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Regional Cooperation for the Sustainable Development and Management in Northeast Asia

Edited by

Yongrok Choi

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Special Issue Editor

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About the Special Issue Editor

Yongrok Choi is a distinguished research professor (Inha Fellow Professor) of the Inha University. He is the president of the Asia Business Forum and the organizer of the Sustainable Asia Conference (SAC). He has published more than 100 papers, including many SCI and SSCI level of journals such as *Energy Economics, Energy Policy, Technological Forecasting and Social Change*, etc. He has also managed more than 10 special editions of the SCI level of journals such as *Energy Policy, Tech. For. & Social Change, Sustainability*, etc. His research focus is on energy and environmental policy analyses, Green IT applications and sustainable management.

Preface to "Regional Cooperation for the Sustainable Development and Management in Northeast Asia"

It is a great honor to introduce this printed Special Issue edition from the open access journal, Sustainability. Since its first inauguration in 2009, the Sustainable Asia Forum (http://abf.inha.ac.kr/) has resulted in numerous papers' being presented every year, due to the proactive participation of researchers, professors, and policy makers worldwide. Based on the presentations at the SAC conference, we have published this edition to find out what new challenges the Asian countries face in a field of sustainable development and global e-governance. As our slogan says, "once a friend, forever a friend!", I look forward to your participation at our annual conferences and submissions to future Special Issues.

Yongrok Choi
Special Issue Editor

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Editorial

Regional Cooperation for the Sustainable Development and Management in Northeast Asia

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Abstract: The Northeast Asian countries are the most pro-active regions in the world to take on the challenges of sustainable development. With this background, there has been an annual series of Sustainable Asia Conferences (SAC) which date back to the first inaugural meeting in 2009. This special issue consists of selected papers from the SAC 2017, held in Nanjing, China, from 23–25 June. With ten years of accumulated experience, SAC became one of the leading international conferences for presenting innovative or fundamental advances in sustainable development issues for Asia. Over time, SAC introduced more performance-oriented approaches to handle the feasibility of the sustainable development solutions. In this special issue, most of the papers focused on the precise and accurate sustainable governance mechanism in harmonizing economic development with a healthier life, while enhancing the quality of all standards of living. The majority of papers in this special issue also deal with two important pillars of the sustainable development: regional cooperation and regulatory effectiveness. This special edition will propose unique implications and feasible or workable suggestions against global warming and environmental degradation.

Keywords: Sustainable Asia Conference (SAC); regional cooperation; green growth; role of regulation

1. Introduction

Against the rapidly aggravating environmental change over time, many countries in the world have been proactively promoting environmentally friendly sustainable development or green growth. In order to examine the global situation, the author conducted a field investigation during January of 2018 in the region of Patagonia, the southernmost point of South America. Patagonia is the region closest to Antarctica and thus, was filled with snow and glaciers everywhere, but not anymore. Ushuaia is located at the end of South America, (El Fin del Mundo), and is the closest city to the Antarctica. In the north of the city, there resides the famous Glacial Martial Mountain. As the name implies, it should be covered by glacial ice, but most of the glacier has already melted with little snow, as shown in Figure 1. Perito Moreno glacier in Patagonia is famous for its ice-breaking sound and beauty. The glacier in Moreno has broken several times, every day, but recently, it has broken down every minute. Every region in Patagonia has experienced the serious effects of global warming. The reason for this aggravated environmental problem may come from the urgent need for economic development, as well as rapid changes due to urbanization, which result in increasing air pollution. As shown in the Figure 2, Santiago, the capital of Chile and the gate to Patagonia, has been experiencing periodic, but persistent hazy toxic air problems. Since the city is located on the basin area, with the Andes Mountains in its backside, there is a lack in wind circulation out of or into the city. Thus, there is a zone of hazy smog all year around. Nonetheless, the smog is bearable during the summer season because it is located at a relatively high altitude, away from the ground surface. Due to the demands on heating by wood, and the low quality of charcoal, this hazy smog zone is moving closer to the ground surface during the winter season. Even if the Chilean government strongly regulated the use of wood for heating during the winter season, the impact would be low due to the level of perceived risk of the hazy smog among the public.

Figure 1. Glacial Martial Mountain without glacier in Ushuaia.

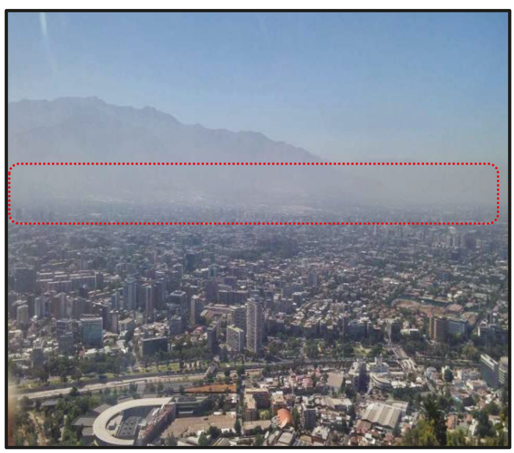

Figure 2. Hazy toxic air zone in Santiago, Chile.

In Patagonia, many people are worried about the rapidly changing environment, which could be seen in the melting glaciers, and the resulting El Niño and La Niña phenomena, but they do not think they should do something against this kind of global warming. Most developing countries may have the same problems. Governments have to put more emphasis on economic development and thus, they think that environmentally friendly sustainable development policies may provide an additional burden to the local economy. At the same time, the people in the region do not want this kind of regulation to protect the environment. Instead, they want to accelerate urbanization to improve infrastructure and public utilities.

Compared with these developing countries, the Northeast Asian countries are the most proactively sensitive to the perceived risks from hazy smog and other global warming phenomena. In 2017, the Chinese government proclaimed, so-called Xi-Jinpingism, as the new paradigm for future challenges. One of the most important paradigms of Xi-Jinpingism is based on the new construction of 'Ecological Civilization' (Shengtai Wenming), implying that the Chinese government shall focus more on environmentally friendly, sustainable development 'to lead the global economy (Zhongguomeng, Dream of China)'. By the same token, the Korean government made a strong commitment that they will decrease greenhouse gases (GHGs) by 37 percent, or about 0.3 billion tones, from its expected business as usual (BAU) till 2030. The Japanese government also experienced the Fukushima nuclear power plant melt-down disaster in 2011, and thus, the public became more proactive toward the perceived risks of environmental catastrophes. Due to this public awareness, as well as a proactive government in the region, Northeast Asia became one of the most dynamic regions moving towards sustainable development or green growth.

Based on these practical backgrounds, the Sustainable Asia Conference (SAC) has promoted the academic network for Northeast Asian professors and researchers to share ideas and cooperate in facing new challenges in the field of sustainable development, green growth, and green IT, since its inauguration in 2009. Over time, there have been more than 100 papers published through the conferences. This special issue consists of these annual milestones, which are based on the SAC 2017, at Southeast University, Nanjing, China, during 23–25 June 2017 [1]. The conference provided diverse opportunities for researchers, specialists, and practitioners to share new ideas, experiences, and to collaborate with each other on future challenges. The scope of this special issue encompasses topics mainly related to sustainable governance in Northeast Asian countries, which were presented and discussed during the SAC 2017 conference. Many of the papers presented in SAC 2017 opened a new frontier of the new 2020 climate regime, and thus, this special issue, with selected papers from the conference, shall provide a new platform to promote sustainable governance towards the sustainable development or green growth in the region. The most common feature for this special edition could be summarized by two pillars; regional cooperation, and the role or functions of the regulations. Therefore, in the following section, we shall shed some light on these directions from the papers.

2. Feasibility Issues of the Regional Cooperation

Several papers examined the feasibility of regional cooperation in Northeast Asia. First of all, Chapman et al. analyzed key drivers for cooperation toward sustainable development in the six Northeast Asian countries, and found out that it is not easy for the countries to cooperate in the field of environmental protection and/or sustainable development, because key driving factors of CO_2 emissions change and energy portfolio trends are different among Northeast Asian countries. Sustainable development is positively related to economic growth in China and Korea, but negatively related with energy efficiency improvements in Russia and the Democratic People's Republic of Korea (DPRK), while it is relatively complicated in Japan and Mongolia due to a combination of these factors [2]. More specifically, in the analysis of total factor energy efficiency (TFEE) of 27 industries in the Jing-Jin-Ji region, Li et al. found the fact that the TFEE changes in the three major industries in the Jing-Jin-Ji region are caused by technological progress [3]. Contrary to this conclusion, Choi et al. concluded in the study of the Sustainable Performance of the Steel Industry in Korea, that most steel firms are increasing returns to scale, so they can enhance their efficiency by increasing their scale [4]. It is noteworthy that even if Korea and China share many common key drivers for green growth [2], the role of key drivers could differ [3,4]. Nonetheless, these two countries share a strong potential to cooperate together on sustainable development strategies such as the emission-trading scheme (ETS) in the macro-perspective, and regional green supply chain management in the micro-perspective.

However, Japan may have different key drivers with these two countries, and thus, it is more difficult to cooperate on sustainable activities all together. Fujii et al. examined the trends in fishery technology innovations using data on patents granted as an indicator of changing R and D priorities focus among the major fishing countries in the Northeast Asia region of China, Japan, and Northeast Korea[5]. They concluded that the number of fishery technology patents granted increased between

1993 and 2015 in Korea and China, but the trend in Japan was the opposite, as the apparent priority given to aquaculture technology innovation decreased during the same period [5].

Using 203 samples collected from port stakeholders in the major ports in Northeast Asia, Kang and Kim examined the operative practices to accommodate current and future demands in a port, and concluded with the five-factor model clustering the relevant issues such as incorporating environmental technologies, process and quality improvement, monitoring and upgrading, communication and cooperation, and active participation [6]. According to them, each country could differ in its emphasis on the categories of the five factors, but all the countries in the region make more effort to promote active participation of the port operator. That is the spirit of public-private partnership (PPP). PPP is decisive for the sustainable development of the Northeast Asian region, because the countries in the region are based on government-led platforms for green growth, and thus, market-oriented support is a key factor for the sustainable governance in the feasibility of the policies [7]. Most of the Chinese resource-exhausted cities may face more severe environmental pollution problems than other cities. In addressing these problems, the way local officials (usually senior party and government leaders) operate is very important, as their focus on political achievements may complicate how they manage environmental pollution in these cities. Zhang et al. examined the relationship between political incentives and environmental pollution by applying the 2004–2014 panel data from 37 resource-exhausted cities [8]. They found that whether the officials are municipal party secretaries or mayors is very important because the former play a greater dynamic role in environmental pollution, and have stronger robustness than the latter [8]. It implies that the regulatory political regime is crucial to Chinese green growth. Nonetheless, the private partnership with mayors should be emphasized for better PPP performance [7].

Over time, the sustainability issues became much more micro-oriented and specific for the research subject. In the early 2010s, most of the research focused on the regional or provincial difference, while during the middle of the 2010s, major focus moved to the city or county level. Xie et al. analyzed the comparative advantages of the environmental incentives on the heavy metal-polluted farmland in China, based on farmers' willingness to accept (WTA) and its compensation for the land [9]. They compared the two provinces of Hunan, where the fallow policy has been implemented, and Jiangxi, where it has not been implemented yet. Even if the farmers' awareness of heavy metal pollution and pollution sources is higher in Jiangxi province than in Hunan province, the WTA of farmers in Hunan Province is a little higher at 934.39 (yuan/mu), than the 839.34 (yuan/mu) in Jiangxi Province. It implies that the factors affecting the WTA of farmers in Hunan Province are much diverse due to the compensation incentives [9]. This comparison showed that too strong intervention by the policy regime may result in moral hazard among farmers. We shall further discuss in the following section, the kinds of roles and limits of the regulation policies for sustainable development.

3. Regulation Toward Green Technology

All policies have two aspects which effect private economic activities: promotion or regulation. Diverse subsidies and incentives for the environmentally friendly activities may give the platform for the private sector to participate in new challenges on the sustainable issues more proactively, while the regulative measures such as ETS or environmental penalties may result in the compulsory decision for the private sector to comply with. That is the same for the development of green technology. Some green technologies, such as LED lights, may not suffer any additional cost to utilize, at least in the long run. Rather, they may give additional benefits (negative costs) to households. These technologies could be utilized easily and effectively if only the government would provide subsidies and/or other incentives to use these free or near-free green technologies. Some more advanced technologies, such as carbon capture and storage (CCS) technology, require risky investment cost, and thus, strong regulatory policies are desperately needed for the private sector to participate [10] (pp. 3–4). The question is how we can identify the turning point between these promotion and regulation policies, in terms of governance and workable mechanisms for sustainable performance [10]? Many papers addressed this turning point in terms of the role and functions of the regulatory policies in this special issue.

When Korea was suffering from hazy toxic GHG in 18th January of 2018 with an air quality index (AQI) of 157, the sky in Beijing was clear and transparent with an AQI of only 55 during the winter season. Most of the population of Beijing recognized that this was a result of the strong regulation of the Mayor of Beijing, who was Minister of Environmental Protection appointed by Xi Jinping, to overcome the terrible air pollution. Based on the urgent priority placed on air pollution, the new Beijing administration replaced all the charcoal heating systems, with gas-driven ones. Beijing city also regulated the absolute number of new car registrations to 100,000, which was much less than demand. Moreover, more than 60 percent of these new car registrations should go to electric cars, resulting in 120,000 electric cars in Beijing. This number implies that Beijing is now the global hub for the electric car, because it now has 12 times the number of electric cars as Jeju island (10,000 electric cars) and 21 times that of Seoul (5500 electric cars) in Korea. Of course, it is not easy for cars registered in other cities to enter Beijing, because these cars are only permitted to drive in Beijing for a period of one week. This could happen, especially in China, due to the strong government leadership of the Communist party. Certainly, there have been many studies which have shown the effective role of regulation by the Chinese government for sustainable development [11–14].

As shown in Beijing, the public have been exposed to heavy-polluting enterprises. Much of the negative social concern forced heavy-polluting enterprises to take downward earnings management to reduce corporate exposure [11]. Zhu et al. showed in their empirical test that heavy-polluting enterprises have stronger preference for downward earnings management, especially in those enterprises that are large in scale, non-state owned, or have a direct relationship with consumers [11]. It implies that strong leadership with rigid regulation on air pollution may lead the private sector to participate in a more effective manner. In the study to assess carbon reduction potential in the heavily resource-dependent Shanxi Province in China from 1990 to 2015, Li et al. concluded that the carbon intensity could drop by 18.78% by 2020 [12]. This potential exceeds the 18% expectation of the Chinese government in its '13th Five-Year Work Plan' for controlling GHG emissions. Unfortunately, this regulation on the carbon intensity of the province could further be reduce by 0.97 GHG ton per 10,000 yuan GDP. Due to this reduction on the local GDP, they suggested a flexible mechanism for reducing emissions, instead of the too strong and rigid regulation [12]. In order to examine the relationship between Beijing's urbanization efficiency and economic growth rate over time, Qi et al. developed a comprehensive index system for assessing Beijing's economic growth rate and urbanization efficiency at the district (county) level for the period 2005–2014 [13]. They concluded that local governments should promote technical change and scale efficiency change, to improve urbanization levels, with optimal strategies entailing strengthening policy support and encouraging investments in technology in specific areas such as Urban Function Development, and City Development Zone [13]. Zhang et al. utilized STIRPAT model to conduct analysis about the driving factors for future carbon emission in Henan Province for the period of 1995–2014 [14]. According to them, every 1% increase in the population, GDP per-capita, energy intensity, and the level of urbanization development will contribute to the growth of emissions by 1.099, 0.193, 0.043, and 0.542%, respectively [14], implying that 'smart regulation' is necessary.

All these arguments imply that regulation could be necessary in the first stage of highly risky green technology development, but the regulation could face another undesirable effect by reckless intervention. Using the average concentration of PM 2.5 in China's major cities from 2000 to 2012, as measured by aerosol optical depth, Zhengning Pu tested the time spatial convergence of fine particulate matter pollution in China [15]. He showed that the growth rate of PM 2.5 in the middle and western zones is significantly higher than that of the eastern zone and the correlation test between regional economic growth and PM 2.5 emissions suggests a significant positive N-type Environmental Kuznets Curve (EKC) [15]. It implies a kind of balloon effect that the strong regulation on the eastern zone caused an exodus of the energy-intensive or heavy GHG-emitting industries into the western and central zones. Therefore, the government should always consider that they cannot override the market or private sector, and that the regulatory policies should be more market-friendly.

Based on the affordability framework of the housing market in Ho Chi Minh City in Vietnam, Seo et al. investigated the price determinants of affordable and unaffordable apartment units using the hedonic regression model [16]. They found common factors between the two types of apartments, such as vertical shared access and proximity to downtown, as well as unique factors for each, such as more high-rise towers, foreign development, proximity to main roads, and shopping malls only for the affordable segments [16]. In order to promote the PPP, they strongly suggested regulatory reforms with revised housing laws and subsidized financial programs, because the market-friendly regulatory reform will result in a variety of beneficial effects on the housing market in developing countries such as Vietnam.

The sustainable energy consumption in Northeast Asia has a huge impact on regional stability and economic growth, which shows the severe bias of the global price volatility. That is the reason China is called the black hole of global resource. In order to investigate the price volatility pattern in different thresholds, Zhang et al. utilized the stretched exponential function to fit the pattern of the recurrence intervals of price fluctuations and found that the probability density functions of recurrence intervals in different thresholds [17]. They utilized a hazard function to introduce the recurrence intervals into the value at risk (VaR) calculation, and concluded that the Chinese government should improve energy futures market construction and promote risk control to enhance the global influence of China's energy futures market [17] (p.11). Here, the prudent regulation is emphasized regarding the fuel oil futures market as well. Xi Jinping, the leader of China claimed the 'dream of China (Zhongguomeng)', to lead the global economy. One of these dreams is focused on Chinese cultural and creative industries, such as animation and online games. Based on a case study of three animation companies, Hao Jiao et al. examined how innovation could be promoted as the profit model [18]. The study uncovers two critical factors that promote profit model innovation in animation projects: the quantity of consumers, and their consumption intention. They emphasized the governance factors of integrating capital resources and channel resources, strategic integration of partners, and industrial chain expansion capabilities into the animation industry as the survival kit of PPP [18].

The role of regulation is important not only in the environmental issues, but in the strategic industries for the country's future. Vietnam, as a new emerging market, especially in e-business, has been promoting its emerging e-commerce market in Asia using aggressive players such as Lazada. Nonetheless, Vietnam has a strong cultural background of risk-averse attitudes, like many other developing countries, thereby deferring sustainable transformation into the e-business revolution. To overcome this cultural barrier of risk-avert attitude, Choi and Mai showed that it is crucial to promote e-trust as a vital element, because Vietnamese consumers lack an initial e-trust in general, and thus the appropriate PPP by the balanced regulation of the government should be emphasized at least in emerging economies such as Vietnam and China [19].

4. Conclusions

Due to the new protective policies of the Trump administration, all countries in the world are experiencing much higher risks and uncertainties in their future challenges. Especially, the United States shifted its paradigm from eco-friendly, sustainable development, to job-creating traditional economic development, without any environmental protection. It is another serious burden and bottleneck for the global economy. The United States will not provide eco-friendly leadership towards a survival kit for sustainable development on Earth. One hopeful sign of new leadership may come from the Northeast Asian countries. Korea and China have promoted the ETS nationwide and this new paradigm shift of countries may bring in diverse new challenges as well as opportunities. The most important thing is the regional cooperation between Korea and China, because these two countries have just begun the ETS in local economies, and due to its adjacent spill-over effect, there are diverse fields of cooperation possible even without any regional integrated

ETS market yet. In order to decrease trial and error in the ETS policies, as well as the future regional challenges, we should emphasize harmonized network management to create values in this region.

All the papers in this special issue give us greater insights, and open new frontiers to handle the contemporary challenges for the regional cooperation in Northeast Asia, one of the most dynamic regions in the world. Since sustainable development requires complex procedural approaches in order to grasp workable mechanisms for all the conflicting issues and interests in the cooperative network, the role of government as the network manager of this collaborative network could not be emphasized enough. Clarifying the causal relations in this cooperative network is not easy, but it is essential for the network manager to guarantee that all parties create and share the values appropriately. This is the slogan of the Sustainable Asia Conference (SAC): Once a friend, forever a friend.

In order to promote the sustainable governance factors, relevant issues should be evaluated for their feasibility in these rapidly evolving Asian economies. Especially, Northeast Asian countries have emphasized more harmonized interrelationship from its historical and cultural background [10]. As addressed in the diverse perspectives on the regional cooperation and regulation-related issues in this special edition, we should work together to find the appropriate Asian models for this sustainable cooperation network mechanism in the future. For this purpose, all the professionals and experts, as well as the policy makers and business men are invited to share the Asian models for the sustainable development at the SAC 2018, held in the Chinese Academy of Science at Beijing, China on 18–21 May 2018 (official websites: http://abf.inha.ac.kr/).

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Article

Eco-Efficiency Evaluation of Regional Circular Economy: A Case Study in Zengcheng, Guangzhou

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Abstract: Circular economies are critical for alleviating resource pressure and improving environmental quality at regional level. Emergy analysis and eco-efficiency evaluations play important roles in measuring regional eco-efficiency and providing supporting information for governmental decision-making. In this study, emergy analysis and input–output analysis were applied to analyze the changes in emergy structure, functional efficiency, and sustainable development capacity of Zengcheng, Guangzhou during the period 2000–2016. The results showed that the proportion of non-renewable emergy in total emergy structure of Zengcheng increased from 55% to 75%, which placed a greater environmental load on the natural ecosystem and gradually weakened the capacity for sustainable development. The rates of emergy utilization and eco-efficiency both showed increasing trends. All indicators about eco-efficiency showed the development of Zengcheng heavily relied on emergy consumption, especially on non-renewable emergy. The relationship between emergy utilization and socio-economic development of Zengcheng can provide decision-making support for economic structure optimization and sustainable community development.

Keywords: emergy analysis; eco-efficiency; circular economy; eco-city; Zengcheng

1. Introduction

Since the implementation of economic reforms and opening-up policy in 1978, China has experienced rapid economic growth and accelerating urbanization. This is resulting in extensive increases of external resource consumption and carbon dioxide emissions and, accordingly, affecting urban development quality [1,2]. Urban areas have become the main hot spots of resource consumption and waste generation [3,4]. The contradiction among economic development, resource shortages, and air pollution is creating urgent need to seek new development pathways, such as circular economies, which play an important role in alleviating resource pressure and improving environmental quality [5,6]. A circular economy observes the principle of reducing, reusing, and recycling (3R), which aims to lower pollutant emissions, implement cleaner production, and minimize inputs of energy and materials in the production process [7]. A circular economy is a sustainable development strategy, which is identified as beneficial from the development economics perspective [8,9]. Promoting circular economies at the regional level could effectively alleviate energy crises, environmental pollution, and resource consumption, and thereby could improve regional sustainability and construction of eco-cities and eco-communities. The economic boom has required significant natural resources inputs [10]. According to china statistical yearbook of 2016, the total energy consumption has increased about 7.6 times from 5.7×10^8 t SCE in 1978 to 4.36×10^9 t SCE in 2016. While the overarching objectives of the circular economy are not only to achieve pure economic growth but also to improve eco-efficiency, the prefix "eco" stands for both ecological and economic performance. Eco-efficiency has been proposed as a concept of "efficiency with which ecological resources are used to meet human needs" [11] and as a tool of sustainable development [12], which connotes the efficiency level of economic activity regarding resources, funds, and services. Changes in urban development sustainability can be assessed based on regional eco-efficiency evaluations over time. Within the context of new urbanization, eco-efficiency assessment may provide support information for policy making to promote regional sustainability with less-negative impacts on the environment, and to better inform construction of eco-cities [13,14].

The application of the circular economy concept in the Chinese context was first proposed in 1998, and formally implemented by the central government in 2002 as a new development strategy [15]. Development policies were carried out mainly for environmental protection and waste recycling, while the circular economy model worked as the end-of-pipe treatment. During the period 2003–2006, pilots of regional circular economies and eco-industrial parks were promoted by the Ministry of Environmental Protection, with the help of special funds. In 2007, the goal of constructing an ecological civilization, presented by the 17th National Congress of the Communist Party of China (CPC), was to vigorously develop a circular economy. The move for such an economy gained momentum on 1 January 2009, when the Circular Economy Promotion Law was enacted.

An increasing number of studies focused on applications of statistical methods for measuring eco-efficiency including the Delphi method [16], ecological footprint method [17], analytic hierarchy process [18], and data envelopment analysis [19]. These methods were mainly applied for analyzing the impacts of emissions on the environment, and the economic benefits [20], while the contribution of ecological products and services to alleviate these impacts was neglected, as were the loads placed on ecosystems and problems related to the carrying capacity of economic and industrial development [21]. Currently, most studies concerning eco-efficiency in a circular economy focus on the scientific planning of eco-cities and eco-communities [22,23]. Lou and Ulgiati (2013) used emergy analysis methods to analyze the advantages and constraints of Chinese ecological conditions for economic development [24]. Pouriyeh et al. (2016) used envelopment analysis to investigate the ecological efficiency of urban suburbs in Iran, and not only solved the problems of inaccuracy in previous approaches, but also provided a creative and scientific way to evaluate fluctuation in the energy structure, ecological efficiency, and sustainable development capacity [25]. Data used in these studies were directly obtained from the related statistical yearbook or survey. Therefore, most research on eco-efficiency has focused on areas such as industrial parks and mega-cities with less focused on that at regional level. Lou et al. (2015) used emergy accounting method to evaluate the regional environmental sustainability in terms of power production, industry, mobility, and buildings four aspects [26], which may be better to reflect the sustainability of sub-economic system and neglected the relationship between different sub-systems. Therefore, in this study, we combined the emergy analysis and input-output method to study the eco-efficiency of circular economy from the whole social-economic system perspective rather than the sub-system. In addition, we aimed to prove the feasibility of combination of these two methods and extend them in investigations about eco-efficiency of circular economy to regional level.

Emergy analysis converts capital, materials, and resources into solar energy values, thereby linking the natural environment system and socio-economic system. Input–output data provide a detailed record of the material or capital inflows and outflows [27,28]. The combination of traditional emergy analysis with the input-output method has been frequently used to measure the flows of regional energy, materials, information, and capital, and to evaluate sustainability at regional level [29,30]. The relative emergy-based indices such as emergy yield ratio, environmental load ratio and environmental sustainability index are directly linked to urban ecosystems in an integrated way through the combined values of the services [31]. It could capture the dynamics of the system and reflect the environmental load, eco-efficiency, the changing trends of energy structures, resource utilization, eco-efficiency, and the ability to achieve sustainable development [32,33]. Additionally, it also can identify issues to be addressed during the process of eco-city construction in the name of circular economy.

Zengcheng, a county in the city of Guangzhou, has taken the lead in eco-city construction in China. We selected Zengcheng as case study to analyze its eco-efficiency change during the period 2000–2016. The rest of this article is organized as follows: the second section is a description of the study area, and the third section covers the data processing and modeling. The fourth section lays out the results that are significant for consolidating existing eco-city achievements, and the final section includes discussions on the key findings and conclusions. This study not only serves as an empirical study for evaluating the eco-efficiency of circular economy in Zengcheng based on emergy analysis, but also provides useful decision-making information to help promote urban ecological integrated management.

2. Study Area

Zengcheng (113°29′ E–113°57′ E, 23°5′ N–23°37′ N) is located in the east of Guangzhou (Figure 1), covers an area of 1616.47 km^2, of which 55.88% is forested. Zengcheng is in a subtropical zone, with annual average temperature of 22.2 °C, precipitation of 1869 mm (73.6 inches), evaporation 1330.3 mm and sunshine of 1830.0 h, which makes it suitable for tropical and subtropical crop growth.

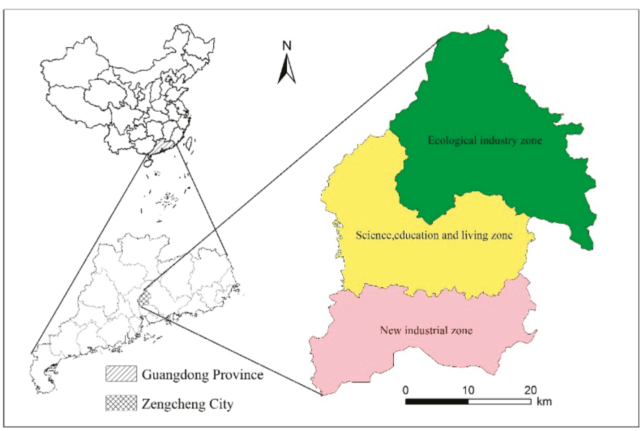

Figure 1. Geographic location and three economic zones of Zengcheng.

With the objective of ecological conservation and under the guidance of the Scientific Outlook on Development, a guiding socio-economic principle of the CPC, a "three economic zones" strategy was employed in Zengcheng to spatially allocate various industries (Figure 1). The northern ecological industrial zone is a strictly conserved area mainly used for tourism and urban agriculture. The science, education, and living zone is planned to form a high-end living area by importing residential and educational components. The new southern industrial zone is served for developing strategic emerging industries to form an industrial agglomeration combining with the original manufacturing industrial base there.

Government of Zengcheng paid more attention to the circular economy in the development of industry. Its sustainable development strategy was implemented via closure of polluting enterprises and rational allocation of manufacturing districts, residential zones, and ecological conservation areas under the guidance of a circular economy. In addition, the environmental remedying strategy was also carried out in 2001. Finally, the government of Zengcheng entitled a privilege of the "Zengcheng model", which was famous for its win-win strategy in terms of ecologically oriented society and economic development. To ensure a mode of circular economy development, on the one hand green cleaner production was required, while on the other hand circular utilization of resources was needed. The annual GDP growth rate in Zengcheng was above 10% from 2000 to 2015. In addition, industrial structure became more and more rational. In 2015, the gross domestic product (GDP) in Zengcheng reached $15.23 billion, with the ratio of the first, second and tertiary industries was 5:60:35, and total exports valued reaching $3.62 billion. The per capita disposable income of urban residents was $5900, while that of rural residents was just $2822. Circular economy was implemented in Zengcheng in 2001. Therefore, there is great value in taking Zengcheng as a case study area to characterize the various aspects of its ecological efficiency and resource utilization, and to speculate on what underlies the crucial problems encountered.

3. Data and Methods

3.1. Data

Natural environment data were employed to calculate the emergy contribution to circular development from the ecosystem, and these consisted mainly of average sunshine hours, annual precipitation, and above mean sea level. The data were obtained from the database of the Resource and Environmental Science Data Center, Chinese Academy of Sciences.

Social economic data were applied to estimate the emergy contribution of resources, funds, and services from the human economic system. It mainly included food consumption (fruit, vegetables, meat, eggs, fish), energy consumption (coal, fuel oil, electricity), metal consumption, GDP, and waste (solid waste, wastewater, and waste gas). These data were mainly derived from the Guangzhou Statistical Yearbooks of years 2001–2017 [34], the Statistical Bulletin of Social Development of Zengcheng, and the input–output (I-O) table of Guangdong Province for 2000, 2002, 2005, 2007, 2010, and 2012. The total consumption of food and energy in Zengcheng was acquired, then the amount of resources, obtained internally and externally, was determined in accordance with the IO table. Owing to the lack of official statistical data of Zengcheng, in this study some data at the Guangdong provincial or municipal scale were interpolated into the spatial scale of Zengcheng by linear regression. For example, the consumption of fuel oil, electricity, and cement were calculated based on the ratio of Zengcheng's GDP compared with those of Guangzhou. Of note, the I-O table for Guangdong was employed for speculating the proportion of import resources in the total.

During the data processing phase, we first calculated the total input emergy of energies, resources, and capital for Zengcheng. Then, the total emergy was divided into local and external emergy in accordance with proportions of total output value of domestic and foreign inflows. Here, to avoid duplicate counting, we followed Lomas et al. (2008) to use the sum of rain chemical emergy and rainwater potential emergy to replace the emergy of renewable energy [35]. The input emergy of various non-renewable resources was interpolated based on multiplication of the resource consumption indicated in the Guangzhou Statistical Yearbook, and the proportion of GDP of Zengcheng within Guangzhou. The emergy of renewable resources excluding food emergy was calculated as the per capita consumption of Guangzhou multiplied by the population of Zengcheng. Proportion of rations accounted for the total amount of grain consumption was 30%; therefore, emergy of grains was calculated by emergy of rations divided 30%.

3.2. Methods

Emergy analysis and the input–output method were incorporated to evaluate regional eco-efficiency. Odum (1983) introduced emergy analysis in the 1980s [36]. There is fundamental difference among various types of energy as long as quality and value are concerned; therefore, energy cannot be added or subtracted directly in a system [37]. The values of various forms of energy were standardized into that of solar energy as the standard energy value, based on their emergy transformity [38]. After conversion, the emergy of the inputs and outputs can be compared and analyzed within the same system [39]. An I-O table records the direction of material and capital flow in the region, providing a detailed database for an emergy analysis [40]. The main procedures of emergy analysis are: (1) determine the boundary of the study area and project the inner relationship within the emergy systems [41] (Figure 2); (2) calculate the emergy of the various energy flows; (3) establish an evaluation index system on a circular economy, and calculate the respective values; and (4) analyze the dynamics and driving mechanism of the emergy.

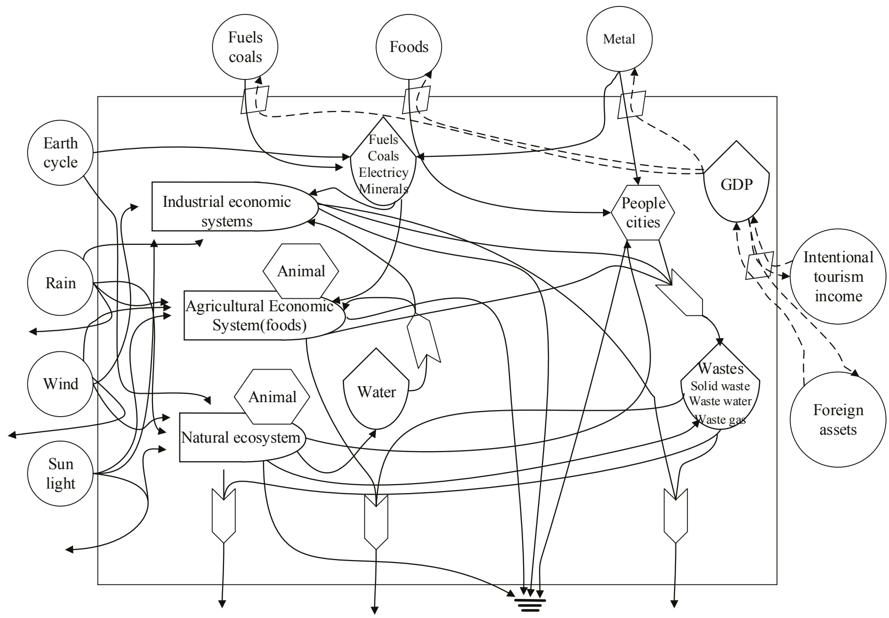

Figure 2. Emergy system in Zengcheng.

