; Peer, S.; Axhausen, K.W.; Gerike, R. A joint time-assignment and expenditure-allocation model: Value of leisure and value of time assigned to travel for specific population segments. *Transportation* **2020**, *47*, 1439–1475. [CrossRef]
37. Limtanakool, N.; Dijst, M.; Schwanen, T. The influence of socioeconomic characteristics, land use and travel time considerations on mode choice for medium and longer-distance trips. *J. Transp. Geogr.* **2006**, *14*, 327–341. [CrossRef]
38. Acker, V.V.; Mokhtarian, P.L.; Witlox, F. Going soft: On how subjective variables explain modal choices for leisure travel. *Eur. J. Transp. Infrastruct. Res.* **2011**, *11*, 115–146.
39. Wardman, M.; Toner, J.P.; Whelan, G.A. Interactions between rail and car in the inter-urban leisure travel market in Great Britain. *J. Transp. Econ. Policy* **1997**, *31*, 163–181.
40. Anable, J.; Gatersleben, B. All work and no play? The role of instrumental and affective factors in work and leisure journeys by different travel modes. *Transp. Res. Part A Policy Pract.* **2004**, *39*, 163–181. [CrossRef]
41. Strömblad, E.; Hiselius, L.W.; Rosqvist, L.S.; Svensson, H. A qualitative case study examining individuals' perceptions of mode choice and the possibility to reduce car mile-age for everyday leisure trips. *Case Stud. Transp. Policy* **2022**, *10*, 2183–2194. [CrossRef]
42. Ha, J.; Lee, S.; Ko, J. Unraveling the impact of travel time, cost, and transit burdens on commute mode choice for different income and age groups. *Transp. Res. Part A* **2020**, *141*, 147–166. [CrossRef]
43. Liu, J.; Zhong, S.; Huang, Y.; Wang, Z. How does the preference heterogeneity affect the elderly's evaluation of bus accessibility? Evidence from Guanzhour, China. *J. Transp. Health* **2021**, *22*, 101094. [CrossRef]
44. Mahdi, A.; Hamadneh, J.; Esztergár-Kiss, D. Modeling of travel behavior in Budapest: Leisure travelers. *Transp. Res. Procedia* **2022**, *62*, 310–317. [CrossRef]
45. Magdolen, M.; von Behren, S.; Chlond, B.; Vortisch, P. Long-distance travel in tension with everyday mobility of urbanites—A classification of leisure travellers. *Travel Behav. Soc.* **2022**, *26*, 290–300. [CrossRef]
46. Baumgartner, A.; Schubert, I.; Sohre, A.; Tomic, U.; Moser, C.; Burger, P. Toward a reduction of car-based leisure travel: An analysis of determinants and potential measures. *Int. J. Sustain. Transp.* **2022**, 1–20. [CrossRef]
47. Wang, Y.; Wang, M.; Li, K.; Zhao, J. Analysis of the relationships between tourism efficiency and transport accessibility—A case study in Hubei Province, China. *Sustainability* **2021**, *13*, 8649. [CrossRef]
48. Cohen, E. Tourism, leisure and authenticity. *Tour. Recreat. Res.* **2010**, *35*, 67–73. [CrossRef]