Traditional evaluation methods, such as material flow analysis, the Delphi method, ecological footprint method, and analytic hierarchy process, focus mainly on a single parameter, without accounting for local ecosystem services or the value of existing natural capital [42]. Furthermore, these methods are not capable of distinguishing the origin of resources (local or external) to assess their contribution to regional economic development, and are not originally designed for the systemic, closed-loop feedback features that characterize a circular economy. Emergy analysis incorporates ecosystems as well as socio-economic systems, analyzes energy flow, material flow, monetary flow, and other ecological flows, and thus enables choosing integrated evaluation indicators to reflect the system's structure, function, and efficiency [43,44]. However, emergy analysis is still somewhat imperfect; that is, the emergy transformity of energy, materials, or capital may vary by region, and it is obtained from various sources, which may lead to inaccurate accounting results.

Classification of emergy. Based on the actual situation in Zengcheng, the emergy is divided into eight types: local renewable energy emergy, local renewable resources emergy, local non-renewable resources emergy, imported renewable resources emergy (domestic), imported non-renewable resource emergy (domestic), foreign input emergy, net output emergy, and waste emergy (Table 1). The emergy is calculated based on the emergy transformity (unit emergy value) of these resources (energy, capital) according to Equation (1), Table A1 (Appendix A) shows all types of emergy in Zengcheng from 2000 to 2016.

$$E_i = f_i \times UEV_i i = 1, \ldots, n \quad (1)$$

where E_i is the emergy of i resources, f_i is the ith input flow of matter or energy and UEV_i is the unit emergy value of the ith flow (from related literature).

Table 1. The types and resources of emergy.

Types	Resources	Emergy Code
Local renewable energy	Sunlight, wind, rain, earth cycle	Em_{R1}
Local renewable resources	Foods (Grain, vegetable, fruit, egg, meat, fishery)	Em_{R2}
Import renewable resources	Foods (Grain, vegetable, fruit, egg, meat)	Em_{R3}
Local non-renewable resources	Water, electricity, metal, cement, oil	Em_{N1}
Import non-renewable resources	Coal, fuel oil, metal	Em_{N2}
Foreign Import	Foreign assets, international tourism income	Em_{IMP1}
Net Output	GDP, total annual exports	Em_Y
Wastes	Solid waste, waste water, waste gas	Em_W

Note: The total import emergy (Em_U) = Em_{R1} + Em_{R2} + Em_{R3} + Em_{N1} + Em_{N2} + Em_{IMP1}; External input emergy (Em_{IMP}) = Em_{R3} + Em_{N2} + Em_{IMP1}. Foods, solid waste, waste water, waste gas, water, metal, cement, coal and fuel oil are measured in unit of tons; Foreign assets, international tourism income, foreign assets, total annual exports and GDP are measured in the unit of USD; electricity are measured in the unit of kWh.

Evaluation index system of emergy. The evaluation index for assessing regional sustainability is capable of reflecting the information of urban ecological planning, construction, and management [45]. To describe and evaluate the changes of the circular economy in Zengcheng from 2000 to 2016, based on the related study of emergy sustainability indicators [46], a series of indexes were selected from the aspects of structure, function, and efficiency (Table 2), all of which supported multiple performance aspects in resource use. The emergy evaluation index was calculated from the material flow and capital flow. Further detailed on the emergy method and emergy evaluation index can be found in [13,24,28,32].

Table 2. Emergy evaluation index system.

First-Level Indicator	Second-Level Indicator	Formula
Structure	Ratio of renewable emergy	$(Em_{R1} + Em_{R2} + Em_{R3})/Em_U$
	Ratio of non-renewable emergy	$(Em_{N1} + Em_{N2})/Em_U$
	Ratio of foreign import emergy	Em_{IMP1}/Em_U
Function	Emergy to money ratio (EMR)	Em_U/GDP
	Emergy yield ratio (EYR)	Em_U/Em_{IMP}
	Emergy use per person	Em_U/Population
	Emergy use per unit area	Em_U/A
Efficiency	Environmental loading ratio (ELR)	$(Em_U - Em_{R1} - Em_{R2})/(Em_{R1} + Em_{R2})$
	Ratio of waste to total import (EWR)	Em_W/Em_U
	Ratio of waste to yield	Em_W/Em_Y
Comprehensive index	Emergy sustainability index (ESI)	EYR/ELR

4. Results

4.1. Changes of Emergy Flow of Circular Economy

The emergy of renewable energy fluctuated widely in Zengcheng from 2000 to 2016, mainly as a result of changes in rainfall, with an average value of 5.31×10^{20} seJ/year, a minimum value of 3.47×10^{20} seJ in 2004 and a maximum value of 6.98×10^{20} seJ in 2016 (Table 3). Additionally, based on the calculation results, we can sort the magnitudes of the emergy of renewable energy inputs to Zengcheng by the Earth's rotational energy, wind energy, and solar energy.

The emergy of renewable resources is characterized by decreasing inputs and a reliance on local supply. It decreased from 7.99×10^{21} seJ in 2000 to 6.84×10^{21} seJ in 2016. The emergy of renewable resources outside the region accounted for about 15% of the total emergy. The types of resources outside the region and imported to Zengcheng include food, fruit, vegetables, and meat, while the region is essentially self-sufficient in terms of fish and eggs. Among the renewable resources, the input emergy of grains was the largest from 2000 to 2016, accounting for over 65%, followed by that of vegetables, accounting for around 15%. However, the input emergy of grains decreased from 6.08×10^{21} seJ in 2000 to 4.93×10^{21} seJ in 2016, and the emergy of meat and fruits increased during the same period. Improved living conditions and changes in people's diet structure were the main reasons behind this. From 2000 to 2016, the figure of grain emergy was the largest, dominated the change trend of renewable resources. Although the population continues to increase, the amount of grains consumption is decreasing rapidly, leading to a variety of renewable resources also showing a decreasing trend.

The emergy of non-renewable resources show an increasing trend: from 1.12×10^{22} seJ in 2000 to 2.75×10^{22} seJ in 2016, respectively. While, Zengcheng's economy has recently rapidly developed, resulting in rising demand for energy, the rising use of private automobiles has also raised consumption of oil and other resources. Among the emergy of non-renewable resources, electricity had the largest proportion, of 40% (except for in 2000, when it accounted for 29%). The emergy of cement showed a decreasing tendency from 2000 to 2016 owing to the well-built infrastructure with less renovations or repairs required; frequency of using cement is resultantly decreasing. The emergy of other non-renewable resources showed differing degrees of increase and emergy outside the region accounted for about 20%. The local supply of coal was at a low level, and depended mainly on resources outside the region. The emergy of electricity, water, and cement reflected the basic self-sufficiency in Zengcheng, while emergy of other resources still needed external supply.

The emergy of foreign inputs and outputs both show an increasing trend, and the gap between the two sides has widened. The emergy of foreign inputs reached 1.44×10^{21} seJ in 2016, which was 2.44 times the 2000 figure. The emergy of foreign outputs increased from 1.99×10^{21} seJ to 1.98×10^{22} seJ during the same time with about a tenfold increase since 2000.

The emergy of outputs is increasing rapidly, though the emergy of waste is still large. The emergy of GDP reached 1.46×10^{23} seJ, with an increase of 1.32×10^{23} seJ over the 17-year period. During this period, the emergy of waste showed an unstable trend, first increasing, then decreasing. The emergy of solid waste accounted for the largest proportion, at about 90%. These data show the cycle capacity of the economic system in Zengcheng is weakening. Disposal of waste and recycling should be strengthened to minimize emissions incurred in future development.

On the whole, the input emergy in Zengcheng maintained an increasing trend. More specifically, the input emergy outside the region increased from 3.16×10^{21} seJ in 2000 to 7.21×10^{21} seJ in 2016, accounting for 16.5% to 21% of the total input emergy. Similarly, the local input emergy also kept an increasing trend, but the proportion decreased, mainly due to introduction of a large amount of oil resources.

4.2. Changes in the Emergy Evaluation Index of the Circular Economy

Figure 3 shows the changes in the circular economic structure in Zengcheng. Non-renewable energy emergy dominates the emergy structure in Zengcheng. The total input emergy was 3.65×10^{22} seJ in 2016, about twice the 2000 figure. The emergy of non-renewable resources increased from 1.12×10^{22} seJ in 2000 to 2.75×10^{22} seJ in 2016, accounting for about 75% of the total input emergy in 2016 (Figure 3). Over the same period, the percentage of the emergy of renewable energy decreased from 39.4% to 18.7%. The change of proportion of foreign input emergy accounting for the total input emergy is not significant over the 17-year period, about 3–10%. These data show the economic development in Zengcheng relies mainly on non-renewable resources, such as coal and oil, and this will inevitably affect the local ecological environment in the processes of development, transportation, and other use.

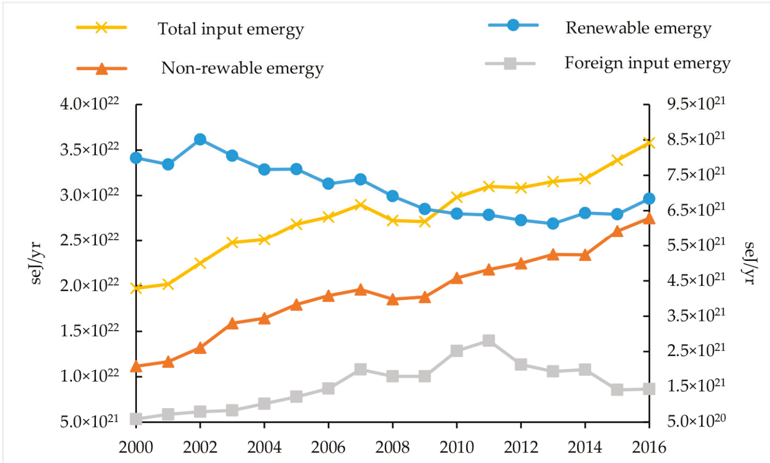

Figure 3. Changes in the total input emergy, non-renewable emergy, foreign input emergy, and renewable emergy in Zengcheng, 2000–2016.

As the socio-economic system in Zengcheng has been improved, the efficiency of emergy utilization and production has increased. The system's emergy became increasingly dependent on the purchase of foreign emergy from 2000 to 2016, with the increase becoming more rapid over time. As a result, the emergy yield ratio (EYR) experienced a partial change in volatility and then finally an overall decreasing trend (Figure 4, Table 4). Emergy use per unit area and per person increased, while the ratio of emergy use to GDP decreased (Figure 5, Table 4). The emergy use per unit area nearly roughly doubled from 1.25×10^{19} seJ/km^2 in 2000 to 2.26×10^{19} seJ/km^2 in 2016, while emergy use per person increased from 2.74×10^{16} seJ/person to 4.14×10^{16} seJ/person. Additionally, the ratio of emergy use to GDP decreased from 1.21×10^{17} seJ/\$10,000 to 2.31×10^{16} seJ/\$10,000 (Table 4), indicated that less emergy was needed to produce something of equal value. It mainly because of that the emergy use efficiency improvement was due to the technical progress.

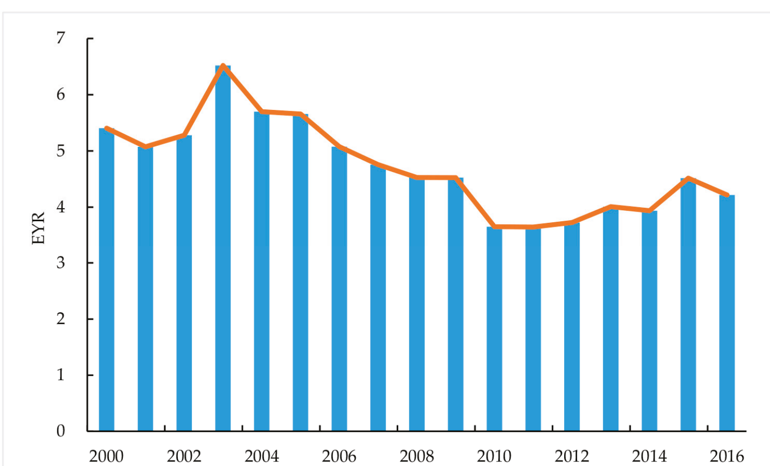

Figure 4. Changes of emergy yield ratio (EYR), 2000–2016.

Table 3. Emergy of inputs and outputs at Zengcheng (unit: seJ).

Emergy	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Local renewable energy ($\times 10^{20}$)	5.42	5.98	4.29	4.01	3.47	5.71	6.56	4.93	6.78	4.87	5	3.78	5.18	5.46	5.34	6.47	6.98
Import renewable resources ($\times 10^{20}$)	8.45	11.11	12.63	7.19	11.09	11.83	15.84	10.77	10.54	10.03	16.93	12.74	9.89	10.64	11.27	10	11.63
Local renewable resources ($\times 10^{21}$)	7.15	6.7	7.25	7.34	6.55	6.49	5.68	6.31	5.86	5.54	4.72	5.11	5.24	5.07	5.31	5.4	5.67
The total renewable emergy ($\times 10^{21}$)	7.99	7.81	8.51	8.05	7.66	7.67	7.26	7.38	6.91	6.55	6.41	6.38	6.23	6.13	6.43	6.4	6.84
Import non-renewable resources ($\times 10^{21}$)	2.32	2.27	2.29	2.31	2.34	2.44	2.54	3.13	3.31	3.3	4.09	4.52	5.3	5	5.11	5.23	6.05
Local non-renewable resources ($\times 10^{21}$)	8.84	9.4	10.92	13.58	14.1	15.51	16.39	16.48	15.23	15.49	16.8	17.29	17.2	18.47	18.32	20.8	21.5
The non-renewable resources ($\times 10^{22}$)	1.12	1.12	1.17	1.32	1.59	1.64	1.79	1.89	1.96	1.85	1.88	2.09	2.18	2.25	2.35	2.61	2.75
Foreign input ($\times 10^{20}$)	5.88	7.2	7.95	8.32	10.23	12.19	14.51	19.93	17.98	17.98	25.16	28.07	21.31	19.38	19.9	14.1	14.4
Net output ($\times 10^{22}$)	1.65	1.91	2.11	2.46	2.86	3.42	4.3	5.33	6.49	7.15	9.08	10.84	11.93	14.01	14.36	15.2	16.6
Wastes ($\times 10^{20}$)	5.62	6.75	7.24	8.47	9.36	8.28	9.34	8.13	9.22	10.24	11.35	9.97	9.08	8.68	6.86	9.23	10.1

Table 4. Changes in the emergy evaluation index of the circular economy.

	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
EYR	5.41	5.07	5.28	6.52	5.70	5.66	5.08	4.76	4.53	4.53	3.65	3.65	3.73	4.01	3.94	4.52	4.22
ELR	1.64	1.85	1.99	2.25	2.69	2.88	3.47	3.34	3.27	3.58	4.81	4.72	4.45	4.71	4.55	4.71	4.73
Ratio of waste to yield (%)	3.41	3.53	3.43	3.45	3.28	2.42	2.17	1.53	1.42	1.43	1.25	0.92	0.76	0.62	0.48	0.61	0.61
Ratio of emergy use to GDP (seJ/$10,000)	12.15	10.8	10.66	10.02	8.86	8.33	7.01	6.03	6.03	4.53	3.93	3.50	2.96	2.64	2.33	2.24	2.28
EWR (%)	2.77	3.25	3.16	3.36	3.68	3.02	3.30	2.76	3.30	3.71	3.74	3.18	2.89	2.70	2.12	2.67	2.77
ESI	3.30	2.74	2.66	2.89	2.12	1.96	1.46	1.43	1.38	1.26	0.76	0.77	0.84	0.85	0.87	0.96	0.89

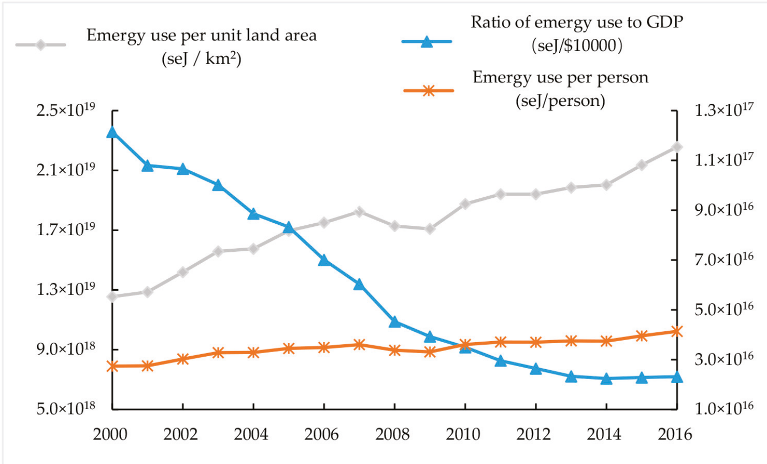

Figure 5. Changes in emergy use per unit land, the ratio of emergy use to GDP, and emergy use per capita, 2000–2016.

Pressure exerted on the ecological environment system gradually increased in Zengcheng during the period 2000–2016. The ELR of Zengcheng showed an increasing trend (Figure 6), mainly because of the decreasing emergy of renewable energy within the system. Apart from that, the increasing input emergy and non-renewable emergy resulted in overall rising of ELR. The ELR changed suddenly in certain years, mainly owing to abrupt decreases in rainfall, which further caused the decreasing emergy of the renewable energy inputs from 2004 to 2010. The EWR and ratio of waste to total imports decreased (Figure 6, Table 4), utilization efficiency of emergy within the entire system increased, and output emergy increased. Although the ratio of waste to total imports continued to decline, the emergy of waste rose, particularly that of solid waste, which was equal to the emergy of renewable energy.

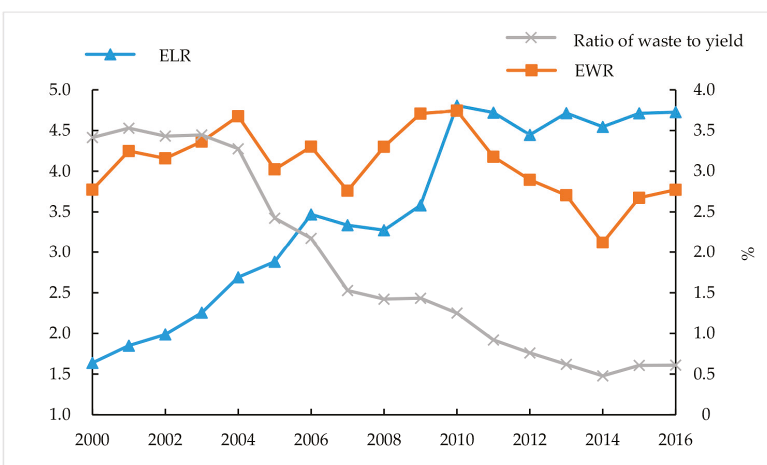

Figure 6. The changes of environmental loading ratio (ELR), Ratio of waste to yield, and ratio of waste to total import (EWR), 2000–2016.

The emergy sustainability index (ESI) decreased with fluctuation during our study time period (Figure 7, Table 4), indicating the system development capability decreased continuously. The ESI sharply decreased from 3.3 in 2000 to 0.76 in 2010. From 2010 to 2016, it kept around 0.8. A large amount of input emergy comes from outside of Zengcheng, and the emergy of non-renewable resources accounts for 80% of the total input emergy. Furthermore, the local renewable energy was decreasing during the study period, which led to a smaller ESI value. These data showed that the sustainability of socio-economy system was decreasing.

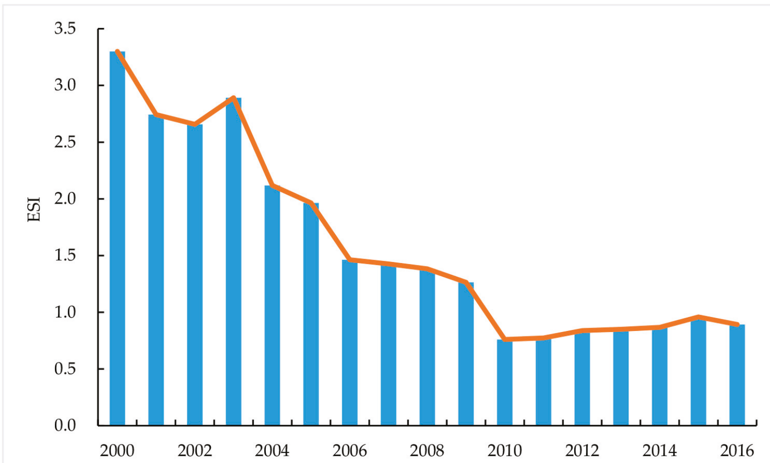

Figure 7. Changes of emergy sustainability index (ESI), 2000–2016.

We examined the accuracy of our results via comparison with related research. We referred to the results of Sweeney et al. (2007) on circular economies in various countries [47]. The ratio of renewable energy in Zengcheng is below the China's average level (0.26 in 2006) and has maintained a decreasing trend in recent years. Our results on ratio of renewable energy are above the average level (0.03 in 2006) in Japan, which may be due to Japan's heavy reliance on resource imports. ELR is about twice more than China's average level (2.83 in 2006). The EYR in Zengcheng is similar to the China's average level (4.03 in 2006), and lower than that for Russia (11.33 in 2006), indicating the efficiency of emergy use is higher in developed countries. The ESI figure is higher than that for Japan (0.04 in 2006), showing better sustainable development of society and the economy in China than in Japan. In sum, the recent development level of the circular economy has increased, but it is still clearly problematic compared with what is seen in developed countries.

5. Conclusions and Discussion

On the whole, the input emergy of Zengcheng has been increasing, mainly stemming from an increase in non-renewable resource emergy, which means non-renewable energy emergy dominates Zengcheng's emergy structure, especially coal resources. The increasing input emergy and relatively low efficiency are the main reasons leading to the large annual amounts of waste emergy. The development model in Zengcheng relies on high emergy consumption, as a tradeoff for economic development. This exerts great pressure on the ecological environment system in Zengcheng. Although the efficiency of emergy utilization and production has increased, the capability for system development has continuously decreased. This mode of development is not sustainable and will affect the system's capacity for sustainable development in Zengcheng. To sum up, the emergy structure in Zengcheng should be adjusted to better reduce the use of non-renewable resources and develop a circular economy in the future. These results help decision makers have a comprehensive understanding of the development of circular economy in Zengcheng and aids in decision-making to promote construction of ecological communities and implementation of urban ecologically integrated management. It also proves combination the emergy analysis and input-output method can be applied to evaluate the eco-efficiency at regional level.

There are some suggestions for policy makers to improve the eco-efficiency and sustainability. Based on the ESI formula, it is abundantly clear that increasing use of local resources is vital for reducing dependence on resources outside the region. Reducing use of non-renewable resources to ensure a relatively high ESI should yield positive effects. First, to develop new energy sources (e.g., solar energy and wind power) and the low emergy demanding technologies, and improve the emergy use efficiency; second, to adjust the energy structure and reduce the dependence on resources outside, especially the non-renewable energy; third, to develop the technology of wastes recycling and improve the use efficiency of wastes; fourth, to adjust the high emergy consumption industries, e.g., energy intensive industries, and accelerate the development of the tertiary industry and optimize local economy structure; at last, local government should encourage citizens to have a low emergy and healthy lifestyles.

The lack of official statistical data on Zengcheng means that we have to scientifically convert data from Guangdong Province or Guangzhou City to derive proportional coefficients. Therefore, there may be errors between the calculated and actual data. However, based on the emergy analysis method and input-output method, compared with the results of Brown (2006) [25], the discounted data in Zengcheng are within a reasonable range. These results reflect the basic changes in the trends of the circular economy and development of a social economic system in Zengcheng from 2000 to 2016.

The present research broadens investigations on regional eco-efficiency evaluation based on emergy analysis. Our results of Zengcheng indicate eco-efficiency calculated via an emergy model is capable of reflecting the comprehensive situation of circular economy development, including structure of resources, function and efficiency, and sustainability of the socio-economic system. Compared with the data at national and provincial levels, there are some difficulties in data collection at regional level. However, the results may reflect a more realistic portrait of the socio-economic system. In the future study, we will carry out field research and consult with the related government bureau about energy flow, material flow in Zengcheng, and to assess the reliability of calculated data thorough comparing the investigated data with the calculated data. Combined with the Chinese characteristic, the construction of circular economy may achieve better results adopting a bottom-up model. In some sense, it is important to evaluate the development of a circular economy at the regional level. The present study provides the database and decision-support information for further optimization the circular economic structure for building an ecological city, ecological communities, and pursuing development at even smaller spatial scales.

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Appendix A

Table A1. The emergy of Zengcheng City, 2000–2016 (unit: seJ/year).

Types		2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Local renewable energy	Sunlight ($\times10^{18}$)	7.10	7.10	7.10	7.10	7.10	7.10	7.10	7.10	7.10	7.10	7.10	7.10	7.10	7.10	7.10	7.10	7.10
	Wind ($\times10^{19}$)	4.99	4.99	4.99	4.99	4.99	4.99	4.99	4.99	4.99	4.99	4.99	4.99	4.99	4.99	4.99	4.99	4.99
	Rain (chemical potential) ($\times10^{20}$)	5.27	5.80	4.17	3.89	3.37	5.55	6.37	4.78	6.58	4.73	4.86	3.67	5.03	5.31	5.19	5.53	6.04
	Rain (geopotential) ($\times10^{19}$)	1.56	1.72	1.24	1.15	1.00	1.65	1.89	1.42	1.95	1.40	1.44	1.09	1.49	1.57	1.54	1.64	1.79
	Earth cycle ($\times10^{19}$)	9.38	9.38	9.38	9.38	9.38	9.38	9.38	9.38	9.38	9.38	9.38	9.38	9.38	9.38	9.38	9.38	9.38
	Total (rain) ($\times10^{20}$)	5.42	5.98	4.29	4.01	3.47	5.71	6.56	4.93	6.78	4.87	5.00	3.78	5.18	5.46	5.34	6.47	6.98
Import renewable resources	Grain ($\times10^{20}$)	3.61	6.07	7.74	2.23	6.80	7.09	11.16	5.98	5.83	5.31	10.98	6.34	5.01	5.25	5.22	4.85	5.97
	Fruit ($\times10^{16}$)	9.17	8.13	8.67	6.60	7.07	6.33	7.63	8.52	8.37	9.96	8.44	8.92	11.04	9.70	11.78	13.27	16.03
	Vegetable ($\times10^{20}$)	2.74	2.83	2.77	2.79	2.19	2.31	2.32	2.42	2.68	2.63	3.29	3.29	3.37	2.36	2.96	3.08	3.40
	Meat ($\times10^{20}$)	2.00	2.13	2.03	2.10	2.03	2.37	2.28	2.29	1.94	1.99	2.57	3.01	1.40	2.92	2.97	1.93	2.10
	Total ($\times10^{20}$)	8.45	11.11	12.63	7.19	11.09	11.83	15.84	10.77	10.54	10.03	16.93	12.74	9.89	10.64	11.27	10.00	11.63
Local renewable resources	Grain ($\times10^{21}$)	5.72	5.23	5.88	5.98	5.23	5.18	4.32	4.95	4.51	4.19	3.27	3.59	3.82	3.64	3.86	4.14	4.33
	Egg ($\times10^{16}$)	1.26	1.51	1.32	1.50	1.45	1.61	1.51	1.50	1.76	1.73	1.91	2.26	2.17	2.10	2.28	2.46	2.88
	Fishery ($\times10^{16}$)	2.05	2.05	2.02	1.81	1.80	1.99	2.08	2.09	2.43	2.41	2.64	3.09	2.91	3.03	3.08	3.27	3.73
	Fruit ($\times10^{19}$)	2.75	2.25	2.29	1.65	1.76	1.55	1.74	1.86	1.74	2.00	1.97	1.59	1.73	1.80	2.50	2.69	3.36
	Vegetable ($\times10^{20}$)	9.12	9.25	8.70	8.24	8.05	7.17	7.82	8.05	6.90	6.38	7.33	6.39	5.27	6.39	6.52	6.98	7.40
	Meat ($\times10^{20}$)	4.91	5.21	4.76	5.14	4.98	5.79	5.58	5.37	6.43	6.95	6.95	8.58	8.82	7.71	7.70	5.36	5.65
	Total ($\times10^{21}$)	7.15	6.70	7.25	7.34	6.55	6.49	5.68	6.31	5.86	5.54	4.72	5.11	5.24	5.07	5.31	5.40	5.67
The total renewable emergy ($\times10^{21}$)		7.99	7.81	8.51	8.05	7.66	7.67	7.26	7.38	6.91	6.55	6.41	6.38	6.23	6.13	6.43	6.40	6.84
Import non-renewable resources	Coal ($\times10^{21}$)	2.23	2.21	2.24	2.26	2.25	2.27	2.45	2.49	2.48	2.49	2.64	2.78	2.52	2.49	2.47	2.56	2.32
	Oil ($\times10^{20}$)	0	0	0	0	0	0	0	5.42	6.87	6.23	11.62	15.63	24.92	21.74	24.19	24.3	34.6
	Metal ($\times10^{19}$)	8.90	5.51	4.59	4.98	8.65	17.37	9.28	9.50	14.59	18.42	28.08	17.67	28.63	34.14	22.01	24	26.9
	Total ($\times10^{21}$)	2.32	2.27	2.29	2.31	2.34	2.44	2.54	3.13	3.31	3.30	4.09	4.52	5.30	5.00	5.11	5.23	6.05
Local non-renewable resources	Oil ($\times10^{21}$)	2.84	2.91	3.15	3.20	3.23	3.36	3.56	3.73	4.05	4.42	4.57	4.45	3.89	4.62	4.49	5.82	6.05
	Electricity ($\times10^{21}$)	3.25	3.73	4.60	5.77	6.84	7.81	8.04	8.92	8.57	8.55	9.66	10.24	10.65	10.96	11.48	12.1	12.8
	Cement ($\times10^{21}$)	2.60	2.55	2.94	4.24	3.58	3.96	4.17	3.10	2.06	2.00	1.97	2.07	2.19	2.28	1.89	2.45	2.13
	Metal ($\times10^{20}$)	1.51	2.07	2.31	3.65	4.44	3.82	6.21	7.36	5.49	5.24	5.97	5.30	4.67	6.07	4.68	4.70	4.81
	Water ($\times10^{16}$)	3.97	5.39	5.18	5.63	5.94	5.69	5.53	5.67	5.78	5.81	5.96	5.95	5.92	6.05	6.17	6.32	6.5
	Total ($\times10^{21}$)	8.84	9.40	10.92	13.58	14.10	15.51	16.39	16.48	15.23	15.49	16.80	17.29	17.20	18.47	18.32	20.8	21.5
The non-renewable emergy ($\times10^{22}$)		1.12	1.12	1.17	1.32	1.59	1.64	1.79	1.89	1.96	1.85	1.88	2.09	2.18	2.25	2.35	2.61	2.75

Table A1. *Cont.*

	Types	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Foreign input	Foreign assets ($\times 10^{20}$)	5.07	6.30	6.83	7.47	9.25	11.10	13.14	18.09	16.52	16.32	22.48	25.81	19.62	17.80	18.10	12.2	12.3
	International tourism income ($\times 10^{19}$)	8.19	9.01	11.2	8.56	9.73	10.92	13.71	18.39	14.53	16.61	26.83	22.61	16.91	15.79	17.60	19.1	20.3
	Total ($\times 10^{20}$)	5.88	7.20	7.95	8.32	10.23	12.19	14.51	19.93	17.98	17.98	25.16	28.07	21.31	19.38	19.9	14.1	14.4
Net output	GDP ($\times 10^{22}$)	1.45	1.67	1.87	2.18	2.49	2.89	3.57	4.36	5.42	6.12	7.68	9.16	10.20	12.05	12.31	13.1	14.6
	Total annual export ($\times 10^{21}$)	1.99	2.43	2.45	2.79	3.66	5.34	7.22	9.64	10.61	10.31	14.01	16.77	17.31	19.52	20.50	21	19.8
	Total ($\times 10^{22}$)	1.65	1.91	2.11	2.46	2.86	3.42	4.30	5.33	6.49	7.15	9.08	10.84	11.93	14.01	14.36	15.2	16.6
Wastes	Solid waste ($\times 10^{20}$)	4.69	5.75	6.23	7.63	8.44	7.49	8.56	7.41	8.05	9.19	10.34	9.00	8.20	7.76	6.16	8.53	9.38
	Waste water ($\times 10^{19}$)	8.94	9.56	9.66	8.05	8.65	7.53	7.42	6.89	11.25	9.99	9.46	8.99	8.13	8.45	6.39	6.34	6.57
	Waste gas ($\times 10^{18}$)	3.41	4.17	4.52	3.33	5.02	4.18	3.70	3.12	3.82	4.68	6.07	7.24	6.26	6.75	6.57	6.39	7.32
	Total ($\times 10^{20}$)	5.62	6.75	7.24	8.47	9.36	8.28	9.34	8.13	9.22	10.24	11.35	9.97	9.08	8.68	6.86	9.23	10.1

Data source: Guangzhou/Guangdong Statistical Yearbook from 2001 to 2017, Guangdong IO Table of 2000, 2002, 2005, 2007 and 2012.

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The Dynamics of Land Use/Cover and the Statistical Assessment of Cropland Change Drivers in the Kabul River Basin, Afghanistan

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Abstract: To cope with the growing agrarian crises in Afghanistan, the government (following the fall of the Taliban regime in 2002) has taken measures through cropland expansion “extensification” and switching to mechanized agriculture “intensification”. However, cropland expansion, on one hand, disturbs the existing land use/cover (LULC) and, on other hand, many socio-economic and biophysical factors affect this process. This study was based on the Kabul River Basin to answer two questions: Firstly, what was the change in LULC since 2001 to 2010 and, secondly, what are the drivers of cropland change. We used the spatial calculating model (SCM) for LULC change and binomial logistic regression (BLR) for drivers of cropland change. The net change shows that cropland, grassland, water-bodies, and built-up areas were increased, while forest, unused, and snow/ice areas were decreased. Cropland was expanded by 13%, which was positively affected by low and plain landforms, slope, soil depth, investment on agriculture and distance to the city, while it was negatively affected by plateaus and hill landforms, dry semi-arid, moist semi-arid, and sub-humid zones, precipitation, population, and the distance to roads and water. Climate adaptation measures, cropland protection in flood prone zones, population and rural migration control, farmer access to credit, irrigation, and inputs are necessary for agricultural deployment.

Keywords: Kabul river basin; land use/cover change; spatial calculating model (SCM); binomial logistic regression (BLR)

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1. Introduction

In Afghanistan, due to weak industrialization, agro-ecosystem services remain as a main source of livelihood and economy. More than 80% of the population of the least developing country is directly or indirectly involved with agriculture and allied activities that contribute 24% to the country’s gross domestic product (GDP) [1]. Furthermore, agriculture accounts for 40% of the active labor force in the country [2]. Agriculture has not been able to meet the food demand of the country despite being a major activity of a large population. Land and water management is the basis for food security and rural economy in Afghanistan. However, following decades of war and instability in the country, the agrarian sector has lost productivity and has become extremely poor. The crisis grows as rapid population growth, coupled with changes in food preferences, further add to the pressure on agricultural production. In the context of this rapid change in land use and related policy implications, this study attempts to analyze the change in land use and land cover (henceforth, LULC) in the Kabul

River Basin of Afghanistan. The paper also explores the drivers of cropland change since it is the most critical land-cover in the context of the growing demand for food in Afghanistan.

To cope with the growing agrarian crises and meet with the increasing food demand in Afghanistan, the current governmental setup (following the fall of the Taliban regime in 2002) aimed at improving the local food production through a combination of conversion of non-cropland into cropland "extensification" and switching to mechanized agricultural "intensification". As per the "National Comprehensive Agriculture Development Priority Program-2016–2020", the government was committed to further increase the irrigated land from 2.4 million ha to 3.1 million by 2025 [3]. However, the cropland expansion comes at a cost of disturbance to the existing LULC base [4]. Implemented at its simplest form, extensification may convert forest, grass, and rangelands into cropland. For instance, the increase of corn and soybean production in the eastern corn-belt in the USA converted significant grassland into croplands [5]. Agricultural land expansion presents a complicated tradeoff of its services. On one hand, agricultural land provides essential food, feed, and fiber and, on the other hand, in their natural state, these lands could provide additional important ecosystem services, such as terrestrial carbon stock.

There are additional complications because investing in agricultural land expansion is not an easy matter. Many socio-economic and biophysical forces may also affect the LULC base. The rapid urbanization and rapid socio-economic development in some areas would challenge the expansion of cropland. Between 2003 and 2013, the population growth in rural and urban area was 16% and 34%, respectively [6]. Additionally, the influences of ongoing climatic and biophysical changes are likely to change the LULC and may affect the capability of the agro-ecosystem.

In the context of the agrarian crisis, the government priority for cropland expansion and the challenge of urbanization and population growth, this study attempts to answer two questions. Firstly, what was the overall change in LULC base in the last decade since the end of the war and, secondly, what are the significant drivers of cropland change? These questions have gained extreme importance for policy-makers as solving agrarian crises through agricultural land expansion is in conflict with saving these lands for other kind of ecosystem utility such as forest covers. Due to the lack of scientific data and trained researchers that resulted from decades of war, the existing scientific studies on LULC change patterns and assessment of the related driving forces are negligible in Afghanistan. On the contrary, worldwide, there have been many studies on the assessment of LULC change and the associated driving factors. Particularly, econometric and theoretical economics have been widely used for this reason [7–10].

Land is considered to be a limited resource with an economic value. The use of land, which is affected by several socio-economic and geophysical factors, determines the value of land. Theoretically, the change of use of land from one to another would follow the demand and supply theory of markets [11,12]. Under the full market competition condition, the conversion of a land use from one type to another will continue until the marginal benefit (MB) and marginal cost (MC) curves of land use change intersect each other. To trace the contribution of different socio-economic and biophysical factors in land use change (i.e., from one value to another), researchers use different models, such as regression, and machine learning algorithms, such as support vector machines (SVM) [13–17]. LULC change models deal with land issues that range from simple system representations to simulation systems based on a deep understanding of situation-specific problems with consideration of a large number of drivers at different spatio-temporal scales [18–20]. There are simulation-based methodologies, such as cellular automata models, which apply complex sets of rules accounting for possibilities of transition of urban land-use to random human behavioral changes in modeling LULC change [21]. However, due to the flexibility of too much modification and the lack of standard rules of transition, cellular automata models are mostly used in academic practice. Recently, many researchers have focused on calibration modeling, as it has defined transition rules that accurately represent the evaluation of past land uses [21]. Traditionally there are two ways of calibration modeling—(1) trial and error based method; and (2) statistical techniques [21,22]. From statistical techniques, the regression modeling is most commonly used [16]. Although the recent simulation models are precise in dealing with small details of LULC change, the statistical regression models are easier in practice and can deal with spatiotemporal changes of land systems in accordance with the changes of driving forces with a fair degree of precision [23]. Within the regression modeling, there are two particular approaches in assessing the spatial dependency—firstly, autoregressive structure (consisting of many models) and, secondly, spatial sampling of plots [24]. In spatial samplings, logistic regression modeling is one of the most utilized approaches in recent years, particularly when predicting land uses [13,16,17].

When, in logistic regression, the dependent variable has two possible outcomes it is called binary logistic and when the possible outcomes are more than two, it is called multinomial logistic regression [25,26]. In the case of binary analysis, based on the understanding of random utility and profit maximization theory of land, the change of land use can be linked with the drivers of change [14,15,27,28].

A large number of the researchers have applied binomial logistic models using four categories of factors as independent variables explaining LULC change—namely, climatic, biophysical, socio-economic, and neighboring factors [29–31]. For instance, Arowolo and Deng used the binomial logistic regression (BRL) model for analyzing the factors of agricultural land use change in Nigeria between the time periods of 2000 to 2010 [29]. Since the outcomes of dependent variables are unobserved and discrete, the ordinary least square (OLS) is not suitable; therefore, the maximum likelihood (ML) method in logistic modeling is used [29].

In some of the cases when dealing with high correlation problem amongst the predictors, other models such as principal component analysis (PCA), general linear model (GLM) [32], and ridge regression method were used for assessment of land use change [33]. In Afghanistan, the impact of war and institutional changes on LULC changes have been studied by selecting four governance periods and comparing the LULC change across and within those periods [34]. Considering the high environmental heterogeneity and the socio-economic turbulence in Afghanistan, the study suggested separate zone-wise LULC studies.

In view of the given importance of agro-ecosystem services, and the unprecedented impact of climatic and socio-economic changes on cropland use in the coming decades in Afghanistan, this study was, therefore, designed to assess LULC change and the related drivers of cropland expansion. Utilizing the existent literature on LULC change modeling, this study attempted to apply such models in the data-scarce situation of Afghanistan and fill the research gap. This study considered the high spatial environmental and socioeconomic variability in Afghanistan for analyzing the LULC, as earlier suggested by De beurs and Geoffrey [34]. This study selected the Kabul River Basin (KRB), the eastern region of Afghanistan, as the study area to investigate the LULC change and the related driving forces of cropland change.

2. Data and Methodology

2.1. Study Area

Afghanistan is located in a semi-dry region where the winter snowfall in high-altitude mountains are the origins of life-supporting river systems. The river systems divide the country into five major basins, namely; he Amu Darya Basin, the Western River Basin, the Helmand River Basin, the Northern River Basin, and the Kabul River Basin (KRB). This research was conducted along the KRB in Afghanistan (Figure 1). The river originates from the northern mountains in Afghanistan and after passing through 700 km, it finally flows to the Indus River in Pakistan [35]. Within Afghanistan, this river flows though many provinces and covers an area of 63,000 km^2. The hydrological and physiographical characteristics divide the river basin into three sub-basins of Panjshir, Upper Kabul, and Lower Kabul. The rainfall during spring and winter seasons derives the Upper Kabul (Logar), whereas the summer snow melt mostly fed the Panjshir River [36]. The significant topographical variation, ranging from 420 m above the sea level to 6000 m above the sea level, characterizes the

KRB. The lowlands, the most suitable land for agriculture, are mainly located in the central and eastern parts of the KRB, whereas, the northern part contains the high-elevation mountains [37]. Moreover, the KRB is also characterized by high spatial variation in mean annual temperature and precipitation. The monthly average precipitation and temperature is about 13 °C and 33 mm, respectively [37,38]. However, the precipitation in the northern Hindu Kush Mountains reaches approximately 160 mm/month.

The river basin is also considered the most critical region for its socio-economic indicators. Almost one fourth of the country's settlements and one third of the total population live in this basin, three times denser than the other four river basins [1]. Some of the major cities, such as Kabul and Jalalabad, are located in this river basin. Agriculture and livestock are the main source of livelihoods in the KRB. Agriculture is largely irrigated and shares around one-fifth of the total irrigated land in the country. The river basin also holds around two-thirds of the total forest resources in the country [39].

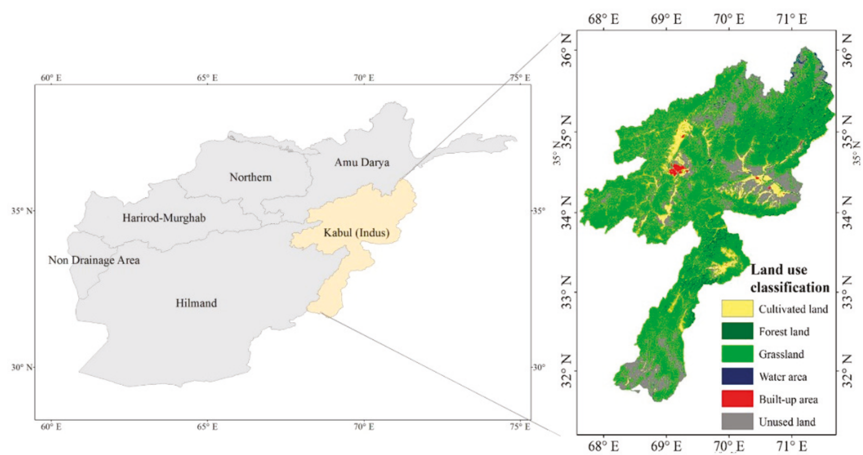

Figure 1. Land use map of the Kabul River Basin [29].

2.2. *Data Handling*

The data used in this study was collected from different secondary sources. The study used several datasets of LULC, socio-economic, and biophysical factors to assess the land use change and the associated determinants of cropland expansion. The LULC, socio-economic, and climate data used in this study were required for the years 2000 and 2010, while the biophysical and neighboring factors, i.e., AEZs, landforms, soil parameters, slope, elevation, distance to city, distance to water, and distance to road networks, as they are assumed constant in shorter period of time, were required as one point data. Additionally, all of the data used in this study were required in gridded maps format. Some of the socio-economic parameters, however, were not available in the form of desired gridded maps or resolution. To cope with this, GIS techniques to interpolate tabulated data and produce gridded maps were used. In order to conduct regression analysis, using GIS 10.2 software (ESRI, Redland, CA, USA) [40], all the data was reassembled to 250 m × 250 m resolutions. Below this resolution, the software was unable to support the large pixel number. The description and source of each data is presented in the subsequent discussion.

2.2.1. Preparation of Biophysical Data

The 30 × 30 m LULC data was derived from the online source of www.globallandcover.com [41]. The overall classification accuracy of this data is 84% and the Kappa value is 0.78 [41]. The descriptions of LULC are presented in Table 1. The topographical aspect data, i.e., slope and elevation were derived from the Shuttle Radar Topography Mission-Digital Elevation Model (SRTM-DEM) which is available online http://srtm.csi.cgiar.org [42]. Similarly, the soil aspects were collected from International Soil Reference and Information Center (ISRIC) www.soilgrids.org [43]. The overall validation accuracy of the used models for soil properties mapping is 61% [44].

Table 1. Land use/cover description.

Reclassification Code	Land Use/Cover Type	Description
1	Cropland	Includes land used for agriculture, horticulture and gardens
2	Forest	Land covered with trees, withvegetations cover over 30%, including deciduous and coniferous forest, and spare woodland with 10–30% vegetation cover
	* Shrubland	Land covered with shrubs with cover over 30%, including and deciduous and evergreen shrubs and desert steppe with 10–30% vegetation cover
3	Grassland	Lands covered by natural grass with vegetation cover over 10%
4	Water bodies	Including river, reservoir, fish ponds etc
	* Wetland	Land covered with wetland, marshes, and peat bogs.
5	Built-up	Land modified by humans such as habitation, industrial and mining area, transportation etc.
6	Bareland (unused)	Land with vegetation cover less than 10%.
7	Permanent snow/ice	Land covered by permanent snow, glacier and icecap

* Note: Due to the marginal size of LULC types and the main focus of the current study, shrub was merged withforest and wetland was merged withwater bodies.

2.2.2. Climatic Data

To capture the impact of climatic factors on cropland expansion, the monthly average temperature and precipitation data was utilized in this study, similar to what was used elsewhere [45,46]. The station-based data were acquired from the Ministry of Agriculture, Afghanistan. To further estimate the impact of climate factors at pixel level, GIS software was used to produce the gridded maps of both temperature and precipitation. For this reason, the Kriging spatial interpolation method was adopted. The similar interpolation method was suggested by earlier studies [47–50].

2.2.3. Socio-Economic Data

Land use change drivers are defined as underlying and proximate [51]. The systematic and structural contact of human with ecosystem reflected by underlying drivers, representing accessibility to technologies, land, information and manpower, lead to human activities and proximate causes of LULC change [52]. The increasing human population and their activities, leading to rapid urbanization and industrialization, continue to pressurize LULC base [33,53,54]. Therefore, the appropriate selection and accurate measurement of the impact of socio-economic factors in land use change modeling remained vital for defining the potential change and avoiding the uncertainty in future planning [33]. Based on the research objectives, methodological techniques and data availability, researchers have used a variety of variables. The study of Deal and Pan [55] specifically mentioned that the socioeconomic factors, such as economic development, demographic distributions, and human mobility interact with the dynamics of LUC processes. Therefore, the economic parameters (such as GDP), spatial interactions of neighboring parameters (such as roads, cities, and water), and most importantly population distribution are the most commonly used socio-economic parameters in LULC modeling [29,55–58]. Based on our study objectives and the data accessibility, we have also used the above factors to understand the socio-economic impact on land use land cover change. As the make-up and impact of the driving forces of LULC may not be the same across regions [59,60], we needed to apply various data processing techniques in order to prepare the spatial layer of socio-economic data.

The pixel level population data for the years of 2000 and 2010 was obtained from the online source of www.worldpop.org.uk [61]. The spatial influence of neighboring factors, i.e., the distance to major cities, water, and roads are, on one hand, considered important for agricultural development and, on other hand, they also attract non-agricultural activities in the area, pressuring agricultural lands. To capture the influence of neighboring factors on cropland change, this study used the distance of cropland from city, roads and water. To measure distance from the city, the coordinates of provincial offices (as a proxy of city center) were identified by using Google Earth Pro software (Mountain View, CA, USA) [62]. Secondly, the Euclidian distance function of the GIS software was used to produce 250 m × 250 m pixel maps of the distance from the provincial capital city. A similar process was also applied to estimate the distance of each pixel from water and roads networks. The shapefiles of water lines and roads were acquired from the online source www.diva-gis.org [63]. Then the Euclidian distance function of GIS software was applied and produced the 250 m × 250 m maps of the distance to roads networks and the distance to water lines.

To assess the impact of economic growth on cropland use change, many researchers have used Gross Domestic Product (GDP) as a proxy. However, due to the lack of GDP data at the small scale in Afghanistan, the percentage poverty and the per hectare governmental investment on agriculture in each province were used as proxies to economic power. The tabulated data of the poverty percentage and investment on agricultural development were obtained from the website of the Central Statistical Organization (CSO). The spline interpolation algorithm function of GIS was applied on these tabulated data and produced 250 m × 250 m gridded maps, similar to the method that was used elsewhere [37].

2.3. Analytical Tools and Equations

The two main questions of the study were analyzed by first evaluating the change rate of different types of LULC in the KRB and then analyzing the magnitude of the impact of driving forces of LULC change on cropland change.

2.3.1. Evaluating the Land Use Change Rate

To calculate the land use change rate in the KRB, the spatial calculating model (SCM) was used [64]. To apply the model, seven types of land-use were identified viz. cropland (1); forest (2); grassland (3); water bodies (4); built-up land (5); unused land (6); and snow or ice (7) for the base year i.e., 2000, and final year, i.e., 2010. Land-use of 2000 was cross tabulated with that of 2010 to derive a Land-use transition matrix. The change rate of land was derived applying the following equation:

$$CRL_i = \left(\frac{\left(LA_{(i,t1)} - ULA_i\right) + \left(LA_{(i,t2)} - ULA_i\right)}{LA_{(i,t1)}} \right) \cdot \frac{1}{T_2 - T_1} \cdot 100\% \quad (1)$$

where CRL_i is the change rate of land during the given time period, i.e., from first time period to second time period; T_1 is 2000 and T_2 is 2010.

i varies from 1 to 7 depending on the type of land-use.

$LA_{(i,t1)}$ and $LA_{(i,t2)}$ represent the pixels/area of i type of land at the years of t_1 and t_2 respectively; and

The term ULA_i is derived from the diagonal elements in the land-use change matrix (Table 3) and represents the total unchanged pixels/area of i type land during this period.

In the equation, the terms $\left(LA_{(i,t1)} - ULA_i\right)$ and $\left(LA_{(i,t2)} - ULA_i\right)$ depict the converted (the decreased part) and gained (the increased part) of i type land to/from other types of lands respectively;

The terms $\left(LA_{(i,t1)} - ULA_i\right) \cdot \frac{1}{T_2 - T_1} \cdot 100\%$ and $\left(LA_{(i,t2)} - ULA_i\right) \cdot \frac{1}{T_2 - T_1} \cdot 100\%$ show the annual decreasing and increasing percentage of change in a land-use type.

The traditional ordinary analysis models by Bruce and Maurice and the single spatial information analysis model by Liu et al. were also commonly used methods [65,66]. However, the SCM models provide the complete information about decreasing and increasing rates of LULC change. The traditional model ignores both decreasing and increasing rates and simply calculates the annual change rate, and the single spatial information model also only considers the conversion (decrease) of land use type and ignores the gained (increase) part. As opposed to them, the SCM accounts for both decreasing and increasing rates of changes in analyzing the land use change. The model also provides the scope to decompose the overall land-use change into various types of land-use and allows for a relevant policy analysis.

2.3.2. Analysis of Driving Forces of Cropland Change

Land use change can be defined as a response to the changes in the possible driving forces of LULC, such as socioeconomic, biophysical, demographic, and climatic forces. Some recent analyses have implemented the land-use evolution and impact assessment model (LEAM) planning support system (PSS) to provide detailed information and policy solutions to planners [58]. The PSS models essentially estimate the environmental impacts of land-use change by controlling a large number of confounding factors of land-use change. The regression models, however, provide a simpler estimation approach by helping parcel out the individual impacts of the predictors. In this analysis, the regression approach was used to identify the significant drivers of land-use change and by analyzing the potential driving forces of cropland expansion; we sought to statistically understand the magnitude of significant impact of different factors on cropland expansion. To avoid multicollinearity amongst the independent variables, a multicollinearity test was conducted. For this purpose, the variance inflation factor (VIF) analysis [29,67] was used. Based on VIF analyses, each independent variable (factor) was linearly regressed against other independent variables (factors). An independent variable with VIF value acceding 10 was considered as serious multicolinearity problem that requires the removal from the analysis. Furthermore, to enhance the computational accuracy, the continuous variable standardization to have a zero mean and unit standardization were also conducted. The descriptions of final selected variables are given in the Table 2.

Table 2. List of independent variables in the logistic modeling.

Variable	Description	Unite
	Bio-physical variables	
Landform (X_1)	Physiographic	
	Plains Lowlands Plateaus Hills	NA
AEZs (X_2)	Agro ecological zones	
	Dry semi-arid Moist semi-arid Sub-humid Humid	NA
Elevation (X_3)	Digital Elevation Model (DEM)	m
Slope (X_4)	Slope gradient derived from DEM	Degree (°)
Soil PH (X_5)	PH value of soil	PH
Soil depth (X_6)	Depth of soil	cm
Mean annual temperature (X_7)	Average mean temperature	°C
Mean annual rainfall (X_8)	Average annual rainfall	mm
	Socio-economic variables	
Population density (X_9)	Change in population density	Persons/km
Poverty (X_{10})	Poverty percentage	%
Investment on agriculture	The amount of investment on agriculture development	AFN/person
	Proximity variables	
Distance to city (X_{11})	Euclidean distance of each pixel to the closest major city	km
Distance to road (X_{12})	Euclidean distance of each pixel to the closest major road	km
Distance to water (X_{13})	Euclidean distance of each pixel to the closest permanent water	km

NA: refer to Not Applicable.

2.3.3. The Econometric Modeling of Cropland Change

The study applied the binary logistic regression (BLR) model to statistically test the LULC factors with emphasis on the probability that a given area converted to cropland depends on the variation in the hypothesized independent variables. The BLR model was first introduced by Cox, Walker, and Duncan [68,69]. The model uses the maximum likelihood (ML) method and predicts the probability of dependent variable 'Y' being 1 given with values of vector X (i.e., independent variables). Since the dependent variable Y takes only two values and cannot exceed 1 or fall below zero, therefore, it is an exponential function rather than a linear function. In this study, if a given location (k) changed to cropland, then Y holds the value of 1, otherwise it holds zero. The equation of the binomial logistic regression model is given as follows:

$$Y_{k(2000-2010)} = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \ldots\ldots \beta_n X_n + \mu \quad (2)$$

where, Y_k = refers to land use at location (k) (if land use change to cropland Y = 1, while Y = 0 is otherwise); β_0 is constant; β_i (i = 1~n) are the estimated model coefficients; X_i (i = 1~n) are the independent variables and, lastly, μ is a random error term.

3. Result and Discussion

3.1. Land Use Change

3.1.1. Land Use Change Direction

Table 3 represents the direction of land use change in KRB from 2000 to 2010. The transition matrix understandably reveals that during the study period, cropland and built-up areas were found with the lowest conversion, i.e., less than 5% of the total land in the year 2000, representing 95% of the stable area. On the other hand, forest and water bodies were significantly unstable. During this period, 41.4% of total forest area and 46.9% of water bodies were converted to other LULC types. Grassland, permanent snow/ice, and unused lands were also noticeably unstable with 17.4%, 84.8%, and 24.1% of converted areas, respectively.

The significant exchange of cropland in KRB happened after 2000 with all the land use types, particularly with grassland, unused land, water bodies, and built-up land. More than 80% of the converted cropland was shared by grassland and unused land (Figure 2). This was possibly due to the water stress situation in some parts of the country due to climate change, as indicated by Savage et al. [70]. The remaining areas of cropland conversion are mostly shared by water bodies and built-up, indicating that the cropland were damages by flood and increasing urbanization. As for the gained part, cropland mainly gained areas from grassland, unused land, and forest implying that the agricultural expansion happened with expenses to the natural lands, such as grasslands and forest areas.

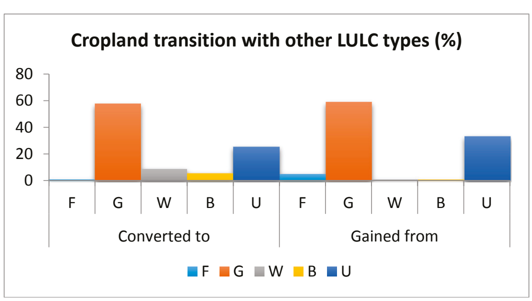

Figure 2. Cropland change direction of cropland change. Note: C = Cropland, F = Forest area, G = Grassland, W = Water bodies, B = Built-up land and S = Sow/ice covered areas.

Table 3. Land use change direction.

Land Use Type	Transition Matrix of LULC Change (in ha)							
	CL	**FR**	**GL**	**WB**	**BL**	**UL**	**S/I**	**Total 2000**
CL	**612,813 (95.1)**	456 (0.1)	18,019 (2.8)	2888 (0.4)	1913 (0.3)	8056 (1.3)	0 (0.0)	644,145
FR	6019 (0.6)	**632,638 (58.6)**	333,569 (30.9)	444 (0.0)	6 (0.0)	107,275 (9.9)	231 (0.0)	1,080,182
GL	66,994 (1.5)	121,263 (2.7)	**3,696,344 (82.6)**	4988 (0.1)	369 (0.0)	583,469 (13.0)	1994 (0.0)	4,475,421
WB	1581 (8.8)	144 (0.8)	4563 (25.3)	**9600 (53.1)**	25 (0.1)	2131 (11.8)	25 (0.1)	18,069
BL	1331 (3.3)	0 (0.0)	400 (1.0)	25 (0.1)	**38,269 (95.2)**	188 (0.5)	0 (0.0)	40,213
UL	38,119 (0.9)	54,681 (1.3)	913,019 (21.7)	3350 (0.1)	1325 (0.0)	**3,193,475 (75.9)**	2,056 (0.0)	4,206,025
S/I	0 (0.0)	94 (0.3)	2444 (7.1)	25 (0.1)	0 (0.0)	2663 (7.7)	**29,156 (84.8)**	34,382
Total 2010	726,857	809,276	4,968,358	21,320	41,907	389,7257	33,462	10,498,437

Note 1: The non-diagonal figures in the table represent the changed area of each LULUC class during the period of 2000 to 2010 while the diagonal figures (in bold) represent the unchanged area of LULC of each class during this period (the figures in the parentheses represent the same percentage of total area of the respective LULC class). The figures in the row cells depicts the area of a specific LULC class (*i*th) that were converted to other non-*i*th LULC classes, while the column cells show the area gained by the *i*th LULC class from the other non-*i*th classes. Note 2: CL = cropland, FR = forest area, GL = grassland, WB = water bodies, BL = built-up land and S/I = snow/ice covered areas.

3.1.2. Land Use Change Magnitude

The magnitude of land use change is described in Table 4 and Figure 3. During the period from 2000 to 2010, an area of 31,331 ha of cropland decreased, while 114,044 ha increased, respectively, sharing 4.3% and 15.7% of total cropland area in 2010. This indicates that the size of increased cropland was 11.4% higher than the size of decreased cropland. The decrease is significant, as also confirmed by rate of change, which was 0.5% for the decrease, compared to 1.8% for the increase, of cropland (the spatial distribution of cropland can be seen in Figure 4). The main reason behind this could be the large investment of government on irrigation projects during this period [3,71]. Currently this basin shares about 20% of the total irrigation land in Afghanistan.

Table 4. The magnitude of LULC change during the period of 2000 to 2010.

LULC Type	Decreased		Increased		Overall	
	Area (000 ha)	Rate (%)	Area (000 ha)	Rate (%)	Change (%)	Net-Change (%)
Cropland	31.3	0.5	114.1	1.8	2.3	+1.3
Forest	447.5	4.1	176.6	1.6	5.7	−2.5
Grassland	779.1	1.7	1272.1	2.8	4.5	+1.1
Water bodies	8.5	4.7	11.7	6.5	11.2	+1.8
Built-up land	1.9	0.5	3.7	0.9	1.4	+0.4
Unused land	1012.5	2.4	703.8	1.7	4.1	−0.7
Snow/ice	5.2	1.5	4.3	1.3	2.8	−0.3

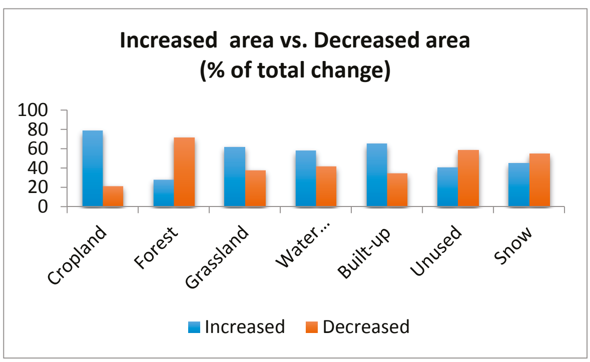

Figure 3. Increased vs. decreased area of each LULC class.

On the other hand, the rate of decrease of forest areas (i.e., 5.8%) was about three times higher than the rate of increase (i.e., 1.6%), resulting in a decline of forest covers. The previous studies on Afghanistan's forest change also confirm the rapid rate of forest cover decrease [72–74]. Use of wood for fuel and heating, illegal smuggling, instability in the forest-dominant areas, weak management, and urban and cropland expansion were considered to be the main drivers of deforestation [39,71,73]. However, the study of Reddy and Saranya [72] showed a declining trend in the deforestation rate in recent years. This could be due to increased conservation measures that have been taken recently. Permanent snow/ice covered land and unused land were also amongst the LULC types that were more on the decline. This is in consistent with previous studies at regional and national scales [74,75]. The decreasing and increasing rates of snow/ice covered land were 1.5% and 1.3%, respectively. The reason behind the shrinking snow/ice covered area could be the increasing temperature that has resulted from global warming, as indicated by Savage et al. [70]. The rapid melting of the snow/ice covered area went hand in hand with the increase in water areas. Haritashya et al., in their study, reported that the decrease of glaciers due to the changing climate conditions had resulted in the formation of high-altitude lakes, and increased the size of existing glacial lakes [75]. There was an increase in water bodies of 1,272,013 ha (55% of 2010) against a decrease of 779,075 ha (39.7% of 2010), resulting in a 6.5% increasing and 4.7% decreasing rate, respectively.

The overall rate of change during the study period shows that water bodies and forest areas had changed the most, with 11.2% and 5.7% of rates of change, respectively. They were followed by unused land (4.5%), grassland (4.1%), snow/ice covered areas (2.8%), cropland (2.3%), and built-up areas (1.4%). The annual net change rate of cropland, grassland, water bodies, and built-up land were positive, whereas the annual net change rate of, forest, unused, and snow/ice covered area were negative.

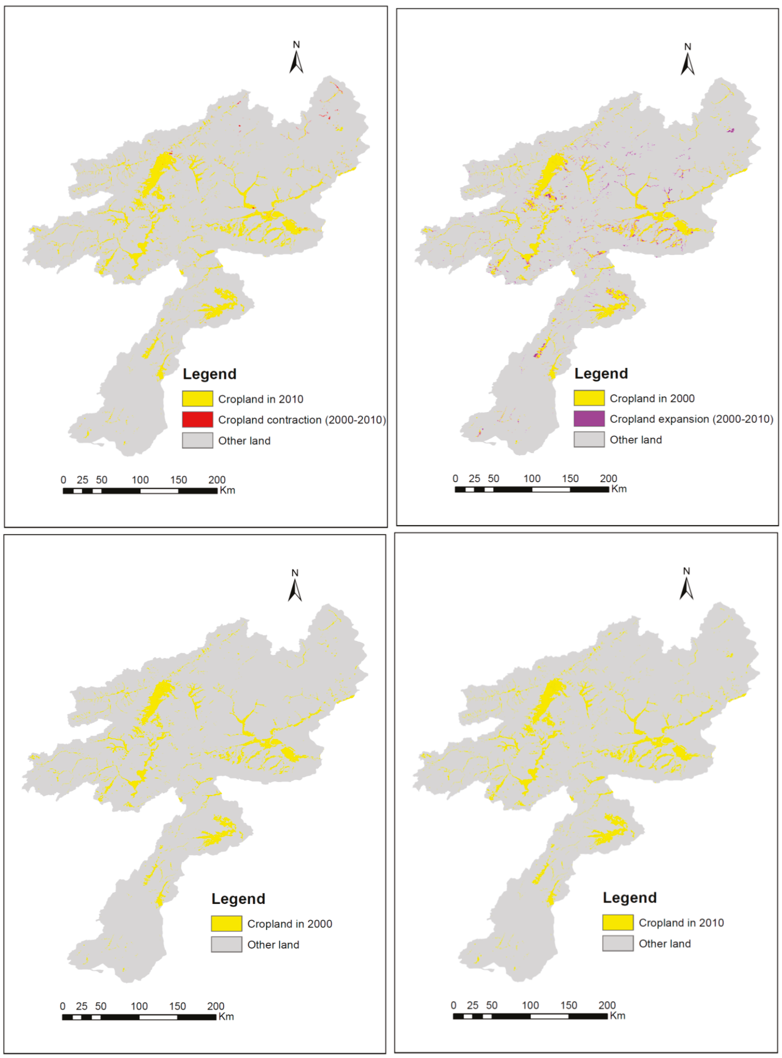

Figure 4. *Cont.*

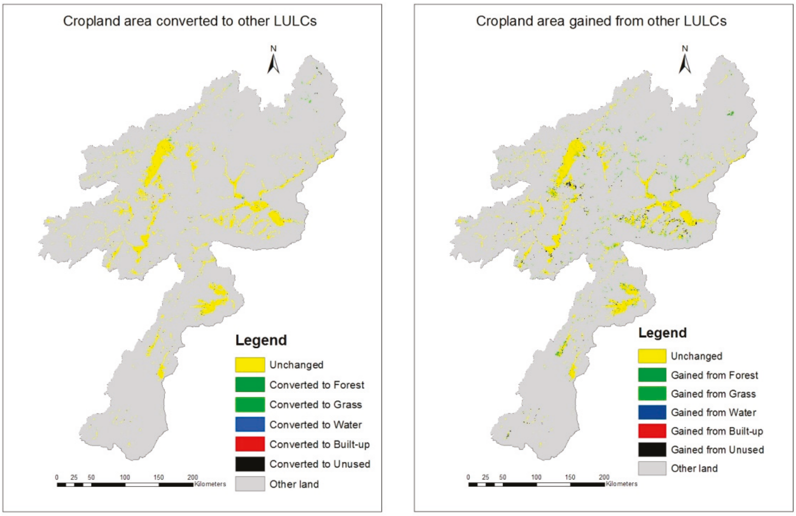

Figure 4. Changes in the spatial distribution of cropland during the period of 2000 to 2010.

3.2. Cropland Use Change Drivers

From the multicollinearity diagnostic analysis we determined that, except for the variable of mountainlandforms, all other variables were not highly correlated. Agricultural practice was also negligible in mountainous areas of the KRB. Therefore, the mentioned variable was eliminated from the model. Table 5 shows the maximum likelihood of the variables that are included in the model. The figure for the area under the ROC curve (AUC) in the table is 0.83, which shows a very good explanatory power of the chosen variables for explaining the cropland expansion. The result of the BLR revealed that both biophysical and socio-economic factors are important in driving the cropland expansion. From the terrain variables, the impacts of lowlands and plains on cropland expansion were highly significant at the 1% level of significance. The impact of plateaus was significant at 5%, while the cropland expansion was non-significant in the mountains. Odds ratios suggested that the cropland expansion in plains and lowlands are, respectively, 1.3 and 1.6 times more likely than the plateaus. This was in line with the fact that agriculture in the KRB is mostly irrigated, which is practiced in the lowlands and plains where river water can be easily diverted for irrigation. As Afghanistan is located in a harsh climatic region of a semi-arid zone, the agro-ecological conditions show an inverse relationship with the cropland expansion. The likelihood of cropland expansion will be reduced with the increase in any of the AEZs, except the humid AEZ. The elevation impact on cropland expansion was negative, while the slope impact was positive. This is because the high elevated areas of KRB are mostly frozen throughout the year and covered by snow, which restricts agriculture. With the increase of each unit of slope and elevation the likelihood of cropland expansion increased by 1%. This reveals that the agricultural expansion has mostly happened in the sloped and low altitude areas, i.e., lowlands and plains. The impact of temperature was insignificant on cropland expansion, however, precipitation showed a negative relationship with the expansion of cropland. Theoretically, this seems to be against the expectations in a dry climate country. However, the possible reason for this could be the spatial differences between the distribution of precipitation and agricultural lands in the KRB. Precipitation in the KRB mostly occurs in the form of snow in high-altitude areas, which later melted into rivers and flow towards the lowlands and plains to irrigate the agricultural lands. The areas with more precipitation (snow) are normally frozen for a major part of the year and, hence, unsuitable for agriculture. The recent study of the National Environmental Protection Agency Afghanistan (NEPA) and the United Nation Environment (UN Environment) reported that the increasing seasonal variation of precipitation has adversely affected agriculture. As per the study, the winter precipitation (which mostly occurs in the form of snow) had shown an increase, while the spring precipitation (directly facilitating crops) had decreased [76]. Additionally, the increasing pattern of intense and irregular rain causes flash floods in the lowlands of the KRB, which subsequently damaged the agricultural lands [70,71].