49. Tarigan, A.K.M.; Sagala, S.; Samsura, D.A.A.; Fiisabiilillah, D.F.; Simarmata, H.A.; Nababan, M. Bandung City, Indonesia. *Cities* **2016**, *50*, 100–110. [CrossRef]
50. Permana, A.Y.; Susanti, I.; Wijaya, K. Architectural tourism development model as sustainable tourism concept in Bandung. *IOP Conf. Ser. Earth Environ. Sci.* **2020**, *409*, 012005. [CrossRef]
51. Wulung, S.R.P.; Brahmantyo, B. Geotourism reinterpretation towards natural tourist attractions in Bandung Basin, West Java, Indonesia. In Proceedings of the 3rd International Seminar on Tourism (ISOT 2018), Bandung, Indonesia, 9–12 December 2018.
52. OpenStreetMap. *Map of Bandung City*; OpenStreetMap: Cambridge, UK, 2023.
53. Wisata Bandung. Wisata Bandung. 3 July 2011. Available online: https://www.wisatabdg.com/2011/07/layanan-taksi-bandung.html (accessed on 14 January 2023).
54. Ali, I. 5 Jenis Mobil Terlaris di Indonesia Lengkap Dengan Harganya. 22 February 2021. Available online: https://www.pricebook.co.id/article/market_issue/7900/jenis-mobil-paling-populer-di-indonesia (accessed on 14 January 2023).
55. Fadhliansyah; Tahu, W. PSBB Resmi Berlaku Mulai Hari Ini, Motor Pribadi dan Ojol Hanya Boleh Digunakan Untuk Hal Ini. 10 April 2020. Available online: https://www.motorplus-online.com/read/252098925/wajib-tahu-psbb-resmi-berlaku-mulai-hari-ini-motor-pribadi-dan-ojol-hanya-boleh-digunakan-untuk-hal-ini (accessed on 14 January 2023).
56. CNBC Indonesia. Pinjaman Bunga Ringan Bantu Kurangi Beban Driver Ojek Online. 29 May 2020. Available online: https://www.cnbcindonesia.com/tech/20200529095417-37-161700/pinjaman-bunga-ringan-bantu-kurangi-beban-driver-ojek-online (accessed on 14 January 2023).
57. Dired. BBM Naik Pengaruhi Transportasi Umum di Kota Cimahi. 6 September 2022. Available online: https://bandung.pojoksatu.id/read/2022/09/06/bbm-naik-pengaruhi-transportasi-umum-di-kota-cimahi/ (accessed on 14 January 2023).
58. Department of Transportation of Bandung City. *Bandung Urban Mobility Project*; Department of Transportation of Bandung City: Bandung, Indonesia, 2015.
59. Correia, G.; Viegas, J.M. Carpooling and carpool clubs: Clarifying concepts and assessing value enhancement possibilities through a Stated Preference web survey in Lisbon, Portugal. *Transp. Res. Part A* **2011**, *45*, 81–90. [CrossRef]
60. Hess, S.; Rose, J.M. Some lessons instated choice survey design. In Proceedings of the European Transport Conference 2009, Noordwijkerhout, The Netherlands, 5–7 October 2009; p. 14.
61. Joewono, T.B.; Kubota, H. The characteristics of paratransit and non-motorized transport in Bandung, Indonesia. *J. East. Asia Soc. Transp. Stud.* **2005**, *6*, 262–277.
62. Rizki, M.; Joewono, T.B.; Belgiawan, P.F.; Irawan, M.Z. The travel behaviour of ride-sourcing users, and their perception of the usefulness of ride-sourcing based on the users' previous modes of transport: A case study in Bandung City, Indonesia. *IATSS Res.* **2020**, *45*, 267–276. [CrossRef]
63. Belgiawan, P.F.; Ilahi, A.; Axhausen, K.W. Influence of pricing on mode choice decision in Jakarta: A random regret minimization model. *Case Stud. Transp. Policy* **2019**, *7*, 87–95. [CrossRef]
64. Ilahi, A.; Belgiawan, P.F.; Balac, M.; Axhausen, K.W. Understanding travel and mode choice with emerging modes; a pooled SP and RP model in Greater Jakarta, Indonesia. *Transp. Res. Part A Policy Pract.* **2021**, *150*, 398–422. [CrossRef]