Apart from biophysical factors, socio-economic factors, such as economic development, population growth, government investment on agricultural development, and access to roads and economic infrastructure, are also important factors of LULC change. The empirical analysis of our model showed an inverse relationship of population density and cropland expansion. The model predicted that with the increase of one unit of population density, the likelihood of cropland expansion decreased by 1%. Increasing competition between built-up land and cropland, particularly along the highly-populated areas (i.e., cities), has led to restrictions on further expansion of crop-lands. As most of the KRB is covered by mountainous regions, the land for agriculture, housing, and other non-agricultural activities is limited. Therefore, to meet the demand of rapidly-growing population and urbanization, the agricultural lands are being converted to built-up lands [39]. This study used poverty rates as a proxy for the economic ability of the region to invest on non-agricultural economic activities, while the investment on agriculture was used to understand the impact of government funding on cropland expansion. The BLR model predicted that cropland expansion has a non-significant relationship with poverty, while the relationship with agricultural investment was significantly positive. With each unit increase of agricultural investment, the likelihood of cropland expansion increased by 2%, suggesting that agricultural still remains as a main economic activity in the KRB. The industrial setup is still weak in the country and 40% of the active labor force is engaged in agriculture. Investment on irrigation schemes to bring new lands under cultivation is one of the main foci of the government and it was evident by the result of the model.

Table 5. Maximum likelihood estimates of the BLR model for cropland expansion (2000–2010).

Variables	Coefficient (β)	Odd Ratio (β)	Std. Error	*p* Value
Landforms: Plains	0.264	1.302	0.045	0.00 ***
landforms: lowlands	0.467	1.596	0.251	0.00 ***
Landforms: Plateaus	−0.065	0.937	0.025	0.01 **
Landforms: Hills	−0.262	0.769	0.236	0.393
AEZs: Dry semi-arid	−0.897	0.407	0.023	0.00 ***
AEZs: Moist semi-arid	−1.043	0.352	0.023	0.00 ***
AEZs: Sub-humid	−1.059	0.157	0.017	0.00 ***
AEZs: Humid	0.059	1.061	0.488	0.898
Elevation	−0.001	0.999	0.001	0.00 ***
Slope	0.015	1.015	0.002	0.00 ***
Soil PH	−0.003	0.996	0.003	0.229
Soil depth	0.05	1.051	0.001	0.00 ***
Mean annual temperature	0.007	1.001	0.006	0.235
Mean annual rainfall	−0.045	0.955	0.003	0.00 ***
Population density	−0.001	0.999	0.001	0.00 ***
Poverty	−0.011	0.989	0.011	0.337
Investment on agriculture	0.018	1.02	0.001	0.00 ***
Distance to city	0.001	1.001	0.001	0.01 **
Distance to road	−0.001	0.999	0.001	0.00 ***
Distance to water	−0.001	0.999	0.001	0.00 ***
Constant	−15.167	0.001	0.001	0.00 ***
N = 10485775				
AUC = 0.83				

Note: *** and ** represent significance at 1% level and 5% level, respectively.

Regarding the proximity variables, the distance to the city showed a positive relationship with cropland expansion, whereas the relationship was negative with the distance to roads and water networks. The odds showed a marginal increment of likelihood of cropland expansion (i.e., less than

1%) if a unit of distance to cities increased. The positive relationship of city distance means the lands in the city and nearby areas are mostly occupied by manmade artificial lands. The negative relationship of cropland with the distance to roads and water indicates that the existence of river networks and market connectivity played important role in cropland expansion.

4. Conclusions

In Afghanistan, monitoring land use change dynamics and its related deriving forces are critical for efficient management of land resources. In the past few years, considering the large investment of government on agricultural land expansion in the given context, the rapidly growing population and urbanization have further added to the importance of land use change studies. To serve the above purpose, this study was conducted to spatiotemporally examine the dynamics of LULC and evaluate the determinants of cropland expansion in the most populated river basin of Afghanistan. The result of the spatial calculating model (SCM) showed that all the LULC classes were significantly changed during the period of 2000 to 2010. Particularly the water areas, forests, unused and grassland were significantly converted. On the contrary, built-up land and cropland were the most stable classes with less than 5% conversion. However, the net change rate showed that, during this period, cropland (13%), grassland (11%), water bodies (18%), and built-up land (4%) increased in percentage, whereas forest (25%), unused (7%), and snow/ice covered areas (3%) decreased. The rate of loss was highest for forests. The main reasons for massive deforestation are uses of wood for fuel, heating, and housing, as well as illegal smuggling [39,72,73].

The cropland expansion was found to be driven by several biophysical, socio-economic, and neighborhood factors. Low and plain landforms, slope, soil depth, investment on agricultural development, and distance to the city positively affected the cropland expansion, while plateaus and hill landforms, dry semi-arid, moist semi-arid, and sub-humid AEZs, precipitation, population, and the distance to roads and water negatively affected the cropland expansion.

From the study, some impending crises from changing LULC and agrarian development have been observed and related to this change, and several policy recommendations can be drawn. Firstly, given the rapid loss of forests, the government needs to take measures to regulate forest exploitation. The provision of alternative fuel sources for cooking and heating, together with educating the local communities about the importance of forest resources, would help to decrease the rapid deforestation. Moreover, the government should implement afforestation and reforestation programs in the potentially suitable and available lands. Secondly, the shrink of snow/ice covered areas are threatening future water security in the KRB. Suitable measures need to be taken to optimize water utilization both through constructing water reservoirs and enhancing water use productivity and efficiency. Thirdly, the negative relationship of precipitation and cropland expansion indicated that climate adaptation measures are important to tackle with increasing irregular precipitation patterns. As in the KRB most of the croplands are located along the riverside, therefore, protected river embankments may help to protect croplands in the flood-prone zones. In Afghanistan most of the agriculture is irrigated and gets it water from the nearby river networks. Thus, investment on irrigation networks will be important for agricultural expansion in the future. Fourthly, the negative relationship of cropland expansion with the distance to road networks reveals the importance of market access for agricultural development. Being a mountainous country, the road networks in rural areas of Afghanistan have not been well developed and farmers have low access to market hubs. With the development of road networks, farmer can be directly connected with the local and international market hubs, which will increase their farm business returns and allow them to spend on additional irrigation. Without a focus on road networks, investment on irrigation could go to waste. Therefore, along with the investment on access to land and water resources, investment on the construction of roads is equally important for agricultural land expansion. Fifthly, the productive agricultural fields in the outskirts of populated cities are threatened by a rapidly-growing population and urbanization. A balance in population growth and the provision of needed facilities in the rural areas would help to control the rapid urbanization and cropland conversion. Finally, the positive relationship between government investment on the agricultural sector and cropland expansion suggests that the increased funding in the agricultural sector for enhancing farmers' access to secure agricultural lands, agricultural credit, irrigation facilities, and farm inputs are necessary for agricultural development.

The factors considered in this study are limited to the data available. There may have been some unseen driving factors that impacted the cropland changes during the study period. For this, future research needs to develop more datasets and select shorter time periods. Additionally, this research only focused on LULC changes and not its consequences in terms of economics and the environment. As such, further studies are needed to investigate the economic and environmental implication of cropland expansion.

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The Sustainable Role of the E-Trust in the B2C E-Commerce of Vietnam

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Abstract: Vietnam, as a new emerging market, especially in e-business, has been promoting its emerging e-commerce market in Southeast Asia using aggressive players such as Lazada. Nonetheless, Vietnam has strong cultural background of risk-averse attitudes, like other developing countries, thereby deferring sustainable transformation into the e-business revolution. Therefore, it is necessary to examine the factors leading to the sustainable performance of e-commerce businesses, because highly risk-avert attitudes still cause many problems due to low levels of trust. In this perspective of trust, this research may contribute to promoting Vietnamese online shopping trends and suggesting ways for sustainable business to achieve success in B2C e-commerce. The purpose of this research is to examine whether or not the characteristics of e-service quality (usefulness, convenience, security, responsiveness, and assurance) have a positive influence on customer loyalty, one of the sustainable success factors in this growing e-commerce industry in Asian markets. Using questionnaires and structural equation modelling, we concluded that it is crucial to promote e-trust as a vital element, because it lacks, in the short-run, an initial e-trust.

Keywords: service quality; trust; customer loyalty; Lazada; structural equation modeling; partial least structure

1. Introduction

Ever since the birth of the internet in the 1990s, online commerce has taken the world by storm. Empowered by the internet, e-commerce quickly spread out to most industries, as enterprises found it an effective method for business performance. E-commerce, which can be simply defined as the utilization of the internet to facilitate and execute business transactions, is a cost-optimized method to promote and run a business [1]. As e-commerce, represented by business to consumer (B2C) type of online shopping mall, has gained popularity all around the world, its role for changing our society as well as cultural norms has become much more important [2]. According to the Global B2C e-commerce report 2016 by E-commerce Foundation, around 2.5 billion consumers in the world found their way to the internet, and the majority of them purchased goods and services online for a total amount of 2671 billion USD. Asia-Pacific and North America are among the top regions for the highest positions, at a total B2C e-commerce turnover of 1057 billion and 644 billion USD, respectively in 2016 [3].

Vietnam, as an emerging e-commerce market in Southeast Asia, has witnessed an impressive expansion. In 2015, the Vietnamese e-commerce market was worth 4.07 billion USD, and it is expected to rise 20 percent per year to reach 10 billion USD by 2020, according to Vietnam e-Commerce and Information Technology Agency [4]. The Vietnamese domestic e-commerce playfield has been more and more crowded, led by the major players such as Lazada, Tiki, Sendo, etc. Based on the globally successful model of Amazon and Alibaba, Lazada was launched in Vietnam in 2012, and it became a leading B2C e-marketplace in Vietnam e-commerce market. In Vietnam, e-commerce market has an enormous potential to grow bigger, but it also encounters many problems due to trust, intrinsic in

Vietnamese traditional culture, and shopping habits. Therefore, in the context of growing e-commerce market in Vietnam, it is necessary to examine the governance factors leading to sustainable performance of e-commerce businesses.

The Pareto principle, also named the 80:20 rule, states that 20 percent of customers contribute 80 percent of profits. It implies that the loyalty of the customer relationship management is a crucial factor for the sustainable performance of the B2C type of online shopping mall. The sustainable performance of web-business services should not be based on simple, instantaneous intentions in the short term, but on reuse intentions based on long term relationships [5]. Therefore, the sustainable success of an EC platform, or an e-intermediary, can be measured by the level of customer loyalty. The purpose of this research is to examine the key governance factors making an EC platform (e-intermediary) sustainably successful in a growing e-commerce industry. For this purpose, we want to examine the following three questions, based on the survey case of Lazada, a leading Vietnamese online shopping mall:

- Whether web-service quality has a positive influence on customer loyalty?
- Whether trust has a positive influence on customer loyalty and at to what extent?
- Whether trust plays a critical mediating role between web service quality and customer loyalty?

The EC platform operates as an intermediary to build the bridge between vendors and consumers. That means in an electronic platform, both sellers and buyers are the clients of the intermediary. However, it should be noted that in this research, we focus mainly on the intermediary-buyer relationship, because very little research focuses on the relationship between intermediary and seller, especially in most developing countries such as Vietnam. This paper will attempt to help these new emerging countries to develop more sustainable e-business strategies, theoretically as well as practically, with market-oriented implications and suggestions. To find out the causal effect interaction among variables from the questionnaires of the Lazada customers, SEM (Structural Equation Modeling) will be employed, with the support of the Partial Least Square (PLS) approach for examining the stability of the model and hypotheses testing. PLS is a SEM technique based on path analysis, which recently became popular for multiple-construct relationship model analysis. Especially, our paper will contribute to overcoming the relatively small sample size with the bootstrapping simulation, which will enhance statistical significance and reliability.

The rest of this paper is organized as follows: Section 1 introduces the research background, research objective, and a brief introduction of the research methodology and structure. Section 2 contains a literature review and proposes some hypotheses. In Section 2, Vietnamese the e-commerce industry overview, as well as the Lazada e-commerce platform, are presented. The previous research regarding service quality, customer loyalty, and trust are also mentioned. Section 3 contains the research model and data collection. Section 4 deals with the empirical results of the model analysis, while Section 5 concludes the study with implications, pointing out research limitations and suggesting new ideas for further research.

2. Literature Review and Hypotheses

2.1. Status of Vietnam E-Commerce

In Vietnam, online shopping malls make up only about 2.8 percent of the total retail market [4]. However, Vietnam has a rapidly increasing emerging e-commerce market in Southeast Asia, which has witnessed an impressive expansion. In 2015, revenue in Vietnam B2C e-Commerce market amounted to 4.07 billion USD. It is expected to show an annual growth rate (CAGR 2015–2020) of approximately 20 percent, expect in a market volume of 10 billion USD in 2020, driven by rapidly increasing internet penetration, a rise in personal income, competitive prices compared with offline stores, and presence of various online retail portals offering a variety of goods [4]. It also should be noted that the number of internet users in Vietnam increases rapidly year by year. There are currently 35.4 million e-commerce users in Vietnam, and it is predicted that 6.6 million users will be shopping online by 2021 [6]. These 42 million potential online shoppers represent 58 percent of the total population, even higher than the world average internet penetration rate of 46.64 percent [3]. The average online revenue per user currently amounts to 160 USD, according to Vietnam e-Commerce and Information Technology Agency [4].

B2C e-commerce in Vietnam supported by the potential environment could be lucrative blue ocean for both foreign and local companies. With the launch of Lotte shopping mall in October 2016, South Korean retailer Lotte expected to gain 20 percent of Vietnam e-commerce market share by 2020. Japanese retail giant Aeon also changed its position from a bystander into an aggressive player with the inauguration of its new B2C website, AeonEshop, in January 2017. Besides, some local e-commerce platforms like Sendo, Tiki, and Adayroi have positioned themselves in their home market as well. Based on the global leading model such as Amazon and Alibaba, Lazada was launched in Vietnam in 2012 and became a leading B2C e-marketplace. According to the results of a survey conducted by Asia Plus Incorporation, Lazada is the most frequently used shopping site in Vietnam with 24 percent of advocating respondents, as shown in Figure 1. Nonetheless, Lazada are confronted with tough competition by both local and foreign players. Although Lazada is a leading Vietnam e-commerce player with high market share, there is still a high risk of changing position happening in the next coming years.

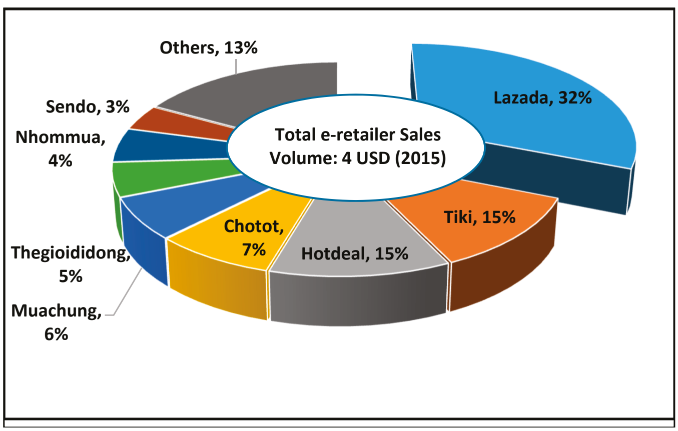


Figure 1. Vietnamese online market share. Source: Asia Plus Inc. (Tokyo, Japan), Vietnam EC Market Survey [7].

Lazada Group began as a privately owned German e-commerce company founded by Rocket Internet with its business in Indonesia, Malaysia, the Philippines, Singapore, and Thailand in 2011. In 2013, it started running e-marketplace model, allowing retailers to sell their products through Lazada's platform. The e-platform accounted for 65 percent of its sales by the end of 2014. As of April 2016, Alibaba Group bought controlling stake in Lazada under a deal worth approximately one billion dollars in order to support Alibaba's expansion plans in Southeast Asia [8]. Lazada launched Vietnam online shopping mall in 2012, reaching the leading position among 10 highest revenue e-commerce websites after three years, as shown in the Figure 1. As a B2C e-marketplace with approximately 14,000 brands and over 40,000 products in many categories, Lazada has gained the highest brand awareness in recent years. According to DI Marketing, the market share of Lazada in the Vietnamese market rose from 24 percent in 2015 to 36 percent in 2016, and it continued to be the market leader in 2017 [9].

Lazada has become an e-commerce pioneer in Vietnam by offering a fast, secure, and convenient online shopping experience. Shortly after establishment, Lazada has introduced mobile application helping mobile-users easily to get access and unlimited-shopping on the go. Lazada Vietnam has reached a milestone of more than 110 million visits to its desktop and mobile sites in the second quarter of 2015, as shown in the Figure 2. This achievement reflects customer preference in shopping on Lazada, affirming its leading position in Vietnam e-commerce industry [10].

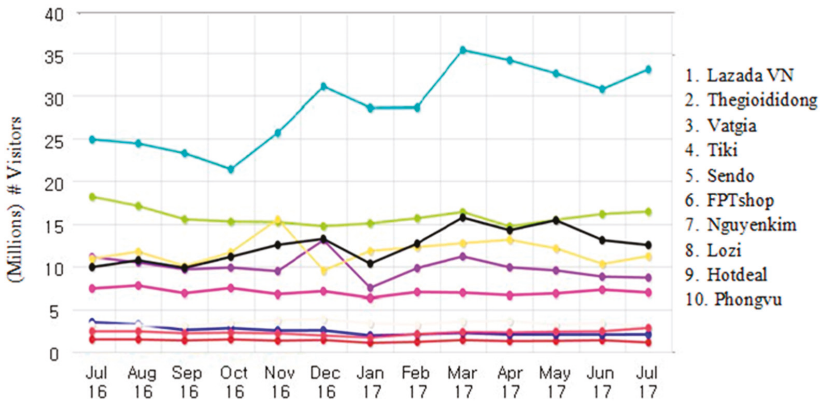


Figure 2. Monthly B2C web traffic in Vietnam. Source: SimilarWeb Ltd. (New York, NY, USA) (www.similarweb.com/website/lazada.vn).

Figure 2 shows that Vietnam B2C e-marketplace was led by the most popular Lazada shopping site, continuously from July 2016 to July 2017, indicating that Lazada gains most of awareness of consumers. Some people might not think of e-marketplace such as Amazon, Alibaba, and Lazada as sales intermediaries, but they are intermediaries with effective connection between sellers and buyers, in a structured and secured environment. In a simple way, intermediary can be defined as a third party that offers intermediation services between two parties. Common to all intermediaries is that they mediate between suppliers (or sellers) and consumers (or buyers) of goods and service [11]. Since the paradigm of the web based service business is based on the "value creation based on the network management" [2] (p. 57), it is crucial for an intermediary in new digital era to generate trust and coordinate the roles of different divisions as a metamediary [12].

Unfortunately, for all online retailers to gain customer trust is the biggest challenge. This is true especially in Vietnam where the consumer is traditionally not acquainted with online shopping. Recently, research analyzed how consumers are complaining about online shopping, with more than 30,000 reviews at 5000 e-commerce websites in Vietnam, Malaysia, Singapore, Indonesia, and the Philippines [7]. As shown in the Figure 3, the research shows that Vietnamese consumers have the lowest reliability when it comes to online shopping. Vietnamese end-users complain about fakes more than any other country in the region. They usually have common queries regarding the product's origin (or product authorization) compared with other Southeast Asian web consumers who only ask about the purchase process. Most of Vietnamese consumers prefer chatting directly with suppliers to acquire more detail about the product. The lack of trustworthiness in e-commerce makes customers unwilling to spend money on online shopping [13]. The great number of sales cancellations implies that products are of a lower quality than what they expected before ordering. Vietnam shows the highest rate of order cancellation, with 30 percent of products being rejected due to product failure. As shown in the figure, product quality concern is the most common reason, accounting for 57 percent of respondents, whilst the second-ranked reason relates to security concern at 25 percent. In reality, a large number of Vietnamese people prefer visiting an offline store to have a real visual-and-touching interaction before making a purchase decision. The concern about low-quality products and leak of personal information makes internet users hesitant to participate in e-commerce. Meanwhile, local businesses have not developed enough trust for Vietnamese consumers to change their purchasing habits, which are traditionally not familiar with online shopping. Building trust with local consumers means understanding their culture. A major hindrance of brand building in several South East Asian markets is a cash-driven culture. Vietnamese chose COD (cash on delivery) as their first choice for e-commerce due to the lack of e-trust [9]. Alipay in Chinese market is the most successful tool to have overcome this kind of cash-based transaction [14].

Lazada has overcome this lack of trust by providing risk-free shopping environment with a broad range of secured payment options (including cash on delivery—the key to getting new customers on board) and 30-day return policy for customers. Besides, they also assure the customers about the qualifications of the sellers through strictly examining and assessing the suppliers. The company has set up a team specialized in sorting and examining products, especially of large brands, to ensure that the products are genuine. In some circumstances, Lazada asks for brand-certified authorization from suppliers to prevent counterfeit goods. In addition, buyers are encouraged to give feedback if they are suspicious about the origin of the product. Lazada is extremely strict and severely punishes on the counterfeit products, removing the vendor from the site if infringements occur several times. Lazada launched a certification program that labels a 'trust-badge' to all products coming from certified sellers. Now, we want to examine these efforts of Lazada to give new hope to the Vietnamese e-commerce market via sustainable governance factors. In order to analyze these governance factors, we shall set up the hypotheses from the literature in the following section.

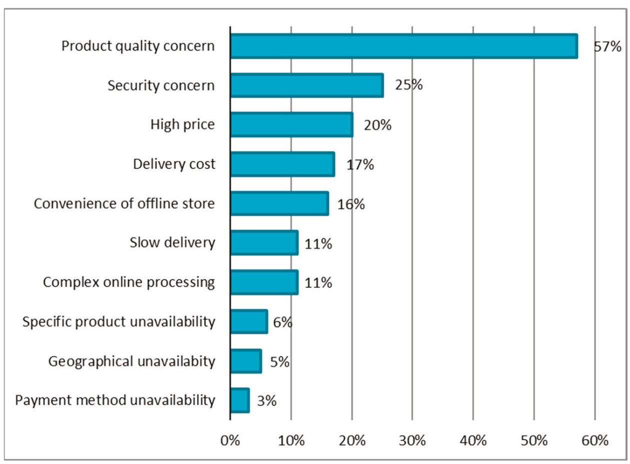


Figure 3. Reasons for not using e-commerce among Vietnamese consumers. Source: Asia Plus Inc. (2016). Vietnam E-commerce Market Survey [13].

2.2. Customer Loyalty

Customer loyalty is defined as a commitment to buy or patronize a preferred product or service consistently, indicating repetitive same brand purchasing, regardless of situational influences and marketing efforts to trigger behavior switching [15]. Srinivasan and Anderson extended a more specific definition of customer loyalty in online shopping of e-loyalty: favorable attitudes of customer towards an electronic business, causing repetitive purchasing behavior [16]. In an increasingly competitive environment, the loyalty of consumers could be one of the main factors to strengthen the market competitiveness and to reinforce sustainable competitive advantage, because appealing to new customers is remarkably more costly than retaining existing customers [17].

Customer loyalty enlarges future sales volumes and exponentially increases sales through viral marketing. Relationship management is central to the creation of value for the network manager.

Web marketing should emphasize relationship building, relationship management, and value creation from relationships [18].

The success of an e-commerce company depends much on maintaining customer loyalty [19]. As a consequence, it is crucial for e-commerce companies to manage a loyal customer base, because long-term customer relationships are not only a current main profit contributor but also have a high potential to enlarge the sales volume in the future. For these reasons, the sustainable success of an e-commerce platform for intermediaries can be symbolized by the level of customer loyalty. This customer loyalty may come from the governance factors of service quality. We will explain this causal relationship in the following section.

2.3. Hypotheses on Service Quality and E-Trust

E-commerce platform is a primary basis for multi-channel transactions in which product or service information is provided by multiple third-parties and transactions are processed by the platform operator. Because of the role in providing product and service information, EC platform operating company can also be considered as a service provider. Therefore, an e-platform consists of the diverse characteristics as a service provider and thus can be evaluated through its service quality. Service quality (SQ) is the comparison between perceived expectations of a service and perceived performance [20]. Parasuraman et al. (1988) proposed five dimensions of this gap of service quality with the SERVQUAL model: Responsiveness, Assurance, Tangibles, Empathy, and Reliability [21]. However, SERVQUAL focuses on the traditional buyer-seller interaction, but does not embrace the interaction between customer and website, which is one unique character of e-commerce service quality. Therefore, Kim et al. (2012) extended this model added by information quality [22]. In online shopping environment, service quality must get assisted with the consumer's purchasing by providing security and accessibility, in addition to speed and other convenience features, creating the importance of the information quality [23]. Information quality is perceived as the assurance value of outputs produced by a website [24].

Ribbink (2004) adopted this assurance and responsiveness from SERVQUAL model in their research [25]. Chiu et al. (2009) chose responsiveness and security as two among seven determinants of repurchase intention [26]. Yang et al. (2009) specified that transaction cost saving (convenience), reliability, responsiveness, and assurance are some of main factors in online game service [27]. Anderson and Swaminathan (2011) suggested interaction, commitment (responsiveness), and assortment (usefulness) as three among eight determinants that have an effect on loyalty in e-market [28]. Kim et al. (2012) mentioned security, variety (usefulness), responsiveness, and receptiveness in their research about internet shopping value and customer repurchase intention [22]. Choi & Sun (2015) chose a set of five dimensions: usefulness, convenience, security, responsiveness, and economy as main quality factors of third online payment service [14]. All these arguments show the common factors of e-service quality with usefulness, convenience, security, responsiveness, and assurance. The last common factor of assurance is especially important in that the Vietnamese cultural background always emphasized the risk-averse attitude in commercial transactions, as shown in the Figure 3. Based on these arguments, we can draw the following hypotheses for the causal relationship between the web service quality and its resulting customer loyalty. All these hypotheses on the five characteristics of web business service platforms and customer loyalty (H1–H5) constitute the research direct model, as shown in Figure 4.

Hypothesis 1 (H1). *Usefulness of e-commerce platform has a positive effect on customer loyalty.*

Hypothesis 2 (H2). *Convenience of e-commerce platform has a positive effect on customer loyalty.*

Hypothesis 3 (H3). *Security of e-commerce platform has a positive effect on customer loyalty.*

Hypothesis 4 (H4). *Responsiveness of e-commerce platform has a positive effect on customer loyalty.*

Hypothesis 5 (H5). *Assurance of e-commerce platform has a positive effect on customer loyalty.*

In the field of e-commerce, the terms and conditions of e-trust are mostly utilized in marketing and information system analyses as well [14]. Due to the risk of purchasing a product online from an unfamiliar vendor, e-trust remains a critical issue in an electronic transaction [29]. Hong and Cho (2011) stipulated that one of the main roles of intermediary in e-marketplace is to convince and appeal consumers into a risk-free e-commerce environment [29]. As Pennanen et al. argued, consumer trust and e-trust could be interchangeably used in the literature [30]. In most of the literature, trust in traditional marketing implies the integrity and reliability of the product, while e-trust emphasizes the safe, riskless transactions available in the online market environment [30]. Based on these arguments, we will use e-trust in this paper with the interchangeable characteristics of traditional trust. Choi and Jin used the initial trust as the concept of e-trust, and on-going trust as the traditional concept of trust [31].

The elements of service quality are expected to have an impact on trust directly. Because there is no face-to-face interaction on the e-commerce platform, the web business service quality becomes much more important as the mediator between the service quality and customer loyalty [14]. Obviously, a first impression of good e-service quality is likely to enhance reliability, which means that higher service quality results in a higher level of trust. Previous research showed the strong relationship between the determinants of service quality and the level of trust [24–27,31]. Based on these arguments, we propose the following hypotheses on the trust.

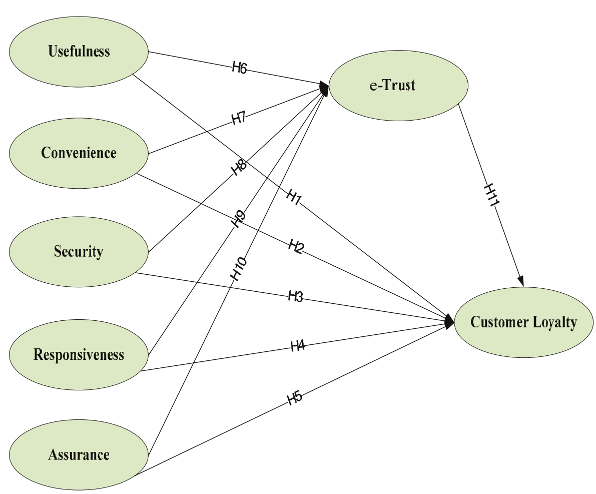
Hypothesis 6 (H6). *Usefulness of e-commerce platform has a positive effect on trust.*

Hypothesis 7 (H7). *Convenience of e-commerce platform has a positive effect on trust.*

Hypothesis 8 (H8). *Security of e-commerce platform has a positive effect on trust.*

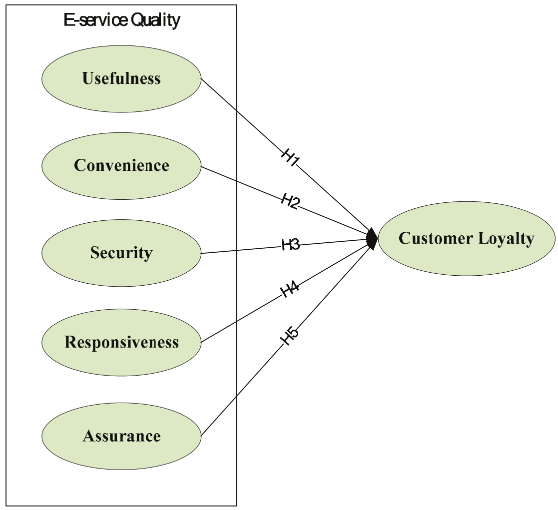
Hypothesis 9 (H9). *Responsiveness of e-commerce platform has a positive effect on trust.*

Hypothesis 10 (H10). *Assurance of e-commerce platform has a positive effect on trust.*



(**a**)

Figure 4. *Cont.*



(**b**)

Figure 4. (**a**) Indirect model with trust as a moderator, (**b**) research direct model between service quality and customer loyalty.

E-Trust is a key to building customer loyalty and maintaining continuous relationship with the consumers. There is a general consensus among the evidence supporting the impact of trust on customer loyalty [24,28,31], resulting in the following hypothesis.

Hypothesis 11 (H11). *Trust has a positive effect on customer loyalty.*

With the appearance of trust as a mediator, our model can be considered as the indirect model. As shown in the Figure 5, the propositions of trust in the framework show its role as a mediator of the path between service quality and customer loyalty. In order to test all these hypotheses and verify the role of mediator, we will explain the method more in detail and results of analysis in the following section.

3. Research Methodology and Data Collection

3.1. Data Collection and Methodology

This research follows the quantitative approach to describe and test relationships among variables: web service quality including usefulness (USE), convenience (CON), security (SEC), responsiveness (RES), assurance (ASR), trust (TRUST), and customer loyalty (LOY). For the stepwise causal relationship, Partial Least Squares (PLS) model is applied to examine stability of the model and to test hypotheses. PLS is a structural equation modeling (SEM) technique based on path analysis and regression analysis, and recently get popularity increasingly for multiple-construct relationship analysis. Although there are still some cautions for using PLS, several advantages to choose PLS as a statistical approach for structural equation modeling can be summarized [31]. First, PLS path modeling analyzes well a small sample and avoids problems from inappropriate sample size. Second, PLS can analyze complex structural equation models with many constructs and variables more effectively. Third, PLS requires fewer assumptions regarding normal variable distribution and error terms. Forth, PLS simultaneously handles both reflective and formative indicators. Fifth, PLS better suits theory development than theory testing and is especially useful for prediction. Sixth, and last, PLS overcomes multi-collinear issue.

From all these reasons, we choose PLS as the analytical method in this research. However, since PLS does not test significance, a re-sampling approach is used for significance testing [32]. To overcome this issue and to simulate a random sample size, the bootstrapping method was applied. Bootstrapping treats the observed samples as if they represent the population [31]. With the bootstrapping simulation, corresponding sample could be used for conducting statistical examination and testing hypotheses. In this research, we set the number of simulated sample at 2000 to achieve stability of parameter estimation [33]. PLS analysis was performed by Smart PLS 2.0 software (Berlin, Germany). Referring to the previous studies [24,25,31], the PLS analysis will be executed sequentially as the following order:

- Reliability test of measurement model
- Convergent and discriminant validity test of measurement model
- Goodness-of-fit of the research model
- Hypotheses testing of direct and indirect model
- Mediation effect testing

A survey was used to collect the original data. The study was conducted in the big cities such as Hanoi and Hochimin city in Vietnam, where the majority of urban residents have access to the internet and high demand for online shopping. First, eight multi-choice questions in the questionnaire are shown to collect basic personal information, such as gender, age, education level, online shopping frequency, etc. The main content of the questionnaire comprises thirty questions based on 5-point Likert scale, ranging from 1 (strongly disagree) to 5 (strongly agree). Quantifiable data were obtained through a structured questionnaire of seven categories: usefulness (5 questions), convenience (4 questions), security (4 questions), responsiveness (5 questions), assurance (4 questions), trust (4 questions), and customer loyalty (5 questions).

The survey was conducted from 16 October to 6 November 2017. The questionnaires were randomly dispatched to e-commerce users via e-mail and messenger. Except for inappropriate responses (including responses from those with no shopping experience on Lazada), 231 out of 265 unique and usable responses were collected, with an acceptance rate of 87.17 percent. The survey sample shows the majority of e-commerce users are in the age range of 18–30; university graduates and post-graduates account for over 90 percent of respondents, implying that millennial generation with good educational background becomes much accustomed to e-commerce sites. Shopping frequency of 1 or 2 times per month accounts for approximately 46 percent, reflecting a reasonable familiarity with online shopping. Table 1 shows the details of the characteristics of the respondents.

Table 1. Descriptive statistics.

Characteristics	Items	Percentage
Gender	Male	55%
	Female	45%
Age	Under 18	0.4%
	18–30	87.4%
	30–45	11.7%
	Over 45	0.4%
Education level	Under high school	0.4%
	High school graduate	2.6%
	College	5.2%
	University graduate	71.0%
	Post-graduate	19.9%
	Others	0.9%
Shopping frequency	Rarely	30.7%
	1–2 times/month	45.9%
	3–4 times/month	13.0%
	Over 5 times/month	10.4%

3.2. Reliability Test, and Convergent and Discriminant Validity Test

In PLS, the indicator of latent construct relationship is referred as the outer model or measurement model. Factor loading and reliability test results of these construct items are important to represent the proxy variables with different but consistent questions. Since the traditional Cronbach's α test tends to give an underestimation of the reliability of latent variables in PLS, and thus, a more appropriate measure, so called Composite reliability (CR) test is applied [34]. This composite reliability test can be interpreted in the same way as Cronbach's α. If composite reliability values of all constructs are higher than 0.7, this suggests that the constructs are reliable and acceptable [34]. In addition, Hair et al. (2010) also suggest a cut-off value at 0.5 as critical requirement for reliability [35]. As shown in Table 2, all the questions for the variables are accepted by this criteria as well.

Table 2. Reliability test results.

Construct	Measurement Items	Factor Loading/Coefficient (*t*-Value) (>0.5)	Composite Reliability (>0.7)	AVE (>0.5)
Usefulness (USE)	Use1 Use2 Use3 Use4 Use5	0.783 *** 0.719 *** 0.757 *** 0.802 *** 0.704 ***	0.868	0.568
Convenience (CON)	Con1 Con2 Con3 Con4	0.843 *** 0.747 *** 0.719 *** 0.817 ***	0.863	0.613
Security (SEC)	Sec1 Sec2 Sec3 Sec4	0.764 *** 0.874 *** 0.884 *** 0.869 ***	0.912	0.721
Responsiveness (RES)	Res1 Res2 Res3 Res4 Res5	0.856 *** 0.746 *** 0.870 *** 0.853 *** 0.871 ***	0.923	0.707
Assurance (ASR)	Asr1 Asr2 Asr3 Asr4	0.743 *** 0.859 *** 0.859 *** 0.863 ***	0.899	0.693
e-Trust (TRUST)	Trust1 Trust2 Trust3 Trust4	0.882 *** 0.873*** 0.916*** 0.822***	0.928	0.764
Customer loyalty (LOY)	Loy1 Loy2 Loy3 Loy4	0.876*** 0.924*** 0.903*** 0.911***	0.947	0.817

*** p-value < 0.001.

Two tests including convergent validity test and discriminant validity test were performed with a view to validating the construct validity. According to Fornell and Larcker [34], the constructs display convergent validity if:

- factor loads of indicators are greater than 0.5;
- reliability value is greater than 0.7;
- the average variance extracted (AVE) is greater than 0.5.

As shown in Table 3, all of the constructs satisfy these criteria, exhibiting favorable convergent validity.

Discriminant validity is used to examine the cross loading differences among different constructs. According to Campbell and Fiske (1959), construct validity tests the extent to which data provide discriminate validity [36]. Discriminant validity is adequate once the correlation of one construct with its indicators exceeds the correlation of that construct with other variables [37]. Table 3 shows us the result of the correlation matrix, indicating whether the square root of AVE is greater than the correlation coefficient of the constructs. All of cross loadings were over 0.6. Indications of both Tables 2 and 3 show that the constructs achieve discriminant validity.

Table 3. Correlation matrix.

Variables	USE	CON	SEC	RES	ASR	TRUST	LOY
USE	**0.7530** [a]						
CON	0.7129	**0.7815** [a]					
SEC	0.5528	0.5925	**0.8477** [a]				
RES	0.5618	0.5952	0.6662	**0.8392** [a]			
ASR	0.6492	0.6764	0.6435	0.6548	**0.8310** [a]		
TRUST	0.6330	0.6202	0.6713	0.7192	0.7619	**0.8732** [a]	
LOY	0.6477	0.6654	0.6151	0.6878	0.7090	0.8079	**0.9035** [a]

USE = Usefulness; CON = Convenience; SEC = Security; RES = Responsiveness; ASR = Assurance; LOY = Customer Loyalty. The bolded numbers [a] on the diagonal are the square root of AVE.

The goodness-of-fit test examines how well it fits a set of variables as a model. Goodness-of-fit is measured by the discrepancy between observed values and expected values in questionnaire. In general, a model fits the data better if the differences between observed values and predicted ones are small and unbiased. R-squared is a statistical measure of how close the data are to the fitted regression line. It is also known as the coefficient of determination, or the coefficient of multiple determinations for multiple regressions. In our model, trust and customer loyalty have R-squared values of 0.69 and 0.71 respectively, implying that the independent variables explain an estimated 69 percent and 71 percent of the variation in Trust and Customer loyalty. Therefore, based on the test, the variables fit reasonably well to the model overall.

4. Research Methodology and Empirical Results

4.1. Structural Model Result

4.1.1. Direct Model Results

In PLS, the path structures between constructs constitute the inner model (structural model). Inner model includes direct model and indirect model. Direct model just shows the simple causality between the service quality and its performance by customer loyalty. To find out this direct causality, Table 4 summarizes the path significance, coefficient t-values and hypotheses testing results. The visualized description is illustrated in the Figure 5.

Table 4. Hypotheses testing results of direct model.

Hypotheses	Path	Path Coefficient	*t*-Value	Result
H1	USE → LOY	0.165 *	2.310	Accepted
H2	CON → LOY	0.159 *	2.395	Accepted
H3	SEC → LOY	0.076	1.308	Rejected
H4	RES → LOY	0.279 ***	4.383	Accepted
H5	ASR → LOY	0.263 ***	4.213	Accepted

USE = Usefulness; CON = Convenience; SEC = Security; RES = Responsiveness; ASR = Assurance; LOY = Customer Loyalty * p-value < 0.05; *** p-value < 0.001.

As shown in Table 4, the direct path of SEC to LOY (security to loyalty) failed to achieve significance, with path coefficient of 0.076 (p-value > 0.05), implying H3 was rejected. It can be inferred that security has no significant influence on customer loyalty. E-commerce users seem to give a fairly low assessment on security factor of Lazada website. Despite the effort of Lazada in offering security protection, customers do not display strong loyalty toward the platform. As shown in Figure 3, security concern is the second critical reason why Vietnamese consumers are reluctant to purchase online, and thus Lazada desperately needs the modulator for this security to be effective in the long term.

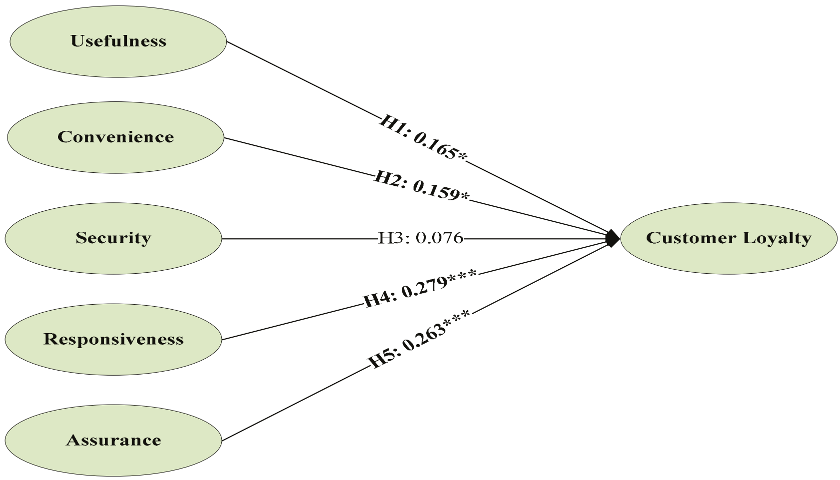


Figure 5. Results of the direct model. Note: * p-value < 0.05; *** p-value < 0.001.

In direct model, apart from H3, analysis results supported for H1, H2, H4, H5: usefulness, convenience, responsiveness, and assurance of the web service quality have a significant influence on the customer loyalty. Since four among five characteristics of e-commerce platform have the direct significant impact on customer loyalty, Lazada should consider these four website characteristics as the strategic factors to enhance the customer loyalty. Especially, responsibility and assurance (H4 and H5) should be paid more attention due to its bigger coefficients, indicating the stronger influence on the customer loyalty (0.279 and 0.263, respectively). If these two key factors are emphasized more, more customers are likely to gladly participate in the long-term transaction.

4.1.2. Indirect Model Results with E-Trust as the Modulator

Now, based on the direct model, the role of e-trust shall be analyzed in indirect model. To find out the change of all the web service quality variables with the trust in the model, the results of the indirect model are shown in Table 5 and Figure 6, with the path significance, coefficient t-values, and hypotheses testing results. In the indirect model, except for H7 (convenience to e-trust), all the other five hypotheses (H6, H8, H9, H10, and H11) were supported at the 95 percent significance level. Usefulness, security, responsiveness, and assurance have a significantly positive influence on trust, while e-trust has a significantly positive influence on customer loyalty.

Among those favorable paths, Responsiveness (H9) and Assurance (H10) showed a stronger effect on the e-trust. Since the moderator, trust, also showed strong effect on the customer loyalty, we want to examine the role of moderator in the model in more detail.

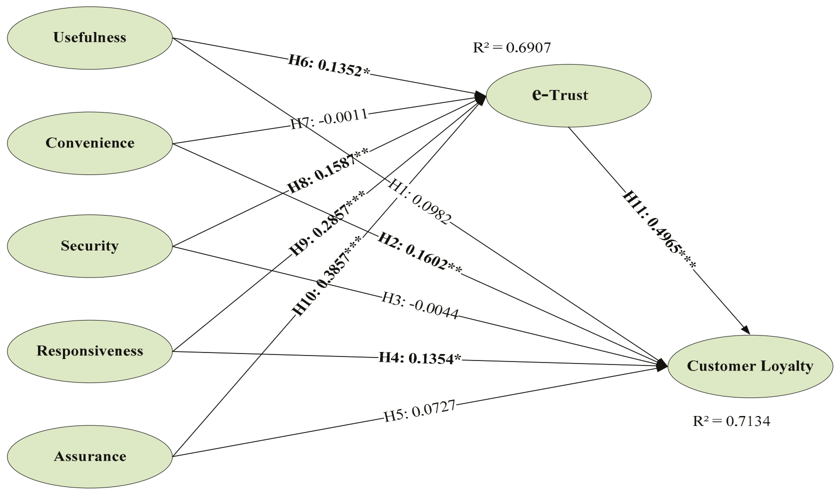


Figure 6. Results of the indirect model. Note: * *p*-value < 0.05; ** *p*-value < 0.01; *** *p*-value < 0.001.

Table 5. Hypotheses testing results of indirect model.

Hypotheses	Path	Path Coefficient	*t*-Value	Result
H1	USE → LOY	0.0982	1.699	Rejected
H2	CON → LOY	0.1602 **	2.817	Accepted
H3	SEC → LOY	−0.0044	0.089	Rejected
H4	RES → LOY	0.1354 *	2.272	Accepted
H5	ASR → LOY	0.0727	1.156	Rejected
H6	USE → TRUST	0.1352 *	2.072	Accepted
H7	CON → TRUST	−0.0011	0.018	Rejected
H8	SEC → TRUST	0.1587 **	2.589	Accepted
H9	RES → TRUST	0.2857 ***	4.127	Accepted
H10	ASR → TRUST	0.3857 ***	6.306	Accepted
H11	TRUST → LOY	0.4965 ***	6.597	Accepted

USE = Usefulness; CON = Convenience; SEC = Security; RES = Responsiveness; ASR = Assurance; LOY = Customer Loyalty * *p*-value < 0.05; ** *p*-value < 0.01; *** *p*-value < 0.001.

4.2. Moderating Effect of the E-Trust

After testing hypotheses of direct and indirect model, then mediation effect test can be performed. According to Baron and Kenny (1986), mediation can be said to occur if following conditions are satisfied [38]:

- Independent constructs significantly affect the dependent construct in direct model;
- Independent constructs significantly affect the mediator;
- The mediator has a significant unique effect on the dependent construct;
- The effect of independent constructs on the dependent construct shrinks upon the addition of mediator to the model.

To examine these criteria, a series of statistical-based methods have been introduced. In this research, three versions of Sobel test (Sobel test, Aroian test, and Goodman test) were taken to analyze the mediation effect. The purpose of these tests is to determine whether TRUST carries the influence of service quality (USE, CON, SEC, RES, ASR) to the customer loyalty (LOY). In order to test the mediation effect by Sobel tests, however, large sample sizes are required. Since Sobel tests evaluate a given sample under the normal distribution, problems may exist with the small sample size [39].

For the appropriate Sobel test, this research employed bootstrapping method to create a simulated sample size of 2000. Thus, the simulated sample totally satisfied the requirement of Sobel tests [40], and the results of the tests are presented in the following Table 6.

Table 6. Mediation effects testing.

Path/Construct Relationship (Role of Mediator)		Path Coefficient *t*-Value	*z*-Value		
			Sobel Test	Aroian Test	Goodman Test
USE → TRUST → LOY (Full)	H6 H11	2.072 6.597	1.977 *	1.960 *	1.998 *
CON → TRUST → LOY (None)	H6 H11	0.018 6.597	0.018	0.018	0.018
SEC → TRUST → LOY (Full)	H6 H11	2.589 6.597	2.410 *	2.386 *	2.434 *
RES → TRUST → LOY (Partial)	H6 H11	4.127 6.597	3.499 ***	3.470 ***	3.528 ***
ASR → TRUST → LOY (Full)	H6 H11	6.306 6.597	4.558 ***	4.531 ***	4.586 ***

USE = Usefulness; CON = Convenience; SEC = Security; RES = Responsiveness; ASR = Assurance; LOY = Customer Loyalty * p-value < 0.05; *** p-value < 0.001.

MacKinnon et al. [40] suggested that the presence of a mediation effect occurs when the absolute z-value is greater than 1.96. According to Baron and Kenny [38], in the case that all of four above-mentioned criteria are satisfied, there may be two possibilities regarding the role of mediator in the model:

(1) If the effect of independent variable becomes minor under the appearance of mediator, then it can be stated that the effect of independent variable is "fully" mediated by the mediator;
(2) If the effect of independent variable stays strong under the appearance of mediator, then mediator's role is "partially" mediated between independent and dependent variables.

It can be proposed from (1) and (2) that, in the case of mediator's appearance supported by the results of three tests in Table 6, there are also two possibilities for the role of mediator: "full" (or "completed") mediation and "partial" mediation.

As shown in Table 6, since no significant relationship between convenience and trust is found, the role of mediator in path CON → TRUST → LOY does not exist (no-mediation). Apart from this factor, all the other z-values of statistics are greater than 1.96, supporting the presence of mediator in four remaining paths. The role of mediator in these paths is listed in Table 6. From the table, the effect of usefulness, security, and assurance on the customer loyalty is "fully" mediated by trust, while the effect of responsiveness on the customer loyalty is "partially" mediated by trust. The effect of convenience on customer loyalty is not mediated by trust.

4.3. Implications and Suggestions

We may understand why usefulness and security are fully mediated by trust. Since trust is the value that cannot be generated just in a short time, the construct in the model that is fully mediated by trust also cannot easily have impact on the loyalty in short-term. Clearly, the effort of improving usefulness by various product lines and effectively usable information, and security by information protection measures, takes time to gain trust from the customers. In reality, a customer cannot immediately believe that he is protected perfectly against risk of security such as uncertainty of transaction information and personal information. It explains, in the direct model, that security construct is rejected for customer loyalty. However, with the repeated purchase, the customer may get the trust, and this trust may bridge between the security provided by Lazada and the customer loyalty completely well. The more satisfying experiences a customer gets, the more he places his trust in the security of the web service platform. Contrary to the security, usefulness is always important for the customer to maintain customer loyalty. Therefore, Lazada should promote diverse construct of usefulness measures to create the customer relationship management in the short run, as well as to maintain it in the long term.

In this research, convenience refers to the benefits from the transaction cost saving: for example, the benefit of time saving when searching for products, benefit of time saving when minimizing delivery time (in comparison with the time of visiting an offline store for direct purchasing), and benefit of money saving when shopping online at a relatively lower price. Because transaction cost-saving benefits are the kind of value that the customers can recognize and get immediately in short-term, they are exempt from linking to "ongoing trust" in the long-term [41]. This can explain why convenience suffers no mediation effect from trust in the indirect model. In order to overcome this weakness, Lazada should make more effort to link this convenience even in the long term. Mileage or repurchase coupon could be good examples of this kind linking service from the short term convenience toward the long-term one to strengthen the role of trust even in the convenience.

Responsiveness shows an impact directly on customer loyalty, but also affects loyalty through trust, implying that loyalty is partially mediated by trust. Like convenience factor, Lazada should make more efforts for the customer to get more trust on the responsiveness leading the customer loyalty. Ironically, among three factors of mediated factors, assurance has the strongest influence on trust, implying that the effort of Lazada in assurance has the most significant effect in generating trust. The effort of Lazada in offering COD (cash on delivery) payment, return, and refund policy, as well as in certifying the products, has had a remarkable impact to appeal trust from customers. Accordingly, assurance could be considered as a strategic instrument to get more and more new customer participation, as well as a way of maintaining the loyalty from existing customers, especially with more emphasis on the long-term.

This paper found that without the strong role of e-trust, B2C intermediary such as Lazada could get successful operations in developing countries such as Vietnam because of its convenience factors. However, in order to achieve sustainable performance, the B2C intermediaries should make more proactive efforts to promote e-trust, because it will complement all the bottlenecks from the cultural or psychological barriers in the market. It is really true that even with their serious risk-avert attitude, most Vietnamese web-shoppers enjoy value creation based on relational support by an intermediary.

Choi and Jin found that this kind of on-going trust is very important in Chinese web marketing [31]. It implies that our findings emphasize not only the role of intermediary in the initial e-trust coming from the convenience, but also the sustainable performance of ongoing e-trust, especially in developing countries such as China and Vietnam. Therefore, the market-oriented policies of the developing government policies will certainly promote the acceleration of the online shopping innovation of the national economy. China showed that this kind of strong transformation, through intermediaries such as Alibaba, and now Vietnam, supported by Alibaba, the new owner of Lazada, will result in a new, successful story of a market-friendly, sustainable revolution in the web marketing through strong e-trust promotion activities [30,31].

5. Conclusions

In this paper, we proved that trust plays an important role in mediating the influence of usefulness, security, responsiveness, and assurance on customer loyalty, fully or partially, implying that the improvement of e-service quality should lead to an increase in credibility and customers' trust first. The analysis showed that customer loyalty is strongly linked to the consumers' trust, which means that in order to create sustainability for an e-commerce firm as an intermediary, it is crucial to consider trust as a vital element. As shown in the Figure 3, of reasons for not using e-commerce among Vietnamese people, product quality and security concern are the highest uncertainties perceived by Vietnamese e-commerce users. In order to overcome this kind of cultural background of risk-averse attitudes in Vietnam, online platform companies should make more effort, not only for the web service quality in the short run, but also more for the trust building in the long run. Based on above discussion, some suggestions could be proposed.

First, Lazada should continue improving their service quality and making long-term development strategy in terms of three factors: usefulness, security, and assurance. Because improving security along with enhancing level of trust is the only way to reach customer loyalty, Lazada should make more efforts to enhance its security.

Second, Lazada should pay more attention to the convenience factor. By fostering a delivery service and keeping a reasonably competitive price, etc., it should make the impact of convenience maintain even in the long term. It should be noticed that the competitive price must be equal to maintain the good quality of products.

Third, Lazada should take assurance as the most effective tactic at generating trust, because it shows the strongest impact on trust. Recently, Lazada has invested a large amount of money in marketing for the purpose of raising awareness among Vietnamese consumers as well as utilizing the efficiency of word-of-mouth or economy of sharing. It could encourage the Vietnamese consumer to be less reluctant towards online shopping and embrace the easy and effective online shopping environment.

Gupta, Su, and Walter pointed out there is a difference in channel risk perceptions of consumers between online and offline channels, and in general, a negative association with channel switching tendency, yet the magnitude of the impact was small, implying that risk perceptions may play a minor role in the adoption of online shopping [42]. Su (2007) also emphasized that an increase in objective product information may lead to a dramatic increase in expected value choices and a corresponding decrease in brand-seeking and price-aversion choices [43]. This is true in our research as well. Even with convenience factors such as more reliable information certified by the e-tailer, the perceived risks could be reduced at least in the initial stage. It might be true that most developing countries may have a serious bottleneck in the e-business due to this missing link of trust in online shopping, and thus the government should promote a more reliable environment with strong regulations on the fraud and misleading behaviors, as well as diverse incentives for e-platform service providers such as Lazada to create and maintain trust more effectively. As shown in this paper, most developing countries were not aware of the e-trust, and thus it is very challenging tasks for these countries to take off toward the everyday online shopping effectively. In order to overcome these challenges, the role of e-platform service providers such as Lazada should be much more emphasized to create values based on their online network management.

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Article

Sustainable Energy Consumption in Northeast Asia: A Case from China's Fuel Oil Futures Market

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Abstract: The sustainable energy consumption in northeast Asia has a huge impact on regional stability and economic growth, which gives price volatility research in the energy market both theoretical value and practical application. We select China's fuel oil futures market as a research subject and use recurrence interval analysis to investigate the price volatility pattern in different thresholds. We utilize the stretched exponential function to fit the pattern of the recurrence intervals of price fluctuations and find that the probability density functions of the recurrence intervals in different thresholds do not show the scaling behavior. Then the conditional probability density function and detrended fluctuation analysis prove that there is short-term and long-term correlation. Last, we use a hazard function to introduce the recurrence intervals into the (value at risk) VaR calculation and establish a functional relationship between the mean recurrence interval and the threshold. Following this result, we also shed light on policy discussion for hedgers and government.

Keywords: sustainable development; recurrence interval; probability distribution; memory effect; risk estimation

1. Introduction

With regard to sustainable development in northeast Asia, the utilization and depletion of energy is always a problem for each country [1]. With the rapid development of emerging nations such as China, energy will increasingly become an important factor affecting regional stability and economic growth. Among many energy sources, fuel oil occupies a prominent position and maintains a country's economic lifeline and livelihood development [2]. However, for a long time, the fuel market in a country like China has mainly been built by agreement pricing, which lacks a buffer mechanism to maintain the endogenous stability of this system [3,4]. The long-term contract pricing of these agreements will make China and entire northeast Asia suffer losses in the international fuel price fluctuations. In 2004, China followed the example of West Texas Intermediate (WTI) and Brent and set up its energy futures market [5], hoping to stabilize the market price and futures expectation of domestic primary fuel consumers and to achieve a more balanced and sustainable development.

Fuel oil is a downstream product of oil and China is a significant fuel oil importing country in the world as well as the largest consumer of fuel oil in northeast Asia considering its Gross Domestic Product (GDP) scale. Although China's enormous oil demand has had a significant impact on the international oil market supply and demand pattern, its role in the global oil price has been negligible owing to lack of impactful oil futures [6]. Therefore, in case of sharp fluctuations in international oil prices, China needs an oil futures market to reflect the supply and demand to determine the "Chinese oil price" in line with China's interests and thus ensure oil security and economic stability. Hence, research of the fuel oil futures market is of necessity, not only allowing regulators to efficiently judge and understand the market capitalization in time and adopt reasonable and adequate control measures but also allowing market participants to make use of the two primary functions—price discovery and hedging—of fuel oil futures for decision-making.

To sum up, the study of the fuel oil futures market has theoretical value and practical implications. From a macro perspective, the participants' behaviors directly determine a resource allocation of the fuel oil futures and spot markets. If the market fails, then the resources mismatch and efficiency decline in the futures and spot markets will directly affect the normal operation of the macroeconomy. From a micro perspective, the normal process of the futures market directly affects the hedging performance of market participants. Though the fuel oil futures market also has some speculative behaviors, its primary function is to preserve value as a financial hedging instrument. If the futures market fails, it will make enterprises or investors suffer massive losses, and then the price volatility will have become a source of economic and financial fluctuations in China. This paper, by using recurrence interval analysis (RIA), will investigate the price volatility pattern of fuel oil futures and estimate the risk.

The remaining sections of this paper are arranged as follows: Section 2 reviews current research. Section 3 briefly describes the approach and gives the basic statistics of the data set. Section 4 conducts empirical research, including probability distribution function, scaling properties, memory effect and risk estimation. Section 5 discusses implications of the study and Section 6 concludes.

2. Literature Review

2.1. Energy Futures Market

For studies about energy futures market, researchers mainly focus on the price discovery mechanism between the prices of futures and spot [7–9]. For example, Bekiros and Disks [10] used a cointegration method to confirm that there may be an asymmetric GARCH (Generalized Autoregressive Conditional Heteroscedasticity) effect between WTI futures and spot. If asymmetric effects are taken into account, the lead-lag relationship between futures and spot markets will change over time. Chen et al. [11] investigated the impact of structural breaks on the relationship between WTI futures and New York Mercantile Exchange (NYMEX) crude oil spot by a cointegration test. The results show that the lead–lag relationship between WTI futures and NYMEX crude oil spot will change with time across both regimes. The situation in China was complicated. China's earliest energy futures appeared in 1993 when the Shanghai Petroleum Exchange launched an oil futures contract, followed by several futures exchanges listing oil futures contracts. However, as a result of the change in national policies, the initially implemented "two-track system" of crude oil and refined oil price was halted and the mechanism in which price was formed automatically by market supply and demand no longer existed. Oil futures with only one-year life were forced to stop trading. For an extended period, the domestic oil futures market was kept under vacuum. Ten years later, on 25 August 2004, another energy futures—fuel oil futures—was listed on the Shanghai Futures Exchange, and domestic scholars have begun to study the issues regarding the Chinese oil market. For example, Li et al. [12] examined the relationship between fuel oil spot, fuel oil futures, and energy stock market in China and pointed out that the correlations are weaker than those in U.S. market due to China's oil price regulation and control policy. Ji and Fan [13] found that China's oil markets were related to domestic and international commodity markets. Additionally, the impact of China's fuel oil futures market on other local commodity markets was high (small) when the oil price was high (low).

Since the early emergence of the energy futures market outside China, a lot of research has been done on the function of price discovery. China's research in this area mainly focuses on the impact of price discovery on the domestic and international futures markets. Also, the current study on oil futures still put different oil markets or related petroleum and related industries together. In the context of financialization in the international oil market, the capital market plays an increasingly important role in the oil futures market with an increasingly significant influence on the oil futures market, especially on the price discovery function of the oil futures market. Hence, the research in this area should be strengthened.

2.2. Recurrence Interval Analysis

Recurrence interval is a measurement to estimate extreme events—events that do not occur frequently but do so with a high magnitude. In the natural environment, extreme events include earthquakes, tsunamis, hurricanes, floods, etc, while in the social environment extreme events include violent conflicts, acts of terrorism, industrial accidents, financial and commodity market crashes, etc. In the long run, extreme events are presumed to be spontaneous. In other words, they are mutually uncorrelated. However, studies have shown that the occurrence of extreme events is not independent, but instead, they congregate together, occurring in relatively short periods of time [14–16]. Therefore, recurrence interval can be applied to estimate the magnitude of price volatility of China's fuel oil futures here.

Recurrence interval analysis (RIA) is a time series method for volatility forecast with high-frequency data, which is widely used in many areas [17–19] including stock and exchange rate markets [20–24]. RIA is frequently applied to risk analysis, assuming that the probability of future volatility is constant and independent of the volatility of the past. Also, the problem of insufficient data can also be solved by finding the scaling behavior of different scale events [25]. At present, the recurrence interval between volatility in the energy market has been widely studied [26–29]. For example, Xie et al. [30] used RIA to investigate four NYMEX energy futures and showed that the long-term correlations have resulted in clusters of recurrence intervals. Suo et al. [31] compared the CSI 300 spot and futures market with RIA and found that futures market has a lower (higher) risk than that in the spot market during volatile (regular) periods. However, to the best of our knowledge, there are insufficient studies on price volatility of China's fuel oil futures by RIA with current high-frequency data.

Therefore, our research has made the following contributions. First, we investigate the price volatility of China's fuel oil futures from a new perspective by using RIA. So far, this is one of the few articles on China's fuel oil futures with RIA. Second, different from previous research using the daily data of China fuel oil futures, we use one-minute high-frequency data that can reveal more price information, providing a new perspective for the study of China's energy derivatives market in the view of high-frequency trading. Third, we focused on the price volatility of fuel oil futures instead of the relationship between fuel oil futures market and other markets.

3. Materials and Methods

We here select fuel oil futures as research subject which was listed on Shanghai Futures Exchange, and Table 1 shows the contract specifications. The data here is obtained from Tongdaxin Database and the sample period covers from 1 January 2015 to 30 December 2016. We have collected 70,635 price observations after removing the days without trading. The return of time series is measured by the logarithmic difference of the price:

$$r(t) = \ln p(t + \Delta t) - \ln p(t), \tag{1}$$

where $\Delta t = 1$ due to the data being 1-min frequent and $p(t)$ is the closing price of the tth time. By taking logarithm difference, the data magnitude is reduced for subsequent calculations. The logarithmic returns of fuel oil futures are shown in Figure 1 and, the statistics is summarized in Table 2.

Table 1. Contract specifications of the fuel oil futures.

Trade Category	Fuel Oil
Trade unit	50 ton
Price quotation unit	yuan per ton
Tick size	1 yuan per ton
Limit up/down	±6% of settlement price on the previous trading day
Contract Months	Monthly (excluding the spring festival)
Trading hours	9:00 am–11:30 am, 1:30 pm–3:00 pm
Last trading day	The last trading day of the month before the delivery month
Delivery day	Five consecutive business days after the last trading day
Delivery grade	180CST fuel oil or other fuel oil of better quality than this standard
Delivery location	The locations designated by exchange
Margin requirement	8% of the contract value
Settlement method	physical settlement
Transaction code	FU
Exchange	Shanghai Futures Exchange

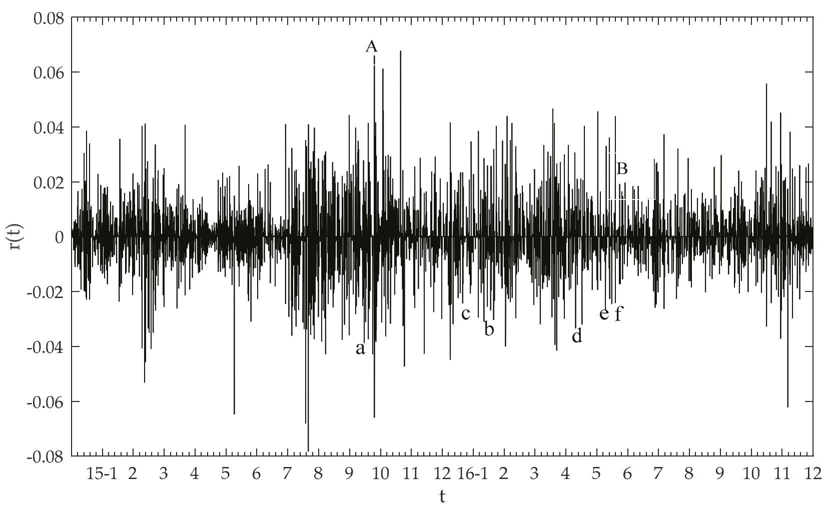

Figure 1. Logarithmic returns of fuel oil futures.

Table 2. Statistics of the logarithmic returns of fuel oil futures.

Average	Maximum	Minimum	Standard Deviations	Skewness	Kurtosis	Nobs
5.2675×10^{-6}	0.0677	−0.0783	0.0028	0.0850	131.7101	70634

From Figure 1, we can see that the fluctuations in the different periods have different magnitudes. For example, a massive volatility like A has a much larger scale than that of a small fluctuation like B. Furthermore, volatilities with similar level tend to cluster with each other. It can be seen in Figure 1 that a large fluctuation tends to follow significant volatility while a small one tends to follow a small one, which indicates the long-term memory effect [32,33]. Also, the X-axis in Figure 1 is from 5 January 2015 to 30 December 2016, hence the more significant fluctuations are approximately concentrated in the second half of 2015 and the first half of 2016. Such fluctuation periods may be related to the events occurring in the international oil market during that period, like Russia bombing Syria, four oil-producing nations reaching cut consensus, the lifting of Iran's oil ban, the Canadian wildfires leading to disruption of oil sands, Nigeria cutting off supply, and the British Brexit vote (see a–f in Figure 1, respectively). We can also find that a volatile period when large volatilities cluster is accompanied with short and dense recurrence intervals. In contrast, the recurrence intervals during the less volatile period are long, few and far between. In Figure 2, we magnify two sections in Figure 1 to represent the period of large and small volatilities, respectively, to present these characteristics. Figure 2a shows the volatility from June 2015 to October 2015, and Figure 2b shows the fluctuations from June 2016 to October 2016. We can see that for a given $r(t)$, assuming 0.02, the properties of recurrence are in accordance with our discussion above.

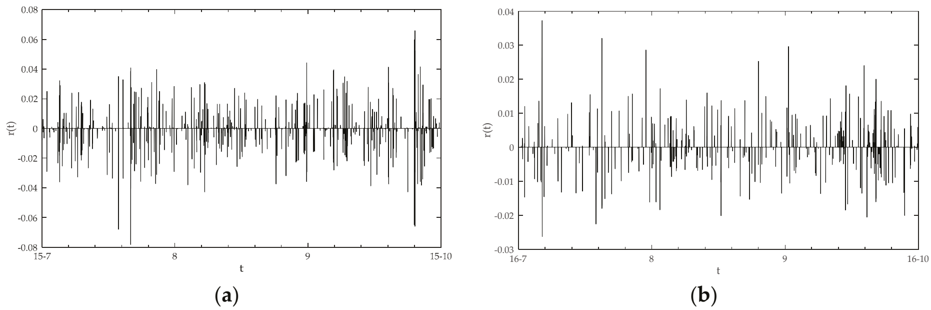

Figure 2. Logarithmic returns of fuel oil futures in different periods. (**a**) Large volatilities; (**b**) small volatilities.

In Table 2, the statistics of the logarithmic returns are not normally distributed but the skewness is near symmetrical, and the kurtosis is leptokurtic, which is also consistent with the findings in most studies on the probability distribution of returns in stock and futures markets [34–37]. Therefore, by using RIA, we hope to promote the risk estimation in the energy futures market by describing the volatility of the fuel oil futures and estimating the time intervals between fluctuations, e.g., what is the probability of the next significant volatility after a larger one?

Considering the recurrence interval τ at the threshold q, the mathematical expression of recurrence interval could be derived as follows:

$$\tau(t) = \min\{t - t' : R(t)\langle q,\ t\rangle t', q < 0\}. \tag{2}$$

Most studies [38–41] have pointed that stretched exponential distribution can better fit the recurrence intervals of fluctuations:

$$P_q(\tau) = \alpha\overline{\tau}\mathrm{e}^{-(\beta\overline{\tau}\tau)^{\gamma}}. \tag{3}$$

Equation (3) means that $P_q(\tau)$ is the probability distribution of recurrence interval τ at the threshold q, where $\overline{\tau}$ is the average recurrence interval and will change when threshold q is different, and α, β, γ are the parameters.

4. Results

4.1. Probability Density Function

Before applying RIA, we need to normalize the time series $r(t)$ by dividing the standard deviation as follows:

$$R(t) = \frac{r(t)}{\left[Er(t)^2 - E^2 r(t)\right]^{1/2}}, \tag{4}$$

where $\left[Er(t)^2 - E^2 r(t)\right]^{1/2}$ is the standard deviation of $r(t)$. For a threshold q, we can get the coresponding set of recurrence interval τ, then calculate the occurance probability of each τ. In this paper, the threshold q is set to a negative value ($q < 0$) because a slump tends to attract more interest to the market participants than a surge. In Figure 3, we draw the empirical (color symbols) and theoritical values (color curves) of the probability distribution function (PDF) $P_q(\tau)$ of recurrence intervals between returns at different threshold q. In addition, Table 3 shows the parameters for theoritical PDFs of each threshold q.

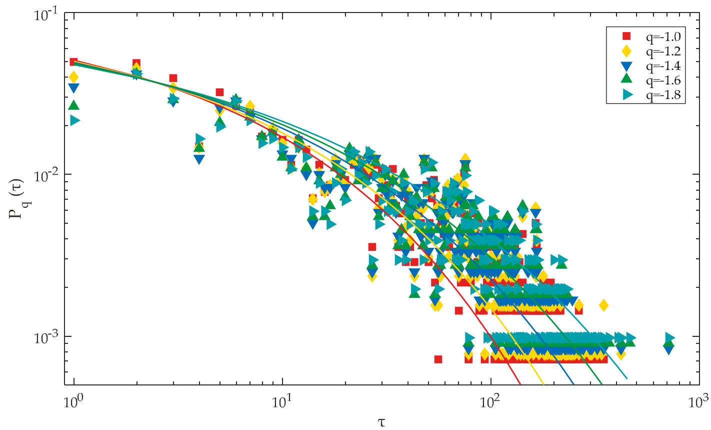

Figure 3. Empirical and theoretical probability distribution of recurrence intervals with different thresholds of fuel oil futures.