65. Risdiyanto, R.; Munawar, A.; Irawan, M.Z.; Fauziah, M.; Belgiawan, P.F. Why do students choose buses over private motorcycles and motorcycle-based ride-sourcing? A hybrid choice approach. *Sustainability* **2022**, *14*, 4959.
66. Belgiawan, P.F.; Joewono, T.B.; Irawan, M.Z. Determinant factors of ride-sourcing usage: A case study of ride-sourcing in Bandung, Indonesia. *Case Stud. Transp. Policy* **2022**, *10*, 831–840. [CrossRef]
67. Sunitiyoso, Y.; Belgiawan, P.F.; Rizki, M.; Hasyimi, V. Public acceptance and the environmental impact of electric bus services. *Transp. Res. Part D Transp. Environ.* **2022**, *109*, 103358. [CrossRef]
68. Choice Metrics. Ngene 1.2 User Manual & Reference Guide; Choice Metrics: 2018. Available online: http://www.choice-metrics.com/NgeneManual120.pdf (accessed on 22 September 2022).
69. Prasetio, E.A.; Belgiawan, P.F.; Anggraini, L.T.; Novizayanti, D.; Nurfatiasari, S. Acceptance of electric vehicle in Indonesia: Case study in Bandung. In Proceedings of the 6th International Conference on Electric Vehicular Technology (ICEVT), Bali, Indonesia, 18–21 November 2019.
70. Bierlaire, M. *A Short Introduction to PandasBiogeme*; Transport and Mobility Laboratory, ENAC, EPFL: Lausanne, Switzerland, 2020.
71. Sabogal-Cardona, O.; Oviedo, D.; Scholl, L.; Crotte, A.; Bedoya-Maya, F. Not my usual trip: Ride-hailing characterization in Mexico City. *Travel Behav. Soc.* **2021**, *25*, 233–245. [CrossRef]
72. Acheampong, R.A.; Siiba, A.; Okyere, D.K.; Tuffour, J.P. Mobility-on-demand: An empirical study of internet-based ride-hailing adoption factors, travel characteristics and mode substitution effects. *Transp. Res. Part C Emerg. Technol.* **2020**, *115*, 102638. [CrossRef]
73. Bhat, C.R.; Gossen, R. A mixed multinomial logit model analysis of weekend recreational episode type choice. *Transp. Res. Part B Methodol.* **2004**, *38*, 767–787. [CrossRef]
74. Alemi, F.; Circella, G.; Handy, S.; Mokhtarian, P. What influences travelers to use Uber? Exploring the factors affecting the adoption of on-demand ride services in California. *Travel Behav. Soc.* **2018**, *13*, 88–104.
75. Sikder, S. Who uses ride-hailing services in the United States? *Transp. Res. Rec.* **2019**, *2673*, 40–54. [CrossRef]
76. Phuong, N.N.D.; Trang, T.T.D. Repurchase intention: The effect of service quality, system quality, information quality, and customer satisfaction as mediating role: A PLS approach of M-commerce ride hailing service in Vietnam. *Mark. Brand. Res.* **2018**, *5*, 78–91.

77. Hall, D.R. Conceptualising tourism transport: Inequality and externality issues. *J. Transp. Geogr.* **1999**, *7*, 181–188. [CrossRef]
78. Wee, B.V.; Annema, J.A.; Banister, A.D. *The Transport System and Transport Policy: An Introduction*; Edward Elgar: Cheltenham, UK, 2013.
79. Archer, B. Domestic tourism as a development factor. *Ann. Tour. Res.* **1978**, *5*, 126–141. [CrossRef]
80. Duval, D.T. Transport and tourism: A perspective article. *Tour. Rev.* **2020**, *75*, 91–94. [CrossRef]
81. Massidda, C.; Etzo, I. The determinants of Italian domestic tourism: A panel data analysis. *Tour. Manag.* **2012**, *33*, 603–610. [CrossRef]

MDPI
St. Alban-Anlage 66
4052 Basel
Switzerland
www.mdpi.com

Sustainability Editorial Office
E-mail: sustainability@mdpi.com
www.mdpi.com/journal/sustainability

Academic Open
Access Publishing

mdpi.com

ISBN 978-3-0365-8943-5