Table 3. Estimates of the coefficients of stretched exponential functions.

q	ff	fi	fl
−1.0	2.004×10^{-3}	7.994×10^{-3}	0.415
−1.2	1.841×10^{-3}	7.343×10^{-3}	0.390
−1.4	1.718×10^{-3}	6.851×10^{-3}	0.362
−1.6	1.583×10^{-3}	6.316×10^{-3}	0.339
−1.8	1.469×10^{-3}	5.858×10^{-3}	0.318

We can see from Figure 3 that when $|q|$ rises, in the whole period, for the same probablility, larger volatilities tend to have larger interval, while for the same interval, larger volatilities will occur more likely than small volatilities, which also means that for large volatilities the time interval between two consecutive events has a higher probability to increase than decline. Combining the observation from Table 3 and Figure 3, it is found that all the curves are in similar shape which leads us to investigate the scaling behavior between these PDFs.

With this question, after observing the behavior of PDFs in Figure 3 and how they may depend on the threshold q, we can see that for different q, the corresponding PDF is not the same and cannot be described by a single distribution as for irrelevant data. To understand the q dependence, the method in Yamasaki et al. [42] is introduced:

$$f_q(\tau/\overline{\tau}) = P_q(\tau)\overline{\tau}, \tag{5}$$

where $P_q(\tau)\overline{\tau}$ is scaled PDF and $\tau/\overline{\tau}$ is scaled recurrence interval. With an increasing threshold $|q|$, $\overline{\tau}$ will change in the same direction, i.e., $(d\overline{\tau})/(d|q|) > 0$, indicating that as the volatility increases, the average length of recurrence interval increases, too. If there exists scaling behavior, $f_q(\tau/\overline{\tau})$ will be independent of the threshold q. Namely, the discrepancy between PDFs of recurrence invervals at different threshold q can be eliminated by calculating $P_q(\tau)\overline{\tau}$. Additionally, the scaling behavior can be demonstrated if $f_q(\tau/\overline{\tau})$ converges to a single curve $f(\tau/\overline{\tau})$, which is given by: $f_q(x) = f(x)$, $q = 1.0, 1.2, 1.4, 1.6, 1.8$. Figure 4 displays the scatter diagram with x-ray as $\tau/\overline{\tau}$ and y-ray as $P_q(\tau)\overline{\tau}$. We can see clearly that $P_q(\tau)\overline{\tau}$ do not converge into one curve when threshold q is different. This suggests that the scaling behavior does not exist here, that is, when data is insufficient, we are unable to derive the behavior of large fluctuations from the behavior of small ones.

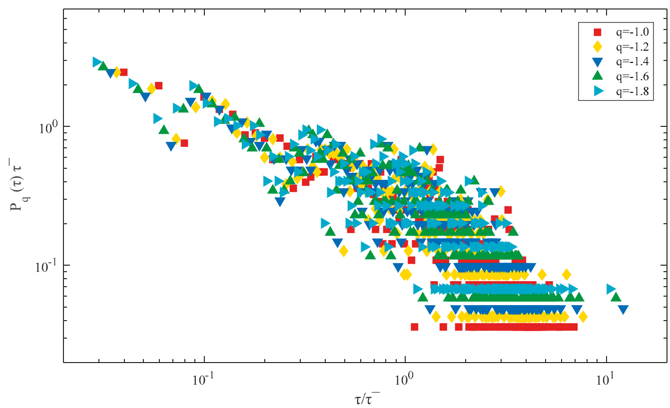

Figure 4. Scaled probability distributions of recurrence intervals with different thresholds of fuel oil futures.

4.2. Memory Effect

In this part, we want to know if there exists a memory effect between recurrence intervals. Short-term memory refers the correlation between two consecutive recurrence intervals, and long-term memory means current volatility was affected by fluctuations not only in the recent past but also from a long time ago, which would cause volatility clusters.

4.2.1. Short-Term Correlation

For recurrence intervals, the short-term correlation will affect the length of one interval after another interval. In this part, we will calculate the conditional probability density function $P_q(\tau|\tau_0)$ to study the short-term correlation within the recurrence intervals [42]. $P_q(\tau|\tau_0)$ refers to the probability of a recurrence interval τ to occur immediately following the last recurrence interval τ_0. When short-term correlation does not exist, $P_q(\tau|\tau_0)$ will be independent of τ_0. However, a certain value τ_0 may result in insufficient data, to avoid that, we have selected a range for τ_0 to calculate $P_q(\tau|\tau_0)$ rather than a fixed value τ_0.

Each threshold q corresponds to a series of recurrence intervals and the set of all the recurrence intervals at threshold q is T. We then divide T into four subsets without overlapping, $T = T_1 \cup T_2 \cup T_3 \cup T_4$, where $T_m \cap T_n = \phi, m \neq n$. In this dividing procedure, the whole recurrence intervals in T are sorted in an ascending order and then T is turned into subsets with the same size. Hence, the 1/4 smallest recurrence intervals are selected to the first subset T_1 and largest quarter goes to the last subset T_4. Therefore, the conditional probability density function is derived as $P_q(\tau|T_m) = P_q(\tau|\tau_0 \in T_m)$, and if short-term correlation does not exist, it could be found that $P_q(\tau|T_m) = P_q(\tau|T_n), m \neq n$.

Figure 5 shows that $P_q(\tau|\tau_0)\overline{\tau}$ is the function of $\tau/\overline{\tau}$ for τ_0. Filled symbols indicate $\tau_0 \in T_1$ and open symbols mean $\tau_0 \in T_4$. It is obvious that $P_q(\tau|T_1)$ from the smallest subset T_1 does not equal to $P_q(\tau|T_4)$ from the largest subset T_4: $P_q(\tau|T_1) \neq P_q(\tau|T_4)$. On the left side of Figure 5, $P_q(\tau|\tau_0 \in T_1)$ is bigger than $P_q(\tau|\tau_0 \in T_4)$ for small $\tau/\overline{\tau}$, while on the right side, $P_q(\tau|\tau_0 \in T_1)$ is smaller than $P_q(\tau|\tau_0 \in T_4)$ when $\tau/\overline{\tau}$ increases. This suggests that short τ is more likely to follow short τ_0, and long τ tends to follow long τ_0, indicating that short-term correlations do exist in the recurrence intervals, i.e., the probability of a short (long) interval existing after a small (long) one is higher than the probability of a short (long) interval after a long (short) one for the volatility with a certain magnitude.

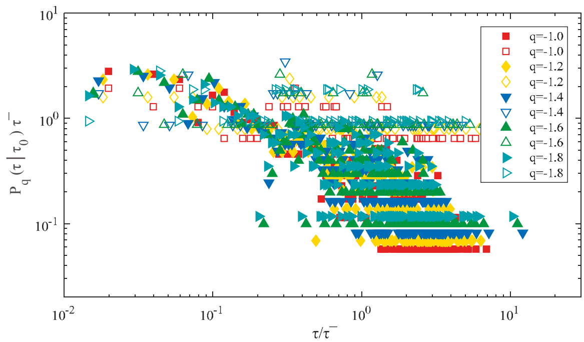

Figure 5. Conditional probability density functions $P_q(\tau|\tau_0)$ with $\tau_0 \in T_1$ (filled symbols) and $\tau_0 \in T_4$ (open symbols) for fuel oil futures.

4.2.2. Long-Term Correlation

The volatility clusters in Figure 1 indicate that long-term correlation exists in the time series. To verify this we employ detrended fluctuation analysis (DFA) method, and the results are shown in Figure 6. DFA was invented by Peng [43] for determining the statistical self-affinity of a signal. In addition, DFA has become one robust method for analyzing time series that appear to be long-memory processes [44–46]. DFA will compute the root-mean-square deviation $F(s)$ from the trend, where s is the length of time windows. After repeatedly calculating the $F(s)$ for a range of different s, a log–log figure of $F(s)$ against s is constructed in accord to the form $F(s) \sim s^H$. H is the Hurst exponent to determine whether there is long-term correlation in the time series. H greater than 0.5 suggests that long-term correlations do exist in the time series while H equals to 0.5 means the time sequence is un-correlated. The results are depicted in Figure 6 and the parameters are in Table 4. As can be seen, each line has a Hurst exponent more than 0.5, which indicates the long-term correlation within the recurrence intervals. This is consistent with previous studies on the recurrence interval and demonstrates the existence of a long-term memory on the recurrence interval in fuel oil futures [47,48], indicating that the fuel oil futures market in China is an inefficient market and the market shows strong trend behavior. This means that in one cycle, the former price volatility and historical information will affect the price fluctuations in the future.

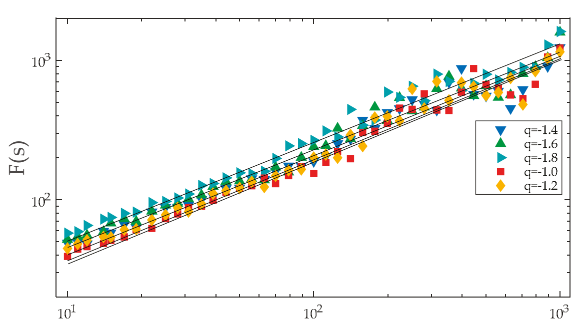

Figure 6. Detrended fluctuation function $F(s)$ of the recurrence intervals.

Table 4. Estimates of exponent H.

q	Exponent H
−1.0	0.71526
−1.2	0.70263
−1.4	0.68133
−1.6	0.68407
−1.8	0.69137

4.3. Risk Estimation

For a specific q, we want to know the probability of an interval after another interval. The hazard probability function $W_q(\Delta t|t)$ is used here to estimate risk of RIA. Assuming that the last big fluctuations greater than $|q|$ have passed t units of time, then what is the chance that the next large fluctuations greater than $|q|$ will happen within Δt units of time? Based on this, the hazard probability can be written as:

$$W_q(\Delta t|t) = \frac{\int_t^{t+\Delta t} P_q(\tau)d\tau}{\int_t^{\infty} P_q(\tau)d\tau}. \tag{6}$$

Equation (6) calculates the theoretical value of hazard probability. As we know, each q has a corresponding stretched exponential function $P_q(\tau)$ and the value of parameters can be found in Table 3. Furthermore, in order to compare the theoretical and empirical values of $W_q(\Delta t|t)$, we shall rewrite $W_q(\Delta t|t)$ as:

$$W_q(\Delta t|t) = \frac{count\big(t < \tau_q \leq t + \Delta t\big)}{count\big(\tau_q > t\big)}. \tag{7}$$

For each threshold q, "$count\big(\tau_q > t\big)$" counts the number of recurrence intervals greater than t units of time and "$count\big(t < \tau_q \leq t + \Delta t\big)$" is the number of recurrence intervals between t and $t + \Delta t$ units of time.

The calculation results of Equations (6) and (7) are shown in Figure 7, represented by color symbols and curves, respectively. In Figure 7, it can be observed that when t is relatively small, the curve is above the scatter symbols, which means that the theoretical value will overestimate the risk in the short term, while with the increase of t the difference between the theoretical and empirical value will gradually decrease. In addition, $W_q(\Delta t = 1|t)$ decreases when t increases, indicating that the longer the time interval between the two volatilities, the less likely the next fluctuation will happen instantly, which confirms that long-term correlations and clustering behavior exist within the recurrence intervals between volatilities. Additionally, we can calculate the recurrence probability of an extreme event for each threshold q.

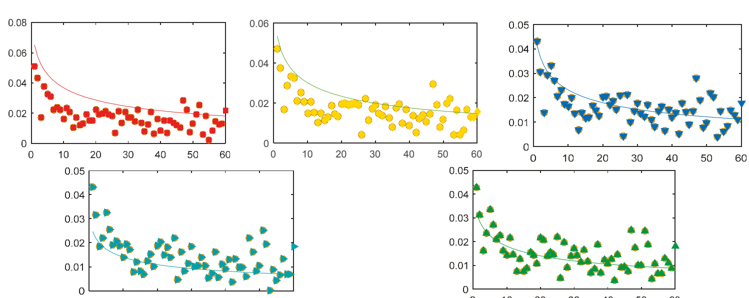

Figure 7. Theoretical (curves) and empirical (color symbols) value of $W_q(\Delta t = 1|t)$ (x-rays are t (unit: 1 min), y-rays are values of $W_q(\Delta t = 1|t)$ for $q = -1.0, q = -1.2$, $q = -1.4$, $q = -1.6, q = -1.8$ from left to right, top to bottom).

We here utilize value at risk (VaR) to estimate the risk. To construct a functional relationship between recurrence interval and VaR, we first define the loss probability at volatility level q:

$$\int_{-\infty}^{q} P(R)dR = P^*, \tag{8}$$

where P^* defines the loss probability, $R(t)$ is the normalized time series given by Equation (4) and $P(R)$ is the PDF of $R(t)$. For a given threshold q, the mean recurrence interval is the average value of total intervals: $\overline{\tau}_q = \frac{1}{N_q}\sum_{i=1}^{\tau_q} \tau_{q,i}$, where τ_q is the recurrence interval and N_q is the number of τ_q. Hence we can derive that $\sum_{i=1}^{\tau_q} \tau_{q,i}$ is approximately equal to the total number of returns and $N_q + 1$ is the number of returns below threshold q. Then we can construct a relationship between mean recurrence interval and VaR:

$$1/\overline{\tau}_q = \int_{-\infty}^{q} P(R)dR = \frac{number\ of\ R(t)\ \text{below}\ q}{total\ number\ of\ R(t)}, \tag{9}$$

where $1/\overline{\tau}_q$ is the function of threshold q as shown in Figure 8. The loss probability in the Y-axis corresponds to the fluctuation degree in X-axis, for example, if the market participants hope to control the risk level of loss at two percent, the fluctuation degree—i.e., the threshold—q meets $1/\overline{\tau}_q = 2\%$ is what they should be aware of. We can also see from Figure 8 that the mean recurrence interval increases with an increasing $|q|$, suggesting that the larger the fluctuation, the greater the interval.

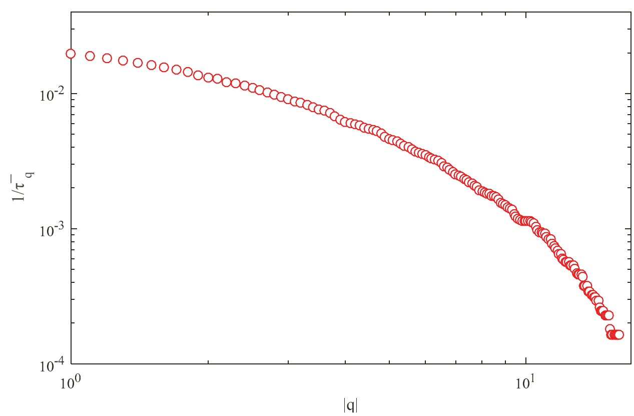

Figure 8. The reciprocal of mean recurrence interval $1/\overline{\tau}_q$ as a function of absolute threshold q ($q = -16 : -1$).

5. Discussion

From the above analysis, it can be seen that there is long-term memory, abnormality, and autocorrelation in the recurrence intervals of China's fuel oil futures market, which shows that this market is mostly a complicated nonlinear system. Therefore, efficient market hypothesis adopting "linear and normal" as the hypothetical premise can no longer efficiently describe and analyze the price volatility of the futures markets [49–51]. This conclusion makes it necessary to alter the linear traditional research paradigm in the futures research when analyzing the energy futures market and introduce nonlinear theory and methods. It also has significant theoretical and practical significance by changing from the linear analysis, equilibrium analysis, and static analysis to nonlinear analysis, evolutionary analysis, and dynamics analysis. Also, long-term memory indicates that the impact of price volatility of the energy futures market does not disappear immediately. Instead, it can have long-term effects. Therefore, based on sufficient historical information and within a specific long-term memory length, it is possible to measure and predict the price volatility of the energy futures market.

Probability density function analysis shows that the occurrence probability of significant and minor fluctuations and the degree of risk are different. When new information appears, some market participants do not respond to the information in time but try to verify the authenticity of the information and identify the impact of the information by analyzing the relevant information. For example, when a new policy is promulgated, the participants cannot understand the purpose of the policymaker in a short period and accordingly decide after some trend is identified after a period. Such information understanding lag means that the information cannot be digested immediately by the participants; on the contrary, it will have some degree of cumulative effect. Participants may react suddenly when some new information arrives continually, or when policymakers' intentions are apparent, which will result in sudden and drastic market volatility, resulting in a flock effect and herd behavior.

At present, China's fuel oil futures market has been established for more than a decade. As a big consuming country, it is necessary to establish an oil pricing mechanism with an international influence to better predict the price and risk. Specifically, the authority can improve the futures market laws and regulations, increase the futures trading volume, continuously develop new varieties of futures, and strengthen the domestic oil market. Furthermore, China's oil futures market should be integrated into the international oil market, accelerating the pace of oil price adjustment, to reflect the real-time domestic oil price.

6. Conclusions

The paper utilized RIA to investigate the properties of recurrence intervals of price fluctuations for different thresholds and to understand the behaviors of large volatilities of fuel oil futures in China with the mass data collected at one-minute high-frequency.

First, we used the stretched exponential function to fit the probability density distribution of recurrence intervals at different thresholds and found that the PDFs do not have scaling behavior at different thresholds. Subsequently, the conditional PDF and DFA respectively confirmed that there is a short-term and long-term relationship between the recurrence intervals, which indicates that the intervals are not only affected by the near-term, but also by the long-term effect. Finally, RIA was used to evaluate the risk for fuel oil futures, which provides a relatively accurate risk estimation and constructs a relationship between loss possibility and volatility scale.

For those hedgers who want to achieve sustainable development, attention should be paid in the short term to significant price fluctuations in the energy futures market, and in the long run, they should make judgments based on specific market conditions to more effectively prevent and mitigate the risk of price volatility. Also, because the energy futures market in China is relatively short and not yet mature compared to Western countries, we can consider cultivating domestic institutional investors and lowering transaction costs. At the same time, we could speed up the opening up of the market to attract foreign institutional investors and mitigate the risks caused by the fluctuations through the connection with the international energy market. The government should improve energy futures market construction and promote risk control to enhance the global influence of China's energy futures market. Through strengthening the pricing power of energy pricing, China could contribute to the sustainable development in China and northeast Asia in the future.

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Key Drivers for Cooperation toward Sustainable Development and the Management of CO_2 Emissions: Comparative Analysis of Six Northeast Asian Countries

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Abstract: This study analyzes the key drivers of the relationship between economic growth and carbon emissions in six Northeast Asian countries (China, Japan, Republic of Korea, Democratic People's Republic of Korea, Mongolia, and Russia) from 1991 to 2015. We apply a decomposition analysis approach using Logarithmic Mean Divisia Index to identify the main contributing factors toward CO_2 emission changes. To discuss the decomposition results in more in detail, we explain the energy portfolio change in each country to understand the energy and resource utilization strategy. From the results, we find that the key driving factors of CO_2 emissions change and energy portfolio trends are different among Northeast Asian countries, driven by economic growth in China and Korea, reduced by energy efficiency improvements in Russia and the DPRK, while being relatively benign in Japan and Mongolia due to a combination of these factors. This result implies that we can better understand the regional cooperation policy for improving each driving factor to achieve sustainable development and management of CO_2 emissions considering the characteristics of each country.

Keywords: CO_2 emissions; decomposition analysis; energy portfolio; Northeast Asian countries

1. Introduction

Under the auspices of the United Nations Framework Convention on Climate Change (UNFCCC), nations around the world work together to address climate change. The UNFCC brings together the 197 ratifying nations of the convention, who jointly develop 'protocols' or 'agreements' in order to advance climate change mitigation objectives. One of the goals of the UNFCCC is to stabilize greenhouse gas (GHG) concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system [1]. Although the first major step of the UNFCCC was to introduce the Kyoto Protocol, intended to reduce GHG emissions, particularly in developed nations, the most recent agreement, known as the Paris Agreement, specifically identifies a target of keeping climate change-induced temperature rises below 2 degrees Celsius compared to pre-industrial era levels. Beyond this goal is an ambitious effort to limit these temperatures to just a 1.5 degree increase [2].

The development of nationally-determined contributions (NDC), including individual GHG reduction targets, forms part of the Paris Agreement, however, only 170 of the 197 UNFCCC ratifying nations have subsequently ratified the Paris Agreement, and one notable exception is the United States of America (USA). The USA is responsible for some 15% of global carbon dioxide (CO_2) emissions from fossil fuel combustion and industrial processes [3], making the cooperation of the remaining nations, and particularly Northeast Asia, (which is responsible for over 40% of global CO_2 emissions), even more important. China, the main contributor to Northeast Asia's CO_2 emissions, has been particularly vociferous about the need for all ratifying parties to work together to implement the Paris Agreement [4].

This study undertakes an evaluation of the six Northeast Asian nations of China, Japan, the Republic of Korea (Korea), the Democratic People's Republic of Korea (DPRK), Mongolia, and Russia. The evaluation uses decomposition analysis of CO_2 emission intensity and fossil fuel share of the energy mix, energy efficiency, economic development, and population to determine the key contributing factors toward CO_2 emission changes in each nation assessed. Further, based on a comparative analysis of these factors, the potential for inter-regional cooperation on carbon reduction and sustainable development is assessed, alongside the necessary enablers and barriers to cooperation.

While cooperation is considered necessary to enhance emission reduction outcomes under the UNFCCC, each nation also has individual policy goals (separate to their NDCs), often linked to national energy strategies, and unique national attributes. For example, China, with the largest economy in Asia, is working toward 'Made-in-China 2025' which calls for an enhancement of industrial capability through innovation-driven manufacturing, quality improvements, optimizing industry, nurturing human talent and, importantly, green development [5]. In addition, China will implement a national carbon trading scheme by 2017, which is expected to lead to a market-oriented carbon emission allowance approach where a number of factors, including fossil fuel pricing, could have an influential impact on this scheme [6]. Similar to China, which has realized the importance of renewable energy generation [7], Japan is pressing toward an energy transition which shifts it away from heavy dependence on international fossil fuel imports, with an interim renewable energy target of 22–24% of electricity generation by 2030, and a broad liberalization of energy markets [8].

For Korea, also heavily dependent on fossil fuel imports, a 'low-carbon, green growth' plan was introduced in 2008, aiming to introduce additional renewable energy and increase nuclear-based generation to meet an ambitious GHG reduction target of 37% by 2030 [9]. Russia has a strategic plan in place which considers the economic, environmental, and social aspects of sustainable development, however, environmental aspects are not considered prominently and economic aspects, particularly sustainable economic growth is considered most important, at least until 2020 [10].

With regard to Mongolia, a heavy reliance on mineral and fuel exports, which make up approximately 40% of gross domestic product (GDP) has stagnated diversification, putting at risk sustainable, inclusive development [11]. An additional challenge for Mongolia is the low level of access to electricity in rural areas, approximately 51% in the year 2014 [12]. The issue of access to electricity is exacerbated in the DPRK, where it is estimated that approximately 41% of urban households and just 13% of rural households have access to electricity [10]. While limited information is available about the status or aims of sustainable development in the DPRK, the United Nations Development Program (UNDP) has a presence, with the goal of "restoring the quality of life of people to the highest level achieved before economic and humanitarian difficulties in the mid-1990s". The three main focus areas for improvement are: food security and rural development, socio-economic development, and environment and climate change [13].

The dual aim of this study is to clarify the key driving factors of CO_2 emissions and their change over time, and, from these results, to identify and discuss the potential for regional cooperation toward carbon mitigation, sustainable development, and green growth in Northeast Asia.

Section 2 outlines the methodology and underlying factors considered to clarify energy system trends over time in each of the assessed nations. Section 3 describes the data sources used in the analysis and outlines the trends identified for CO_2 emissions, carbon intensity, and renewable energy share, as well as the diversity of each nation's energy supply portfolio. Section 4 discusses these results and their applicability to inter-regional cooperation toward sustainable development and the management of CO_2 emissions, along with the enabling mechanisms for such cooperation. Section 5 summarizes the conclusions of this study.

2. Methods

This study applies the Kaya Identity as a decomposition analysis framework to clarify the key driving factors involved in CO_2 emission changes [14]. We use the following five indicators to decompose the CO_2 emissions changes: carbon intensity (CI), fossil fuel share in total primary energy supply (Share), energy efficiency (EE), economic development (Econ), and population at the country scale (Pop).

We define the CI indicator as the CO_2 emissions (ton-CO_2) per fossil fuel use (TJ) to provide the information about energy strategy of low carbon fossil fuel. The CI indicator increases if the high carbon fossil fuel consumption increases more quickly than the low carbon fossil fuels. Next, the SHARE indicator is defined as the fossil fuel use (TJ) divided by the total primary energy supply (TJ), which indicates the share of the fossil fuel use in total energy use. This indicator increases if the fossil fuel consumption increases more quickly than the renewable energy use.

The EE indicator is defined as total energy use (TJ) per unit of GDP. This indicator reflects the energy efficiency of economic activities. EE can be decreased by reducing the total energy consumption while keeping the GDP, or increasing GDP without total energy consumption growth. The ECON indicator is defined as GDP per population, which represents the country's economic development. Finally, the POP indicator is defined as the population and represents the scale of the country.

Here, we introduce a decomposition approach. The CO_2 emissions change (CO_2) is decomposed using fossil fuel use (Fossil), total primary energy use (TPES), GDP, and population, as shown in Equation (1):

$$\mathrm{CO_2} = \frac{\mathrm{CO_2}}{\mathrm{Fossil}} \times \frac{\mathrm{Fossil}}{\mathrm{TPES}} \times \frac{\mathrm{TPES}}{\mathrm{GDP}} \times \frac{\mathrm{GDP}}{\mathrm{POP}} \times \mathrm{POP} = \mathrm{CI} \times \mathrm{SHARE} \times \mathrm{EE} \times \mathrm{ECON} \times \mathrm{POP} \tag{1}$$

We consider the change in CO_2 emissions from year $t - 1$ (${CO_2}^{t-1}$) to year t (${CO_2}^{t}$). Using Equation (1), the growth ratio of the CO_2 emissions can be represented as follows:

$$\frac{{\mathrm{CO_2}}^{t}}{{\mathrm{CO_2}}^{t-1}} = \frac{\mathrm{CI}^{t}}{\mathrm{CI}^{t-1}} \times \frac{\mathrm{SHARE}^{t}}{\mathrm{SHARE}^{t-1}} \times \frac{\mathrm{EE}^{t}}{\mathrm{EE}^{t-1}} \times \frac{\mathrm{ECON}^{t}}{\mathrm{ECON}^{t-1}} \times \frac{\mathrm{POP}^{t}}{\mathrm{POP}^{t-1}} \tag{2}$$

We transform Equation (2) into a natural logarithmic function to obtain Equation (3):

$$\ln{\mathrm{CO_2}}^{t} - \ln{\mathrm{CO_2}}^{t-1} = \ln\left(\frac{\mathrm{CI}^{t}}{\mathrm{CI}^{t-1}}\right) + \ln\left(\frac{\mathrm{SHARE}^{t}}{\mathrm{SHARE}^{t-1}}\right) + \ln\left(\frac{\mathrm{EE}^{t}}{\mathrm{EE}^{t-1}}\right) + \ln\left(\frac{\mathrm{ECON}^{t}}{\mathrm{ECON}^{t-1}}\right) + \ln\left(\frac{\mathrm{POP}^{t}}{\mathrm{POP}^{t-1}}\right) \tag{3}$$

Multiplying both sides of Equation (3) by $\omega^{t} = \left({\mathrm{CO_2}}^{t} - {\mathrm{CO_2}}^{t-1}\right) / \left(\ln{\mathrm{CO_2}}^{t} - \ln{\mathrm{CO_2}}^{t-1}\right)$ yields Equation (4), as follows:

$${\mathrm{CO_2}}^{t} - {\mathrm{CO_2}}^{t-1} = {\mathrm{CO_2}}^{t,t-1} = \omega^{t}\ln\left(\frac{\mathrm{CI}^{t}}{\mathrm{CI}^{t-1}}\right) + \omega^{t}\ln\left(\frac{\mathrm{SHARE}^{t}}{\mathrm{SHARE}^{t-1}}\right) + \omega^{t}\ln\left(\frac{\mathrm{EE}^{t}}{\mathrm{EE}^{t-1}}\right) + \omega^{t}\ln\left(\frac{\mathrm{ECON}^{t}}{\mathrm{ECON}^{t-1}}\right) + \omega^{t}\ln\left(\frac{\mathrm{POP}^{t}}{\mathrm{POP}^{t-1}}\right) \tag{4}$$

Therefore, changes in the CO_2 emissions (ΔCO_2) are decomposed by changes in the CI (first term), SHARE (second term), EE (third term), ECON (fourth term), and POP (fifth term). The term ω_i^t operates as an additive weight for the CO_2 emissions.

The decomposition technique for the emission change factors is called the Logarithmic Mean Divisia Index (LMDI) and was developed by Ang et al. [15]. The term ω^t operates as an additive weight for CO_2 emissions estimated within the LMDI framework. The LMDI approach has been used predominantly in energy studies [16]. As far back as 1991, LMDI has been used to investigate the drivers of CO_2 in the manufacturing sector [17] and, more recently, the LMDI approach has been applied to corporate environmental management research to clarify the key drivers of toxic chemical emission changes [18,19]. Additionally, LMDI was applied in patent decomposition analyses to investigate research and development priority changes over time [20,21].

3. Data and Results

3.1. Data

This study uses five data variables for decomposition analysis from three databases. We obtained the CO_2 emissions data from "CO_2 emissions from fuel combustion 2017" published by the International Energy Agency (IEA). Additionally, fossil fuel use and total energy use data are obtained from "World Energy Balance 2017" [22]. Finally, we obtained the GDP ($ in 2011 prices) and population data (person) from the world development indicators published by the World Bank [23].

Additionally, we obtained renewable energy use data to understand the CO_2 emissions reduction strategy. This data is also obtained from World Energy Balance 2017.

This study focuses on regional cooperation for CO_2 emissions reduction in Northeast Asian countries. We selected six countries from within this region, including China, Japan, Korea, Russia, Mongolia, and the DPRK. Data covers the time period from 1991 to 2015.

3.2. Trend of CO_2 Emission Changes and Driving Factors

Figure 1 shows the accumulative changes in CO_2 emissions and decomposed factors calculated by the LMDI model.

A positive score indicates an emissions increase, whereas a negative score indicates an emission decrease compared with emission levels in the year 1991. In Figure 1, the line chart indicates the accumulative CO_2 emission change ratio compared to 1991, and the bar chart shows the cumulative effect of each indicator with respect to the emission change. The sum of the accumulated bars is equivalent to the charted line. By comparing the results in the figure, we can distinguish the characteristics of CO_2 emission changes for each country assessed.

According to Figure 1, the trends of CO_2 emission changes are diverse among countries. China and Korea continue increasing CO_2 emissions from 1991 to 2015. The main driver of CO_2 emissions growth is economic development. Meanwhile, DPRK and Russia decreased CO_2 emissions in this period. Energy efficiency improvement is the key factor responsible for decreasing CO_2 emissions in both countries. Finally, Japan and Mongolia have relatively small emission changes when compared with other nations. In Japan and Mongolia, CO_2 emission reduction is affected mainly by energy efficiency improvements, which are canceled out by economic development.

It should be noted that the energy efficiency factor contributed to decrease CO_2 emissions in all six countries. The energy efficiency factor represents two points; first, the technological progress for energy use, and, second, the industrial composition change from energy intensive sectors to non-energy intensive sectors. Figure S1 in the supplementary information shows that GDP composition is shifted from the industrial sector to the service sector in Japan and Russia. Thus, energy efficiency improvement in these two countries is affected mainly by industrial composition changes.

3.3. Change of Carbon Intensity and Renewable Energy Share

Next, we investigate the changes in carbon intensity and the renewable energy share within total energy use. Figure 2 represents the scatter plot of carbon intensity and renewable energy share from 1991 to 2015. The black-colored plot points delineate the data in the year 1991 and the year 2015.

From Figure 2, we can observe China and the DPRK shifting in opposite directions. China increased carbon intensity and decreased renewable energy share, which means that fossil fuel dependency grew. Over the same time period, the DPRK decreased carbon intensity and increased renewable energy share, especially from 2008 onwards.

Another finding is that Japan, Russia, and Korea are all located in a similar position which represents both low carbon intensity and a low renewable energy share. This trend implies that these three countries have an advantage to use fossil fuels incorporating low carbon technologies (e.g., clean coal technology). Mongolia was located in a position which represents high carbon intensity and a low renewable energy share.

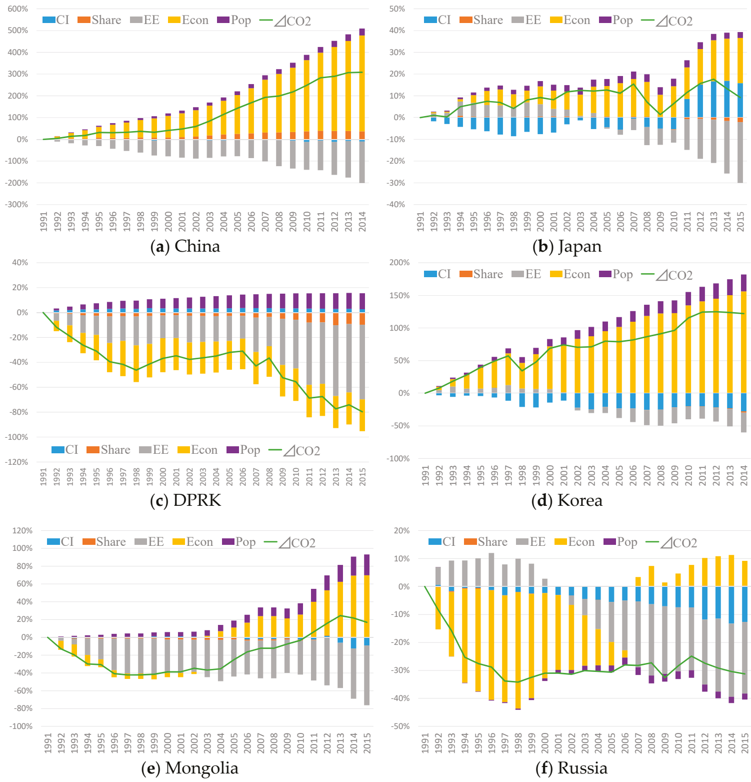

Figure 1. Trends of CO_2 emission changes and driving factors. (**a**) China, (**b**) Japan, (**c**) DPRK, (**d**) Korea, (**e**) Mongolia, (**f**) Russia.

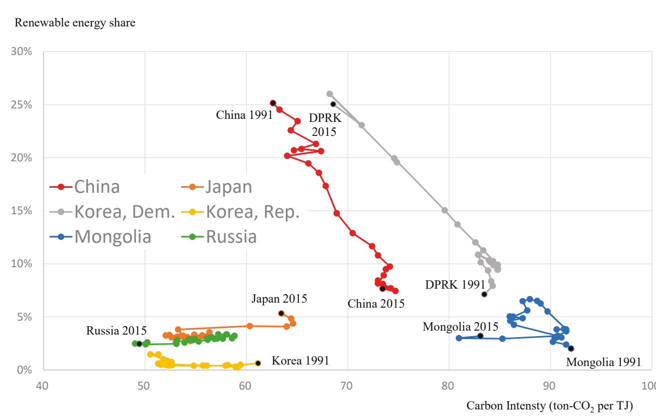

Figure 2. Carbon intensity and renewable energy share for six Northeast Asian countries from 1991 to 2015.

3.4. Change of Fossil and Renewable Energy Portfolios

Figures 3 and 4 represent the fossil and renewable energy portfolios in the six assessed countries from 1991 to 2015. As shown in Figure 3, the dominant energy source varied between countries. China, DPRK, and Mongolia are highly dependent on coal, while Russia mainly uses natural gas. Japan and Korea use coal, oil, and natural gas. These results show that Japan, Korea, and Russia have a relatively low coal dependency, which decreases their carbon intensity, even without a high renewable energy share.

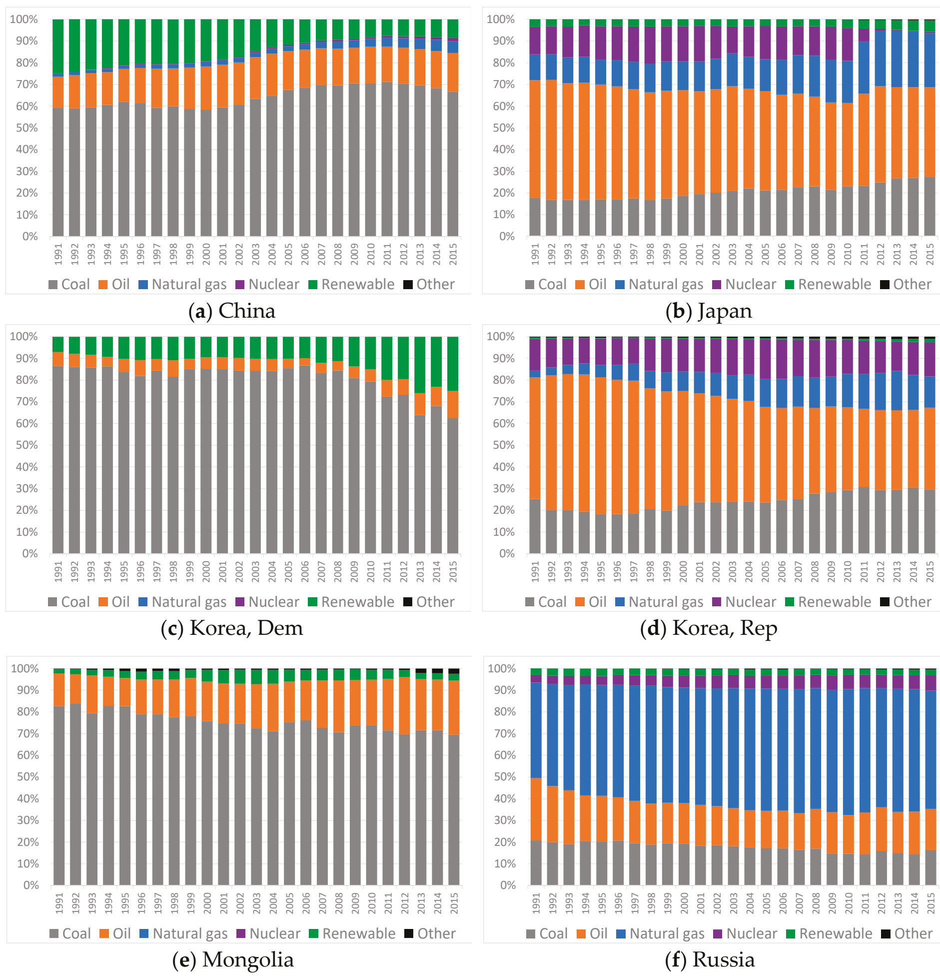

Figure 3. Trend of energy portfolios with respect to total primary energy supply. (**a**) China, (**b**) Japan, (**c**) Korea, Dem, (**d**) Korea, Rep, (**e**) Mongolia, (**f**) Russia.

Another finding is that China, the DPRK, and Mongolia have a comparatively low share of natural gas, which is a lower carbon-intensive energy source. This implies that these three countries have a significant potential to decrease carbon intensity due to an energy supply composition shift from coal to natural gas.

Considering Figure 4, renewable energy sources also showed varying trends among countries. Biofuel energy holds a large share in all assessed countries except for Russia. Another major renewable energy source in the Northeast Asian region is hydro power, especially in Japan, the DPRK, and Russia.

Additionally, China, Japan, and Korea have all expanded their share of solar energy in recent years, while China and Mongolia have increased their share of wind power in the 2010s. Unique characteristics include the large shares of geothermal energy in Japan and waste to energy in Korea.

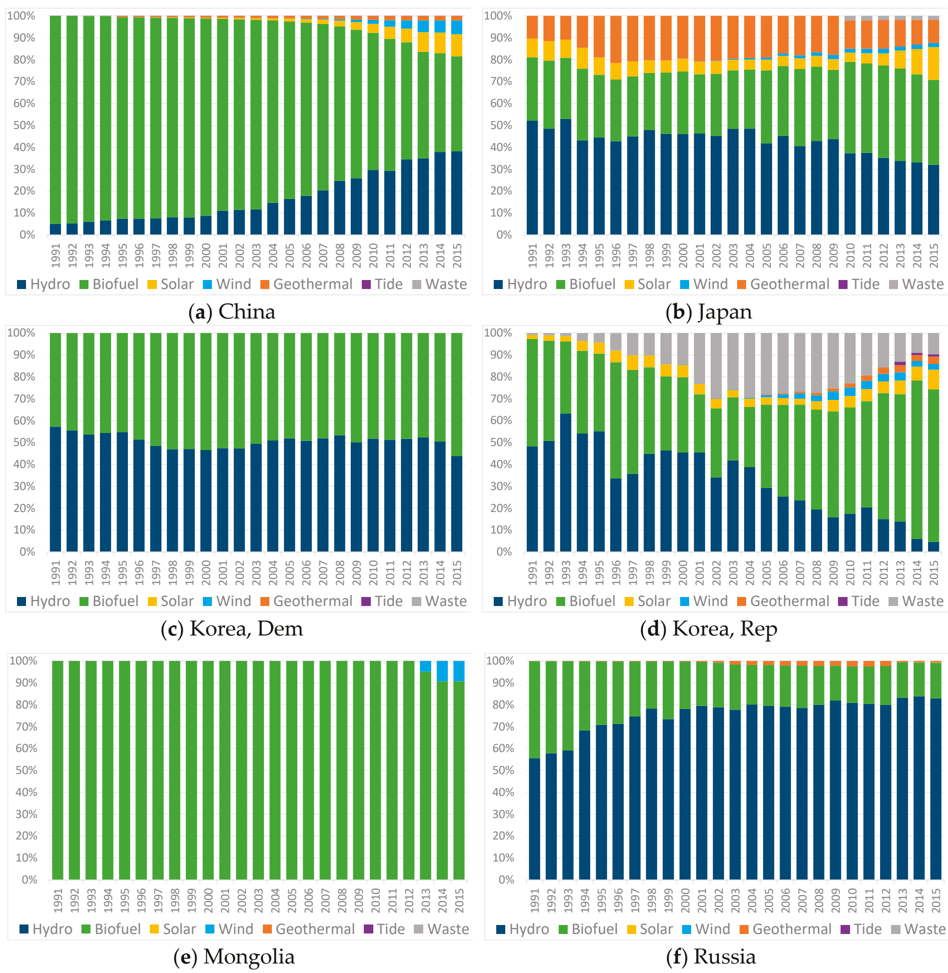

Figure 4. Trend of energy portfolios with respect to total renewable energy supply. (**a**) China, (**b**) Japan, (**c**) Korea, Dem, (**d**) Korea, Rep, (**e**) Mongolia, (**f**) Russia.

4. Discussion

The countries assessed in this study each have distinct levels of development, culture, political systems, and geographic realities which lead to a broad range of sustainable development issues which need to be addressed. Of the six countries assessed, all except Japan share at least one land border, boding well for future regional cooperation in terms of an interconnected grid, or the physical transport of people and resources. This study discusses the DPRK, however, under the United Nations Resolution 2375, passed on 11 September 2017, in addition to preceding resolutions, meaning that certain energy imports are restricted and joint ventures and international movement of workers is prohibited [24]. In this research, these restrictions are ignored in order to develop 'possible' regional cooperation mechanisms. Regional cooperation is considered in terms of sustainable development, and particularly the concept of green growth [25] with a focus on cooperation between developing and high-income countries in terms of green innovation, human and natural capital, infrastructure, and policy design.

From the results presented regarding CO_2 emissions and their underlying factors, it is apparent that Korea and China (and, to a lesser degree, Mongolia) have rapidly-growing economies, which have led to a commensurate increase in emissions. Conversely, the DPRK and Russia have experienced a reduction in emissions due to efficiency gains, but also have limited economic growth, in the case of Russia, or negative growth, as in the DPRK. These outcomes seem to offer a symbiotic arrangement, whereby countries with rapidly-growing economies and high emissions could shift or outsource some of their economic activity to nations with lower CO_2 emissions. The potential of such cooperation can be assessed by considering each nation's comparative technological readiness (the ability of a nation to adopt existing technologies which enhance the productivity of industry) and innovation capacity (the availability of innovation funding and research prowess etc. [26]) alongside the results presented in this study. Of the six nations considered, Japan and Korea have the highest comparative technological readiness and innovation capacity scores [27], suggesting that they might be best suited as 'donor' countries in terms of technology know-how and funding. This is further supported by the high level of diversity of renewable energy sources currently in use in Japan and Korea (see Figure 4), not seen in DPRK, Mongolia and Russia, which rely heavily on biofuel and hydro sources. In recent years, China's renewable energy portfolio has begun to diversify, particularly in terms of solar and wind, with a small contribution from geothermal sources.

From our results, it appears that cooperation could potentially flow in two distinct ways. Firstly, with a shifting of some emission-intensive activities from Korea, China, and Mongolia into the DPRK and Russia, and, secondly, through the provision of technological know-how and funding for sustainable development from Japan and Korea into the DPRK, Mongolia, and Russia.

There are a number of measures which can be employed to enhance cooperation between countries in enhancing their sustainable development and for mitigating CO_2. Under the administration of the UNFCCC, three flexible mechanisms are currently available: emissions trading, the clean development mechanism (CDM), and joint implementation (JI). These flexible mechanisms were initially defined under the Kyoto Protocol to enable the cost-effective reduction of emissions in cooperation with other countries [28]. In addition, Article 6 of the Paris Agreement identifies new market and non-market mechanisms for international cooperation. The nature of these mechanisms is currently under development within the UNFCC [29] and are expected to succeed the Kyoto Protocol mechanisms. It is anticipated that new market mechanisms may include internationally-transferred mitigation outcomes (ITMOs), a new carbon market incorporating the World Bank (Carbon Market 2.0) and enhancement of CDM outcomes and targets [30]. With regard to Kyoto Protocol mechanisms, CDMs are still in effect, and are initiated in Annex I countries (Japan and Russia), and then conducted in non-Annex I countries (DPRK, Korea, Mongolia, and China), in such a way that funding and assistance flows from developed to developing countries improving sustainable development while also reducing emissions in the developed country. The current major beneficiaries of CDMs include China and Korea, first and third, respectively, in the number of certified emission reduction (CER) credits issued [31]. JIs on the other hand, take place between Annex I countries, allowing investment in emissions reducing projects in preference to reducing emissions within national borders.

Based on the findings and potential cooperation flow recommendations identified in this research, CDMs could be enhanced between Japan and the DPRK, Mongolia, and Russia, along with JI-based investment flows from Japan to Russia. Emissions trading on the other hand, which can be undertaken both within and outside of the UNFCCC framework, which may help to offset CO_2 emissions in one country, does not guarantee any improvement to sustainable development in the country taking on the emissions.

In terms of proposed Paris Agreement mechanisms, Japan has initiated the Joint Crediting Mechanism (JCM), a project based bilateral offset crediting mechanism to diffuse low carbon technologies. The JCM offers opportunities for technology transfers which enable emission reductions, with some feasibility studies already underway for highly-efficient, ultra-super critical (USC) coal power plants (Japan to Vietnam, India, and Indonesia). These feasibility studies may lead to cooperation whereby countries that are highly dependent on coal, including China, North Korea, and Mongolia (see Figure 2) can benefit from emerging technologies being developed and implemented by Japan [32]. In addition, these same three countries all have relatively low penetration of natural gas-based electricity generation, which has a lower carbon intensity than existing generation approaches. Countries with natural gas know-how, such as Japan and Russia, could use JCMs to deploy natural gas facilities into nations which are heavily reliant on coal and, therefore, have higher national carbon intensities (see Figure 2).

An alternative approach to sustainable development cooperation under the UNFCCC, is through more conventional investment-based approaches, including the investment option known as 'green bond'. Green bond markets can provide financial support to countries where a demand for green infrastructure investment is high, but traditional bank loans are not as readily available. Additionally, labelling a bond 'green' conditionalizes its use toward verifiable green projects [33]. This green bond market is rapidly growing, from US $42 billion in 2015 to US $86 billion in 2016, with strong interest from China, Japan, Russia, and Korea in terms of both investment from multilateral development banks and international financial institutions, and the development of guidelines to facilitate future investment in sustainable development. Such investment is expected to help sustain growth of the global economy and to mitigate climate change and adaptation risks, which include financial loss and market volatility [34].

The Paris Agreement furthers the process of harmonizing emissions reduction goals, and all six nations in this study have signed the agreement [35], seeking to reduce emissions. Further, the focus of Asian cooperation has been highlighted recently, cognizant of the strained relationships between some of the investigated nations, however, highlighting the need for energy cooperation in order to provide a counterbalance to Middle Eastern instability and the supply of fossil fuels into the region [36].

5. Conclusions

This study sought to achieve two aims; the clarification of the driving factors of CO_2 emission trends, and to identify opportunities for cooperation toward sustainable development in Northeast Asia. The driving factors of CO_2 emissions were found to be unique between individual nations, with a growth in CO_2 emissions driven by economic development in Korea and China, a reduction in emissions experienced in the DPRK and Russia due to efficiency improvements, and a limited change in Mongolia and Japan, the result of economic development and energy efficiency improvements somewhat cancelling each other out. Of the five factors investigated (population, energy efficiency, economic development, fossil fuel share, and carbon intensity of energy generation) economic development and energy efficiency were found to be the most influential. Underpinning these findings, the energy system in each country was also found to be somewhat unique, both in terms of the share of fossil and renewable fuel sources, and the diversity of the energy supply portfolio.

Based on these findings, the potential for cooperation between countries was identified. The range of cooperation initiatives found to be appropriate to the investigated Northeast Asian countries are linked to the transfer of know-how and funding from developed to developing nations, and the enhancement of economic activity in developing nations, in order to reduce CO_2 emissions in the most developed nations. In addition to established mechanisms for such cooperation, this study also assesses green bonds as a further stimulus for green infrastructure in countries where traditional financing instruments are difficult to obtain.

In order to achieve inter-regional cooperation, the harmonization of environmental policies and regulations between countries is required. Although the Paris Agreement is a positive step towards harmonization of environmental goals, further work is required in the region to realize sustainable, green growth.

Supplementary Materials: The following are available online at http://www.mdpi.com/2071-1050/10/1/244/s1, Figure S1: GDP share in each sector.

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Price Determinants of Affordable Apartments in Vietnam: Toward the Public–Private Partnerships for Sustainable Housing Development

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Abstract: Since the Doi Moi policy of economic reform in 1986, Vietnam has experienced economic development and housing market growth with increasing foreign direct investment. While high-end apartment development has dominated since the emergence of the privatized housing market, more recent focus is on the affordable apartment segment with the remarkable surge of middle-income households in Ho Chi Minh City (HCMC). While most previous studies have analyzed housing price determinants based on locational classification, this study is based on the affordability framework of the housing market in HCMC. It aims to investigate the price determinants of affordable and unaffordable apartment units using the hedonic regression model. The study identified common factors between the two types of apartments, such as vertical shared access and proximity to downtown, as well as unique factors for each, such as more high-rise towers, foreign development, proximity to main roads, and shopping malls only for the affordable segments. The findings have valuable implications, not only for future investors and developers in setting up successful housing development strategies, but also for the public sector in strongly encouraging public–private partnerships for sustainable housing development in Vietnam.

Keywords: Vietnam; Ho Chi Minh City; affordable housing; apartment; hedonic regression model

1. Introduction

1.1. Economic Growth and Housing Development in Vietnam

Vietnam has registered dynamic national growth following the introduction of economic reform, the Doi Moi (Đổi Mới: open door) policy, in 1986. It has moved away from the government-led economic structure by opening up the local market. The economic renovation attracted foreign investment and promoted overseas business to promote economic growth. The policy goal was to create a socialist-oriented market economy and to accelerate the economic transition to industrial manufacturing, creating employment opportunities and economic output [1]. This led to a remarkable growth in foreign direct investment (FDI) and spurred industrial manufacturing development in Vietnam. The reforms have achieved a steady annual GDP growth of 5–10% for the last several decades, enabling Vietnam to leap forward as one of the fastest-growing countries in Asia, with falling poverty rates and improved quality of life [2]. The resulting surge in foreign direct investment (FDI) into Vietnam was particularly evident in the real estate sector, which received the second-largest proportion of FDI (18%) after the manufacturing and processing industries (58%) [3].

The housing market in Vietnam has been steadily growing over the last two decades. From 1999 to 2009, 275,000 housing units were supplied in Vietnam and an additional 325,000 are expected between

2009 and 2019. Housing demand has increased by about 10% every year, and reports suggest an additional 394,000 housing units need to be built annually until 2049, considering Vietnam's current urban population growth rate (3%). This is equivalent to 1079 homes per day or 45 homes per hour [2]. In particular, with a recent surge in the middle-income class, the popularity of affordable apartment segments for the middle class can be observed in various market analysis reports. The rapid and continuing increase in Vietnam's middle class (the fastest in Asia) means demand for affordable apartments is predicted to increase fivefold between 2013 and 2020, a demand that can only be sustainably met by apartment projects in urban areas to provide the quantity and quality of housing needed [4,5].

The popularity of apartments is associated with urbanization trends and traffic issues in Vietnam. According to Seo and Kwon (2007), apartments are the preferred choice of middle-income purchasers, with commuting conditions and transportation being the key factors [6]. As the economy booms, so does vehicle ownership [7]. Car ownership has increased at over 10% per annum (320% in the period 2005–2014) while there are now more motorbikes (8.5 million) than people (8.2 million) in Ho Chi Minh City (HCMC) [8]. This overburdening of the city's road capacity has led to massive traffic congestion and declining air quality for commuters. Apartments, therefore, are seen as at least a partial adaptation to this problem. While other forms of housing (e.g., row houses) suffer from urban densification and poor vehicular accessibility, high-rise apartments built with foreign investment offer spacious units, open spaces, parking lots for cars and motorbikes, and excellent access to main roads [9].

1.2. Affordable Housing in Vietnam

Housing affordability generally indicates a ratio approach between household disposable income and housing prices. In other words, the affordability estimates if the household's purchasing power is sufficient to secure a residential property in the housing market. Affordable housing in developing countries is defined with the following criteria: housing-related spending should be no more than 30 to 40% of household income, adequate living space and amenities should be available, and 80% of middle-income residents should be able to afford the housing based on the Housing Affordability Index [10]. According to the World Bank, household purchasing power has been estimated for each income quantile with regard to payment capacity and access to housing finance in Vietnam. The monthly income of a median quantile household was USD 460 and that of the highest income class USD 1340. In this income structure, it was difficult for the middle-income households to obtain access to housing. To enhance housing affordability for the middle-income class, the Vietnamese government launched a subsidized mortgage program as per the regulations of the central banks in June 2013 called 'VND 30 Trillion Home Loan Package,' which was available at a maximum fixed annual interest rate of 6%, a maximum loan tenure of 15 years, and a loan to the value of 70 to 80% of the purchase price for first purchasers of social housing or apartments. Since the subsidized program was launched, around 80% of apartment buyers in HCMC have taken advantage of the package [11,12].

The dynamic of high-rise apartment development is mainly evident in HCMC and Hanoi, representing between them 85% of Vietnam's total housing market. This is particularly the case for HCMC as Vietnam's largest city and key economic hub. With GDP growth at an annual 10% for 10 years and HCMC experiencing annual urban growth of 3%, the city's ever-increasing population means the housing market is experiencing remarkable growth but is also under severe pressure. According to the statistics for 2010–2015, 58% of the total housing supply in HCMC was affordable high-rise housing: 153 apartment projects, containing 79,967 units, were supplied to the middle-income bracket. In 2015, 77 affordable apartment projects with 40,008 units were developed, while growth in the high-end housing market was also strong [13]. Future projections for affordable apartment demand are remarkable: according to the EZLand study (2016), only 12,128 units were produced in 2013 to meet a demand for 23,838 units. By 2020, demand is expected to reach 130,962 units while the supply will be only 31,042 units (Figure 1), leading to an even more critical housing shortage in HCMC.

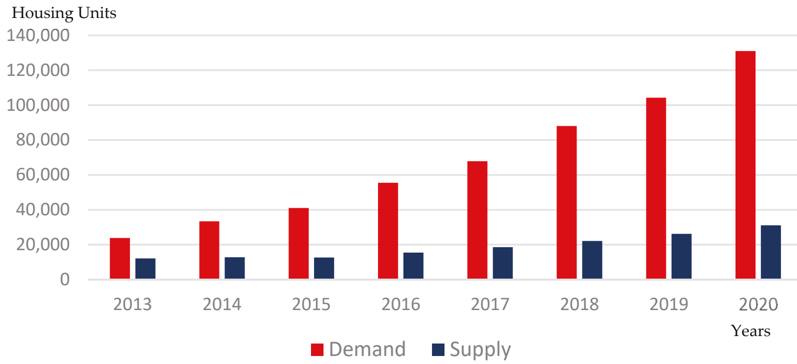

Figure 1. Affordable Apartment Demand and Supply (Source: EZLand [13]).

1.3. Study Purpose and Framework

While high-end apartment development has prevailed in Vietnam since the emergence of a privatized housing market, the affordable apartment segment has recently come to the fore with a remarkable surge of middle-income households in HCMC. This research therefore attempted a different approach to find an answer to the research question of identifying the similarities and differences in price determinants between affordable and unaffordable apartments. Since apartment housing on the Vietnamese real estate market is classified into affordable, mid-end, high-end, and luxury apartment segments, this study classifies these last three segments as "unaffordable" (Figure 2). By dividing the apartment projects into affordable and unaffordable segments, the housing attributes that affect the market price of each segment will be investigated and compared, and the reasons for the similarities and differences discussed in the urban context of HCMC. This provides valuable references for housing developers and investors to understand the pricing determinants in the Vietnamese housing market, helping them to make decisions for successful investment and development by utilizing appropriate development strategies for various classes of people. This can also help central and local authorities improve the quality of a diverse range of developments with public–private partnerships.

Figure 2. Affordable Apartments (**left**); and Unaffordable Apartments (**right**) (Copyright: Authors).

2. Literature Review

2.1. Hedonic Price Model

Court (1939) was an early pioneer in using the term 'hedonic' to investigate demand and prices for individual sources of pleasure [14]. He believed heterogeneous commodities contained multiple attributes to meet individual preferences for usefulness and desirability. This significant application of multivariate statistical methods had major implications for housing price studies. Lancaster (1966) then developed the argument further with the theory of consumer demand [15]. He demonstrated that composite goods contain a variety of attributes; thus, customers make a decision to purchase when the composite attributes meet their specific desires. Rosen (1974) then took the discussion to a new level by applying hedonic theory to a pricing model. He argued that the total price of an item means the sum of the prices of the individual attributes of the item, and that each characteristic can be a unique implicit price in the market [16]. This provided critical implications for advanced price regression models, a way to find which unique attributes influence total composite prices [17]. Once Rosen's theory of a hedonic pricing model was generally accepted, regression analysis methods began to be broadly used for housing market analysis and urban studies. The basic hypothesis of the hedonic price model for housing studies is that the total price of a property represents the combined individual attributes of the property and what customers are willing to pay for the package of attributes. There are numerous empirical studies proving the hypothesis and the attributes can be categorized in three groups: housing structure, community, and locational attributes.

Housing structure describes the physical characteristics and conditions of housing and land. Specific attributes are lot size, unit size, building age, number of bedrooms and bathrooms, garage, swimming pool, fireplaces, and air conditioning [18,19]. The importance of structural attributes can change over time and vary among countries in accordance with culture, tradition, and local climate but the attributes of room number and housing unit size are relatively critical in most nations [20].

Community attributes indicate the quality of socioeconomic and environmental characteristics in the neighborhoods. Education is the most influential factor in housing choice decisions. Kilpatrick and Hefner (1998) found an association between school quality and housing price [21]. In particular, Gibbons and Machin (2003) highlighted the influence of primary school quality on prices [22]. The socioeconomic characteristics of the community population are also significant, such as high-income neighborhoods and the presence of western (as opposed to non-western) residents, as these lead to a presumption of better community quality and amenities [23]. Baumont and Legros (2009) investigated the metropolitan districts of Paris and housing prices and found that neighborhood renewal plans and policies can influence housing prices [24]. In addition, the environmental externalities of neighborhoods can be critical for housing choice and price [25–27]. Aircraft and transportation noise were negative determinants for housing prices [28–31] while air and water quality were similarly influential [32–35]. On the other hand, public open spaces and urban parks increased the value of community environments with more fresh air, recreational facilities, and aesthetic enhancement [36–39].

Locational attributes consist of accessibility and proximity to major public facilities and places, such as downtown areas, shopping malls, transportation stations, main roads, highways, and schools [40–43]. The distance to central business districts (CBDs) has been critical for housing choice and prices with the "access/space trade-off" model [44,45] depicting a trade-off between the reduced land cost of suburban areas and the increasing commuting cost of travel and transportation to CBDs. Hwang and Thill (2011) found an association between job accessibility and housing price by measurement of travel-time-based job accessibility in Seattle [46]. There have been, however, contradictory debates regarding the model due to the assumption limitation, such as monocentric urban structures, the isotropic condition of terrain, and perfect competition markets [41,47,48]. For other attributes, Bowes and Ihlanfeldt (2001) found proximity to railway stations significant for housing prices due to lower costs and better convenience for commuting [49], while Debrezion et al. (2006) further developed the impact of the railway network on house prices [50]. Munoz-Raskin (2010) examined the positive significance of proximity to bus rapid transit (BRT) networks for property values [51]. There is also a study that shows the significance of spatial accessibility to retail and commercial centers for housing values [52]. As previously noted for community attributes, proximity to urban parks, public open spaces, and education facilities is also critical for increasing prices.

2.2. Studies of Apartments for Price Determinants in Vietnam

While housing price determinants in other countries have been intensively studied and analyzed, few studies for apartment price determinants in HCMC are available. Chung et al. (2014) analyzed 197 HCMC apartment projects using the hedonic regression model [9] and found pricing factors for three groups: whole city, downtown, and the new town district (Phu My Hung city). The result was that positive pricing factors for the whole city were land prices, projects by foreign developers, swimming pools, and proximity to international schools, parks, the new town, and downtown. The negatively significant factors were the age of the buildings and distance to downtown. In the case of downtown apartments, the positive factors were the total number of apartment units in a project, unit area, swimming pools, and unit access structure (vertical shared access), and the negatively significant factors were ward population density and land prices. For the new town apartments, positive factors were land prices, ward population density, and the proximity of parks and international schools. This study found similarities and differences between apartment price determinants among downtown, the new town, and the rest of the city.

Huynh's study (2015) analyzed the determinants of the apartment prices of the new town, Phu My Hung city and its surrounding areas, in HCMC [53]. Twenty apartment projects with 263 units in the new town and 16 apartment projects with 172 units outside were analyzed by the hedonic regression model. It was found that the positive factors were apartment project land size, housing unit size, and apartment grade. The negatively significant determinants were building age, floor area ratio (FAR), and distance to downtown.

Jung et al. (2013) analyzed the development patterns of foreign and local developers' apartment projects through the factor analysis and logistic regression model [54]. An investigation of 139 foreign and local projects in HCMC found that numerous foreign apartment projects were developed in suburban areas because land prices were relatively cheaper and legal licensing for housing development was easier than in downtown areas. The influential independent variables for the foreign developments were accessibility to downtown, higher sale prices, various public community amenities and their proximity to housing, potential population growth with job opportunities, larger apartment units, and proximity to rivers.

These previous studies show that the price determinants of apartments in HCMC can be summarized as follows: (1) structural characteristics of apartments such as housing unit size, community density, FAR, and unit access structure (horizontal corridor access and vertical shared access); (2) locational features of the project such as proximity to downtown, the new town, and suburban areas; (3) public facilities in the community such as swimming pools and retail units, and mixed-use development; (4) accessibility and proximity to public facilities such as urban shopping malls, international schools, urban parks, and rivers (Table 1).

Table 1. Housing Attributes and Price Determinants for a Hedonic Price Model.

	Studies for Cities World-Wide	Studies for Cities in Vietnam (Apartments)
Housing Structure	Land size/Unit size/Building age/Number of bedrooms and bathrooms/Garage/Swimming pool/Fireplaces/Air conditioning	Project land size/Unit size/Apartment grade/Mixed-use development/Building age/Floor Area Ratio/Land price/Foreign developers/Unit access structure/Natural ventilation
Community Attributes	School/Ethnicity/Income level/Redevelopment policies/Transportation and aircraft noise/Water quality	Swimming pool/International school Park/Neighborhood population density/Riverfront
Locational Attributes	Accessibility to central business districts Proximity to transportation stations Proximity to shopping malls Proximity to main roads and highways Proximity to coast Proximity to parks/public open spaces	Proximity to downtown Proximity to new town Proximity to shopping malls Proximity to rivers Proximity to main roads Accessibility to work places

While most previous studies have analyzed housing price determinants based on locational classifications like downtown, new town, and peripheral areas in cities, this study started by examining the question of the housing affordability framework of the real estate market in HCMC, which is experiencing rapid economic growth. While high-end apartment development has been dominant since the emergence of the privatized housing market, the recent remarkable upsurge of middle-income households in HCMC has produced a new emphasis on the affordable apartment segment. Since apartments in the Vietnamese housing market are classified as affordable, mid-end, high-end, and luxury apartment segments, this study separates the affordable segment from the mid-end, high-end, and luxury apartments ('unaffordable' segment).

3. Methods

3.1. Data Collection

This study used a data set covering 714 unit prototypes in 211 apartment projects in HCMC that have been sold since 2000, which covers most apartment projects in the period. We collected the data set in three steps. First, the bulk of raw data on apartments was provided by the National Housing Organization (NHO), which is an affordable housing development institute in Vietnam, and the NIBC Investment and Consulting company (Ho Chi Minh City, Vietnam), which conducts professional housing market surveys and feasibility studies for housing development in Vietnam. The series of data sets included apartment unit prices, multiple apartment unit sizes and drawings, project land size, and lists of public facilities. They were restructured for the purpose of this study. Second, additional data on more apartment projects were collected through popular Vietnamese real estate websites (http://khudothimoi.com/ and https://batdongsan.com.vn/). Third, the information on proximity to urban public facilities was measured based on Google Maps. This data includes distances to urban parks, schools, shopping malls, rivers, main roads, the downtown area, and so forth. When we got the data from the collection procedure, we double-checked the data set with local real estate consultants.

3.2. Identification of the Price Range for Affordable Housing in Vietnam

As mentioned earlier, it is the ratio between housing prices and a household's disposable income that determines housing affordability, a measurement of whether or not a given household has sufficient purchasing power to secure a residential property. Since the government of Vietnam launched subsidized mortgage programs, such as mortgage finance, the VND 30 Trillion Home Loan Package, and housing microfinance, to enhance housing affordability, the Vietnamese consumer's power has increased remarkably and this has significantly impacted on the housing market [11,12]. In this context, according to the 2016 JLL data for the HCMC real estate market, affordable housing was categorized as having an average price of USD 740 per square meter, with mid-end housing at USD 1343 per square meter in secondary prices [12]. A maximum value for affordable housing can be estimated at $ 1041 per square meter, which is the mean of the two average prices. Therefore, we considered the price range of affordable housing as under $1041 per square meter in this study.

3.3. Variables for Hedonic Regression Model

In this study, the apartment unit price per square meter is set as the dependent variable. It is a standardized value regardless of the size of the apartment, so it is possible to objectively investigate the factors that affected the apartment price. The independent variables were based on the factors considered from earlier studies on apartments in HCMC. The hedonic regression model uses the following formula:

$$Lnp = \beta 0 + \sum_{k=1}^{K} \beta_k x_k + \varepsilon$$

where

p denotes the per-unit sales price of property;
ε is a random error term vector;
β_k ($k = 1, \ldots, K$) indicates the coefficient matrix of independent variables x and shows the rate of price change with the characteristics x.

The dependent variable, *Lnp*, is the log of the per-unit sales price of property. Using a logarithmic scale for the price makes interpretation easier than other methods [55]. The β shows the coefficient matrix of independent variables. The independent variables were selected based on previous hedonic model studies of Vietnamese housing and various discussions with local experts on housing development. Most variables were categorized under general headings, while some were removed due to correlation. In the case of land prices, we considered a special land pricing system for Vietnam as the process here does not follow that normally observed in capitalist systems. The socialist system does not allow private land ownership but provides land use rights in the form of a lease. Thus, the official land price, which the Vietnamese government sets, is not for a permanent property value but a transferrable value. The price estimation is based on the street value evaluation method and we found that the land price of our data set was not closely correlated with other factors. Thus, the independent variables were categorized into three groups: housing unit values, residential community features, and proximity to urban public facilities. Table 2 shows the contents and details of each.

Table 2. Variable Descriptions for Hedonic Price Modeling.

Categories	Variables	Code	Unit	Note
Housing Structure	Apartment price (Dependent)	AptPrice	USD/m^2	Sales price per square meter
	Unit size	Area	m^2	Unit area
	Building age	Year	year	Building age
	Total floors	AllFloors	floor	Number of building floors
Community Attributes	Ward population density	WardDen	person/ha	Ward of apartment location
	Total units of apartment	AllUnits	unit	Total number of units
	Swimming pool	Pool	dummy	Existence in the project
	Mixed-use apartment	Mixeduse	dummy	Commercial and residential
	Foreign development	ForeignDev	dummy	Foreign developer
	Natural ventilation	Ventil	dummy	Possibility of natural air flow
	Unit access structure	UnitAccess	dummy	Access types to each unit
	Land price	LandPrice	USD/m^2	Street value evaluation
Locational Attributes	Location to new town	Newtown	dummy	Phu My Hung new town
	Proximity to main road	Road	dummy	Over 4 lane road
	Dist. to downtown	Cbd	m	To the Presidential Palace
	Dist. to park	Park	m	Formal urban parks
	Dist. to river	River	m	Formal urban rivers
	Dist. to international school	School	m	Primary to secondary schools
	Dist. to shopping mall	ShopMall	m	Corporate shopping malls

The formula was structured in a semi-logarithmic form as this is widely used in hedonic regression models for proportional understanding of the interaction between a property's price and its housing characteristics. When sales prices are expressed as logarithms, the coefficients can be interpreted as the percentage change in price resulting from an additional unit of the independent variable. For the dummy variables, the coefficients can be interpreted approximately as the percentage difference in price between properties with the attribute and those without.

4. Results and Findings

4.1. Descriptive Statistics

Table 3 shows the descriptive statistics for 714 apartment prototype units in 211 HCMC projects that have been built since 2000; this includes most apartment projects in the period.

Table 3. Descriptive Statistics.

Variables		Total		Affordable		Unaffordable	
		n = 714		*n* = 427		*n* = 287	
		Mean	**S.D.**	**Mean**	**S.D.**	**Mean**	**S.D.**
Apartment price	AptPrice	1060	588	718	151	1570	627
Unit size	UnitArea	94.7	43.4	83.9	39.7	111	43.8
Years since construction	Year	4.06	3.13	3.63	3.12	4.71	3.05
Total floors	AllFloors	18.3	6.85	17.2	6.43	19.8	7.17
Ward population density	WardDen	178	237	158	218	209	260
Total apartment units	AllUnits	562	1014	682	1241	384	466
Swimming pool	Pool	0.52	0.50	0.40	0.49	0.68	0.47
Mixed-use apartment	MixedUse	0.18	0.38	0.13	0.34	0.25	0.43
Foreign development	ForeignDev	0.21	0.41	0.08	0.26	0.42	0.49
Natural ventilation	Ventil	0.42	0.49	0.45	0.50	0.37	0.48
Unit access structure	UnitAccess	0.14	0.34	0.18	0.39	0.07	0.25
Land price	LandPrice	500	414	307	229	789	459
Location to new town	Newtown	0.19	0.40	0.10	0.30	0.33	0.47
Proximity to main road	Road	0.42	0.49	0.31	0.46	0.59	0.49
Dist. to downtown	Cbd	6298	3069	7687	2829	4230	2096
Dist. to park	Park	2441	2959	3348	3469	1094	919
Dist. to river	River	1102	1767	1319	2039	780	1192
Dist. to international school	School	2439	2811	3454	3197	929	804
Dist. to shopping mall	ShopMall	1436	1728	1847	2055	825	725

In the housing unit category, the average price of the apartments is 1060 dollars per square meter, 718 dollars for affordable housing, and 1570 dollars for an unaffordable apartment. The average unit size of unaffordable housing is 24 percent higher than that of affordable housing. In the residence community category, the average land price of the unaffordable group is 61 percent higher than that of the affordable one. The average apartment unit number in the latter is 44 percent higher than that of the former, indicating a far higher building density for the affordable housing project. It was also observed that the unaffordable group has more mixed-use development and foreign development projects and is more closely located to international schools, parks, and riversides (Figure 3). In addition, the affordable group shows more heterogeneous data patterns in the variable of total apartment units and the unaffordable group in foreign development within the community attributes. In the locational sectors, the affordable group is more heterogeneous, particularly for distances to parks, rivers, international schools, and shopping malls (Table 3).

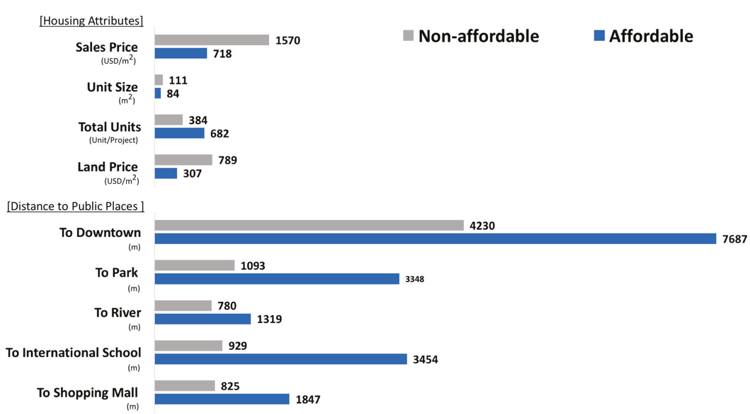

Figure 3. Average Data Comparison of Descriptive Statistics Between Affordable and Unaffordable Housing (Housing Attributes and Distance to Public Places).

4.2. Regression Results

The hedonic model produced regression results as shown in Table 4. The stepwise method was applied to the regression model for accurate factor finding. As shown from the results, it reported significant independent variables for each group: full samples, the affordable group, and the unaffordable group. In the total group, positively significant independent variables for price determinants are housing unit size, existence of a swimming pool, mixed-use development, foreign development, land price, and new-town (Phu My Hung) location. The negatively significant factors are length of time since construction, ward population density of the projects, and distance to downtown (District 1) and shopping malls. In the affordable group, positive significant factors are total floors, foreign development, unit access structure, and accessibility of main roads. The distance from downtown and shopping malls are negatively significant factors. In the unaffordable group, positive factors are housing unit size, existence of a swimming pool, unit access structure, and land price. Negatively significant are building age, ward population density, natural ventilation, and distance to downtown, the river, and international schools (Table 4).

Table 4. Regression Results.

Dependent Variables	Total Apts.	Affordable Apts.	Unaffordable Apts.
UnitArea	0.052 (2.503) *	−0.035 (−0.896)	0.137 (3.89) **
Year	−0.149 (−6.607) **	−0.066 (−1.444)	−0.214 (−5.458) **
AllFloors	0.041 (1.728)	0.166 (4.575) **	0.041 (0.977)
WardDen	−0.061 (−2.717) **	0.062 (1.53)	−0.322 (−7.086) **
AllUnits	−0.033 (−1.729)	−0.03 (−0.817)	−0.007 (−0.194)
Pool	0.084 (3.645) **	−0.072 (−1.568)	0.304 (7.044) **
MixedUse	0.103 (5.234) **	0.048 (1.065)	0.072 (2.047) *
ForeignDev	0.272 (11.26) **	0.226 (6.171) **	0.058 (0.861)
Ventil	0.002 (0.077)	0.013 (0.296)	−0.101 (−2.622) **
UnitAccess	−0.003 (−0.146)	0.111 (2.826) **	0.192 (5.462) **
LandPrice	0.429 (16.367) **	0.034 (0.716)	0.507 (10.324) **
Newtown	0.081 (3.391) **	0.046 (1.161)	0.061 (1.342)
Road	0.031 (1.533)	0.098 (2.574) **	−0.02 (−0.568)
Cbd	−0.411 (−14.419) **	−0.563 (−14.867) **	−0.387 (−6.311) **
Park	0.033 (1.374)	0.066 (1.478)	0.05 (1.336)
River	0.013 (0.673)	0.069 (1.895)	−0.078 (−2.238) *
School	0.025 (0.928)	−0.004 (−0.082)	−0.16 (−4.426) **
ShopMall	−0.065 (−3.178) **	−0.137 (−3.595) **	−0.057 (−1.579)
n	714	427	287
Adjusted R^2	0.761	0.452	0.710

Notes: T-stats in parentheses. ** denotes 1% significance level; * denotes 5% significance level. The Chow test was conducted to verify whether the coefficients in two regressions on the data sets are equal. The test statics is 33.68 and this is bigger than the critical value for F (18,678). Therefore, there was no problem with this structure.

In the results, two determinants, unit access structure and distance to downtown, are shown for both the affordable and unaffordable groups. The rest of the significant variables are, however, different for each group (Table 5). It indicates that a larger number of housing characteristics and environmental factors affect the price structure of housing property in the unaffordable housing segment, like high-end and luxury apartments.

Table 5. Comparison of the Price Determinants Between Affordable and Unaffordable Housing.

	Affordable Apts.	Unaffordable Apts.
Positive (+)	Unit access structure ** Total floors ** Foreign development ** Proximity to main roads **	Unit access structure ** Swimming pool ** Land price ** Unit Area ** Mixed-use development *
Negative (−)	Distance to downtown** Distance to shopping malls **	Distance to downtown ** Distance to international school ** Distance to river * Building age ** Ward population density ** Natural Ventilation **

Notes: ** denotes 1% significance level; * denotes 5% significance level.

5. Discussion

5.1. Common Price Determinants for Both Affordable and Unaffordable Segments

Both apartment segments display locational influences to downtown. The prices increase as the housing is more closely located to the downtown area, location of District 1 (the central business district). This is related to heavy traffic congestion on roads and poor commuting conditions for citizens, regardless of affordable or unaffordable apartments. Since a high proportion of workplaces in HCMC are concentrated in the downtown districts, accessibility and proximity are critical for housing choice. With insufficient road capacity and increasing numbers of vehicles every year, peak-hour traffic congestion has become appalling [56]. Commuters using motorbikes battle daily against not only heavy traffic jams but also contaminated air quality. A report from the Ministry of Natural Resources and Environment in Vietnam showed that 70% of pollution gases were generated from motorized vehicles in cities [57]. Motorbikes are the main polluters and the drivers are, consequently, exposed to the contaminants every day [58]. In addition, 70% of urban areas will be vulnerable to seasonal urban flooding, further worsening traffic conditions [59] (Figure 4). In this regard, proximity and accessibility to downtown can be a critical factor for apartment selection.

Figure 4. Peak Hour Commuting (**left**) and Urban Flooding in HCMC (**right**) (Copyright: Authors).

The structural attributes of housing also affect housing prices. Apartment developments generally consist of two types of home access: vertical shared access and horizontal corridor access (Figure 5). The former, which allows access to homes organized around a vertical core of elevators or stairs, is a determinant for higher apartment prices in both segments. It shows a greater level of residence individuality than the other and enables more intimate social interaction with neighbors, limiting the number of homes around the core to a manageable number. It can also allow more fresh air and light in communal spaces. However, although the horizontal corridor access carries the benefit of efficient circulation by hallways for more units on each floor, its higher density is a negative factor due to lack of privacy, exposure to noise, and increased feelings of anxiety, stemming from perceptions of insecurity and increased vulnerability to house invasion or robbery which occur frequently in Vietnam.

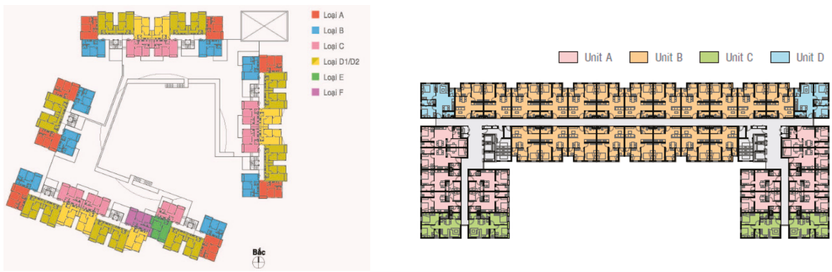

Figure 5. Vertical Shared Access of Nest Home Apartments (**left**) and Horizontal Corridor Access of First Home Apartments (**right**) (Copyrights: NHO).

5.2. Unique Price Determinants for Affordable Apartments

First, one of the determinants that only applies to affordable housing is foreign development. This means that the prices of apartments built by foreign developers are more expensive than those of local developers. A large portion of affordable housing has been built by the land owners and local builders, who are not professional designers or constructors. The housing unit spaces are not well arranged and the quality of community facilities and open spaces is substandard. However, foreign developers normally supply better-quality affordable housing with superior amenities, and this positively affects their price. The unaffordable apartment segment, on the other hand, is not influenced by whether they have been built by local or foreign developers. Most international developers are focused on the unaffordable segments of the market and there are also professional local developers such as the Vinh Group and Novaland, which have already completed dozens of luxury apartment projects in Vietnam. They are highly appreciated for the excellent quality of their housing developments, which are popular with both foreign and local customers. Therefore, the factor of foreign development only affects the sales price of affordable apartments.

Second, proximity to main roads is a critical price factor for this segment. Affordable housing is located farther from CBDs than unaffordable, at respective average distances of 7.6 km and 4.2 km (Table 3). While the downtown districts of HCMC were systemically planned in the French colonial period with a main road network, other districts enclosing the historic downtown districts have grown organically with massive self-built housing developments leading to urban densification and the formation of an unmanaged road infrastructure. Indeed, roads are so narrow (less than 1.5 m in self-built housing districts) that entire areas are inaccessible to either cars or public transport [3]. Thus, since affordable apartments have normally developed in the self-built dense districts far away from CBDs, proximity to main roads is critical for vehicle accessibility and it affects price determination.

Third, high-rise residential towers with more floors also influence prices in the affordable segment of the market. In Vietnam, due to lower land costs, a large proportion of affordable high-rise apartments (with an average of 17 floors; Table 3) were developed within semi-urban districts comprising widespread low-rise townhouses of 2–4 floors. In the physical context, higher affordable apartments located in the low-rise blocks can see their prices increase because of their association with what are seen as conspicuous landmarks in the districts (Figure 6). However, mid- and high-end apartments are normally located relatively close to downtown comprising numerous high-rise buildings, and thus the attribute of apartment development height is not critical for price determinants in this segment.

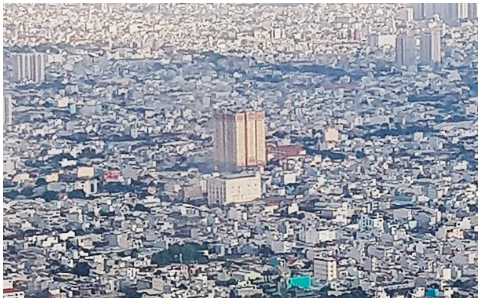


Figure 6. Affordable Apartments in District 12 (**left**) and Unaffordable Apartments in District 1, CBD (**right**) (Copyrights: Authors).

Fourth, closer proximity to shopping malls is also a price determinant. This trend more clearly appears in the affordable segment as its coefficient (−0.137) in regression modeling is more than twice as high as that (−0.065) of total apartments (Table 4). As the unaffordable housing is relatively closer to the commercial malls (an average of 0.8 km) than the affordable (1.8 km), this determinant is not critical in that segment. In HCMC, considering the lack of community facilities and a tropical climate with dry and wet seasons, with an average temperature of 28 degrees Celsius with the highest peak of 39 degree Celsius around noon, proximity to a shopping mall can be an influential factor for housing choice, particularly for the lower-middle class. Since HCMC is modernizing with an ever-growing boom in supermarkets and shopping malls in recent decades (such as Coopmart, Big C, Aeon Mall, and the Vincom Center), they are positioning themselves not only as commercial centers but also as cultural epicenters for communities of families and friends to enjoy the air conditioning and a variety of entertaining events and performances with free access for the lower-middle class.

5.3. Unique Determinants of Price for Unaffordable Apartments

In the unaffordable housing segment, it was found that the older the apartment, the lower the apartment price. Overall operation and maintenance of apartments in Vietnam is not well managed with a variety of disputes between apartment residents and developers. According to official reports, there is misuse of public areas in the communities, cost disputes over the operation and maintenance of facilities, and issues pertaining to fire prevention and safety, construction quality, unqualified maintenance teams, public security, and inconsistent sales contracts [60]. These are leading to a rapid aging of apartments and a depreciation of property prices. As affordable apartments have been developed relatively recently (average building age 3.6 years; see Table 3), the building depreciation rate is a less sensitive issue for them.

Apartments containing a swimming pool are more expensive in the unaffordable segment. In the tropical climate of HCMC, this is one of the most popular public facilities in the residential sectors. While this is an optional service for the affordable segment, high-end and luxury apartments invariably provide swimming pools as part of a public amenity package, even competing in this area with more advanced outdoor locations and higher quality such as eye-catching rooftop pools. This factor positively influences housing prices.

Weather conditions also had a negative significance on the determinant of natural ventilation in the unaffordable apartments. This is not preferred due to both the tropical climate and security issues. To avoid hot weather (an annual average temperature of 28 degrees Celsius with the highest peak of 39 degrees Celsius around noon in HCMC), the residents of unaffordable apartments always opt for air-conditioning at home; natural air flow is not a requirement for them. In addition, natural ventilation requires additional windows facing public alleys or corridors in many apartments in

Vietnam. This is considered a threat to home security as burglars in Vietnam often break into luxury apartments through windows.

It is also found that the larger the unit size of an unaffordable apartment, the more positive its impact on housing price, in that its coefficient (0.137) is twice that of apartments in general (0.052) (Table 4). However, the affordable segment does not show the significance of unit size itself since customers in this segment tend to base their choice of housing units not on unit size but apartment layout, for instance, composed of one room with two toilets or two rooms with two toilets, based on the market price. This means that unit layout conditions are more important than the unit size. According to developers of affordable housing, the bottom line for housing prices is almost fixed for the affordable market at around 50,000 USD and what is most critical in development is more efficient unit layouts enabling more rooms, toilets, and a living room. In sales and marketing brochures, developers frequently use statements such as "An apartment of two bedrooms and two toilets for only USD 40,000", while in the case of high-priced apartments, brochures usually advertise them with comments like "$2500 per square meter in premium New Town".

Mixed-use development integrating residential units, commercial units, or offices is becoming a popular trend for property developers in Vietnam since it is considered as a sustainable trend in the compact city concept, minimizing commuters' need to travel and reducing the demand on the urban infrastructure network. While mixed-use structures significantly influence higher housing prices in the unaffordable segment, normally leading to well-managed leasing businesses with secure tenants, the popularity of the trend is not observed in affordable projects due to insufficient mixed-use cases or unsuccessful leasing status with empty retail units or offices, and thus it does not affect housing prices.

Proximity to international schools and rivers are also critical determinants in this segment. There are numerous previous studies showing a positive significance of better education facilities and natural conditions, such as parks and rivers, for housing prices. However, in the case of HCMC's affordable housing, an international school with expensive tuition fees is not realistically an influential factor in their lives. Rivers and urban canals near affordable housing in peripheral districts are mostly contaminated and not well managed, so proximity to the environment is not critical for the price of the affordable housing segment.

6. Conclusions

Apartment development in HCMC has been driven by both the housing shortage caused by the rapid population influx and the boom in real estate investment. Since the opening of the Vietnamese housing market, high-end apartment development has dominated, but the affordable apartment market has also grown gradually in recent decades with the growth of a middle-income class. As demand for this market continues to rise significantly every year, housing developers and policy makers need to understand the market's dynamics and how price determination is affected.

According to the hedonic regression model, significant common price determinants were found for both affordable and unaffordable housing segments. Structurally, vertical shared access in apartments creates an upward trend in housing prices because it secures both dwelling individuality and social intimacy with a manageable scale of neighbors, in contrast to horizontal corridor access. In addition, proximity to downtown is also a critical factor in the higher price of apartments in HCMC in terms of proximity to workplaces, given the lack of public transportation, serious traffic congestion caused by enormous numbers of private vehicles, and frequent flooding on roads.

Unique price determinants in each segment of housing are related to geographical conditions and their physical environment. Higher multistoried apartments raise the price of affordable housing since they attract premium values as landmarks in low-rise residential districts. Since these districts have developed organically, with urban densification and narrow streets, an apartment's proximity to main roads enabling efficient vehicular access is critical to boosting housing prices. Foreign developments are associated with higher expectations for improved quality of design and construction. However, in the case of the unaffordable housing segment, better housing quality and enhanced amenities in neighborhoods boosted housing prices, as did more recently developed and bigger housing units. Further advanced community facilities and environmental aspects, such as swimming pools, mixtures of residential and commercial development, lower-density neighborhoods, and proximity to rivers and international schools, significantly influence housing values.

These results can be valuable references for future investors and developers to set up successful housing development strategies and directions in Vietnam, enabling them to understand the different approaches and determinants for multiple classes of residents, and thereby making the national housing supply more economically and socially sustainable. Having largely focused until now on the provision of apartments for the upper-middle classes as a popular and cost-efficient response to housing demand, the government should now strengthen the public–private partnerships to achieve the same result for the lower-middle classes through promoting affordable apartment development. The government and local authorities, who have led regulatory reforms to incentivize further private developer participation and played active roles to encourage an affordable housing supply, should pay close attention to and take account of this study's findings.

The regulatory reforms with the revised housing laws and subsidized financial programs have had a variety of beneficial effects on the housing market in HCMC. They have helped to reorient private housing developers toward the affordable housing market where there are real home ownership needs [11]. They have also reduced vulnerability to investment due to increased household purchasing power and enhanced the variability of the housing market. In particular, since the revised Housing Law of 2015 structured the government's interventions in social housing development, the public and private sectors have been encouraged to work in partnership and this has led to a specific plan for social housing including land selection, housing design, construction, and housing provision. As this study shows key price determinants of locational attributes for affordable housing with proximity to main roads and shopping malls, these partnerships should select available land for social housing construction, securing road connectivity and accessibility to community facilities. As customers prefer affordable housing built by foreign developers because of the more professional quality of design and construction, the partnership should strictly monitor quality management during the course of the development. Therefore, both the private and public sectors need to understand the housing market dynamics associated with customers' preferential interests and urbanization issues in HCMC. This study is, therefore, important in understanding how to pursue housing development in Vietnam on an economically and socially sustainable basis.

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sustainability

Article

A Study on the Sustainable Performance of the Steel Industry in Korea Based on SBM-DEA

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Abstract: Since South Korea has implemented its emissions trading scheme (ETS) in 2015, several studies have explored the sustainable performance of ETS in terms of production efficiency. However, few studies focused on Korean company-level data in their model. Thus, this study focuses on data from firms in the steel industry, which is a representative greenhouse gas emitter. Based on the slack-based measure (SBM) approach, we find the following implications: First, this paper evaluates both environment energy efficiency (EEE) and traditional energy efficiency and discovers that the efficiency value, in general, is overestimated, when greenhouse gas emissions are ignored. EEE still shows a decreasing efficiency value over time, implying that strong regulation is needed to increase efficiency. Second, this paper provides the return to scale status of decision-making units in the steel industry, through decomposing EEE. Results show that many steel firms are in the state of increasing returns to scale, so they can enhance their efficiency by increasing their scale. Finally, this paper provides benchmark information with which an inefficient firm can enhance its performance.

Keywords: steel industry; emissions trading scheme; environment energy efficiency; non-radial SBM-DEA

1. Introduction

South Korea (hereafter "Korea") has promoted its ambitious green growth optimal path control up to 2030, since it hosted the 2009 G20 summit in Seoul. As one of the core solutions to meet this challenge, Korea initiated the emissions trading scheme (ETS) in 2015. To accomplish its ambitious challenge, the government has made great efforts to decrease greenhouse gases (GHG) based on a selective concentration on the heavier emitters across all the major industries. Unfortunately, there are many debates on the "pros" and "cons" regarding this ETS policy, especially in its sustainable performance to reduce GHG levels, while maintaining Korea's competitiveness in international trade. Prior to the Korean ETS, EU has similar problems. According to Martin, Muuls and Wagner (2016), the allocation of carbon emission allowances for free in the initial stages of the EU-ETS resulted in firms with high carbon emissions actually benefitting from the EU-ETS [1]. Oestreich and Tsiakas also found that this kind of carbon premium, coming from transition trial and error on the inappropriate carbon market price, is shown for a specific period that commences about one year before the beginning of Phase I and disappears about one year into Phase II [2]. Based on this experience of the EU ETS, the Korean government should make this kind of trial and error on the carbon market price as short as possible [3]. In this perspective, the feasibility analysis of ETS policies is crucial for sustainable development in Korea as it just initiated its ETS.

The steel industry is called the "rice of industry" due to its importance as a platform industry of the national economy. It is also true that without sustainable performance of the steel industry, it is impossible for heavy industries, such as the automotive, shipbuilding, and mechanical equipment industries, to be sustainable (see Appendix A). Thus, the steel industry is the platform industry because it is related to the sustainable performance of other industries as well. At the same time, the steel industry is also one of heaviest energy consumers. Its share of energy consumption among manufacturing industries in Korea is 27% [4]. Thus, the volume of GHG produced by the steel industry is overwhelming compared to that by other industries. Hence, the amount of carbon emissions allocation for the steel industry among industries covered by the Korean ETS is also large. Therefore, it is essential to manage the steel industry so that it reduces its GHG emissions by up to 37% until 2030. However, in contrast to the fact that GHG emissions have been stable for five years, as shown in Table 1 and Figure 1, firms' revenues have been decreasing (Based on the comments by a reviewer, we changed all the turnover volume at the constant dollar terms in 2011. Our current measure (nominal $US) could be affected by price changes, which are unrelated to efficiency measures as a reviewer commented. We checked the possible change in the trend due to the exchange rate fluctuation, and determined there is no significant change. We found there is temporal upturn in 2014 due to the exchange rate fluctuation, but it was not significant to change the empirical results). Therefore, it is important to examine whether this decreasing trend in revenues may or may not stem from the newly-introduced environmental regulation in the steel industry. In addition, from this analysis, we could speculate about the industrial characteristics of ETS-covered steel firms, especially regarding returns to scale, and suggest the optimal way to increase each firm's performance compared to the benchmark case. This is the basic motivation for this study.

Table 1. Revenue and GHG emissions data for firms in the steel industry (based on sample data of this study).

	2011	2012	2013	2014	2015
Turnover (billion USD)	662	597.8	540.7	567.7	470.6
GHG (CO_2 equivalent million tons)	101.1	99.1	97.7	103.7	100.2

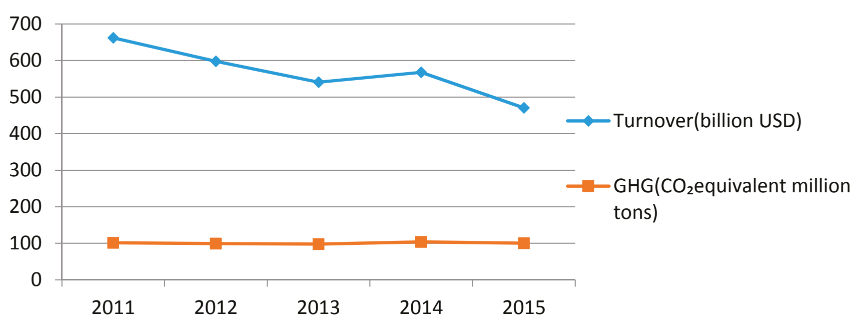

Figure 1. Trend of the revenue and GHG emissions in the steel industry

There are two widely used methods for measuring production efficiency: stochastic frontier analysis (SFA), based on a parametric approach, and data envelopment analysis (DEA), based on a nonparametric relative scale. In general, the SFA model is used to calculate shadow price. Wang et al. [5] estimate shadow prices of steel enterprises in China. Che [6] estimates CO_2 shadow prices in China's iron and steel industry at the regional level, from 2006 to 2012. The characteristics of SFA are based on the theoretic form of the production function. Due to this functional constraint, there is also the limitation that an incorrect functional form may lead to incorrect results [7].

Meanwhile, the DEA model proposed by Charnes et al. [8] has some advantageous characteristics. First, it derives sole relative efficiency, which makes it suitable to be adopted in a complex industrial environment. Second, the DEA approach does not require the imposition of a functional form on the underlying environmental technology; it provides an easier and more flexible means of estimation [9]. Finally, for ineffective DMUs (decision making units), DEA can provide the corresponding improvement suggestions according to the projection theorem. Due to these advantages of DEA, there have been diverse papers that analyze the steel industry by adopting the DEA model. Zhang and Zhang [10] examined the technical efficiency of China's iron and steel firms in the 1990s using the DEA approach. Yang et al. [11] also analyzed the Chinese regional iron steel industry through network bootstrapping DEA model and discovered a significant geographical difference across provinces. Wei et al. [12] analyzed the energy efficiency of the Chinese iron and steel industry by using DEA. Cho and Bae [13] measured the total factor productivity (TFP) changes in Northeast Asian countries' steel industries and decomposed the TFP change into technical change and technical efficiency. Sheng and Song [14] used firm-level census data to calculate the TFP of firms in China's iron and steel industry and examined its potential determinants over the period from 1998 to 2007.

With respect to the Korean steel industry, Lee and Kim [15] used a DEA model to analyze the steel industry. The results provided a comparison of efficiency between CCR, BCC, and each firm's returns to scale (RTS). Ha and Choi [16] adopted DEA to evaluate the steel industry. Their study conducted a super efficiency test for efficient DMUs that show an efficiency of 1 and distinguished between them. In addition, this study also provided a benchmark result and suggested the implications for the Korean steel industry. However, these previous studies evaluating the performance of the Korean steel industry neglected to address the environmental impact of undesirable output, such as greenhouse gases. Almost all of them used desirable output only. Since the steel industry is a representative GHG-emitting industry, if undesirable output is ignored, the estimated efficiency value will be overestimated. To evaluate the unbiased sustainable performance, GHG emission should be incorporated into the model framework as undesirable output. Furthermore, previous studies did not take into consideration the effect of ETS, because this policy was launched in 2015. To overcome all these limitations, we examine unbiased production efficiency with undesirable output of GHG to determine whether ETS policies directly influence efficiency.

Meanwhile, a DEA model could be divided into two types of approaches: radial and non-radial models. A radial model is an approach adjusting input and undesirable output by the same proportion to the efficiency target. Thus, it may lack some information regarding the idle (or neglected) efficiency of the specific inputs or outputs involved in the production process [17]. Moreover, the radial efficiency approach neglects the slack variable, leading to biased estimation [18], and it has weak discriminating power for ranking and comparing decision making units (DMU). Due to these limitations, we introduce slacks-based measure (SBM)-DEA, which directly accounts for input and output slacks in the efficiency measurements, with the advantage of capturing the entire aspect of inefficiency. In the Energy and Environment (E and E) field, there have been diverse studies adopting an SBM model to explore efficiencies with undesirable output [10,18,19].

In addition, since SBM always assumes the non-radial approach, it can overcome the limitations of a radial model. We can determine the difference between radial and non-radial approaches in Figure 2. As shown in this figure, under the radial approach, DMU "c" should move to "a" on the efficiency frontier. To move point "a", "ef" amount of energy input should be saved in this process, because the radial model is based on the proportional reduction and enlargement of variables. However, SBM deals directly with input excess (potential reduction) and output shortfall (potential expansion) of an observation, by using variables called slack variables. The SBM projects the observations to the furthest point on the efficient frontier, in the sense that the objective function is to be minimized by finding the maximum amounts of slacks. Under SBM, "c" could move to "b", and this means that the value of the potential reduction in energy input could drop from "oe" to "od". To examine this characteristic of SBM in our empirical study, we will also compare two results derived from a radial and non-radial model, respectively.

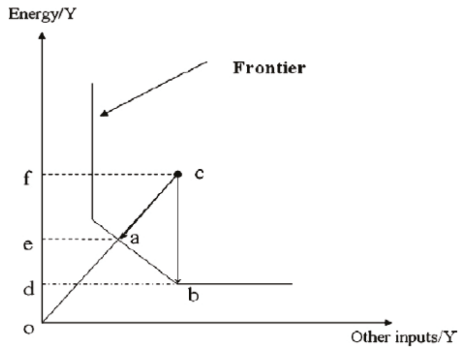

Figure 2. Graphical illustration of radial efficiency measure vs. SBM-efficiency measure.

Therefore, the purpose of this paper is to suggest the following implications: First, we will examine the efficiencies of 20 ETS-covered Korean firms in the steel industry for five years (2011–2015). In fact, the Korean government inaugurated Korean ETS in 2015 and, thus, it might that be our empirical tests do not reflect well the policy effect on the firm's performance. However, since the Korean government initiated its carbon targeting management system (TMS) in 2010, it is implied that the regulatory effect of ETS could be reflected well in our empirical tests. Nonetheless, the short-test period may not cover the full trials and errors in the initial stage.

Based on the result, we can find each firm's efficiency status for five years and the efficiency change over time. In addition, we can check whether undesirable output causes a significant efficiency difference. Second, we will provide "returns to scale" for each DMU, and this will be helpful for each DMU when deciding the optimal path in their production. Third, we will arrange for benchmark information that each DMU can find in their concrete input-output structure to increase their efficiency.

Most of all, this paper aims to prove that the strong regulatory policies are much more important to shorten the trials and errors experienced in EU-ETs. Especially, under the strong regulatory regime, the firms shall more effectively find their role models as the benchmark to enhance their short-term environmental energy efficiency.

The rest of this paper is organized as follows: Section 2 presents a methodological framework for the SBM model and describes the data collection; Section 3 presents the results of the empirical study of the steel industry; and Section 4 concludes this paper with some policy implications.

2. Methodology

In this section, the SBM model will be introduced in the first stage. The model shows how to estimate environmental energy efficiency. In the next stage, we will decompose the efficiency into pure energy efficiency and scale efficiency to analyze the characteristics of the production process in the steel industry over time. In the last stage, we also adopt a directional distance function ('DDF') model to compare the resulting efficiency to that of the SBM model.

In order to introduce the undesirable SBM, the term "environmental production technology" should be defined. Assume that there are $j = 1, \ldots, N$ decision-making units (DMUs). In our study, these DMUs are steel industry firms. Suppose that each DMU uses input vector $x \in \Re^M_+$ to produce jointly a good output vector $y \in \Re^S_+$ and a bad output vector $b \in \Re^J_+$. Environmental production technology is expressed as:

$$T = \{(x, y, b) : x \text{ can produce } (y, b)\}$$

where T is often assumed to satisfy the standard axioms of production theory. Inactivity is always possible, and finite amounts of input can produce only finite amounts of output. In addition, input and desirable output are often assumed to be freely disposable. With regard to regulated environmental technologies, weak disposability must be imposed on T. The weak disposability assumption implies that reducing undesirable output, such as GHG emissions, is costly in terms of relatively decreased desirable output in the production process. Further, the null-jointness assumption is adapted, implying that GHG emissions are unavoidable in production and that the only way to remove GHG is to stop production. Mathematically, these two assumptions can be expressed as follows:

$$if(x,\ y,\ b) \in T\ and\ 0 \leq \theta \leq 1,\ then(x,\ \theta y,\ \theta b) \in \tag{1}$$

$$if(x,\ y,\ b) \in T\ and\ b = 0,\ then\ y = 0. \tag{2}$$

SBM Model

Radial efficiency measure neglects slack variables that may overestimate efficiency when there are non-zero slacks. To overcome this limitation, the non-radial DEA approach was developed [15]. SBM is a non-radial approach. It directly accounts for input and output slacks in efficiency measurement, with the advantage of capturing the entire aspect of inefficiency. This characteristic is suitable for analyzing efficiency considering undesirable outputs, such as CO_2 emissions or GHG. The original SBM-DEA was developed by Tone [20]. However, because Tone's original SBM-DEA model does not incorporate undesirable output, we should modify his model. Based on Tone's approach, the non-oriented SBM model could be specified as follows when considering undesirable output slack [21]:

$$\begin{gathered} \varnothing^* = min\frac{1-(1/m)\sum_{i=1}^{m}(s_{i0}^-/x_{i0})}{1+(1/s_1+s_2)(\sum_{r_1=1}^{s1}\left(s_{r_10}^g/y_{r_20}^g\right)+\sum_{r_2=1}^{s2}\left(s_{r_20}^b/y_{r_20}^b\right))} \\ \text{S.T.} \\ x_0 = X\lambda + s_0^- \\ y_0^g = \text{Y}^g\lambda - s_0^g \\ y_0^b = \text{Y}^b\lambda + s_0^b \\ s_0^- \geq 0,\ s_0^g \geq 0,\ s_0^b \geq 0,\ \lambda \geq 0, \end{gathered} \tag{3}$$

$i = 1, 2, \ldots, m$ index of inputs S_1 slack variables (potential reduction) of inputs;
m number of inputs S_2 slack variables (potential expansion) of outputs;
$r_1 = 1, 2, \ldots, S_1$ index of desirable outputs;
$r_2 = 1, 2, \ldots, S_2$ index of undesirable outputs;
S_0^- slack variables (potential reduction) of inputs;
S_0^g slack variables (potential enhancement) of desirable outputs;
S_0^b slack variables (potential reduction) of undesirable outputs; and
λ a non-negative multiplier vector for PPS (The production possibility set) construction linear programming.

Equation (3) defines a non-radial, non-oriented measurement of SBM model. When $\varnothing^* = 1$, this means all slack variables are 0, ($s_0^- = 0,\ s_0^g = 0,\ s_0^b = 0$), and the DMU is efficient in the presence of undesirable outputs. However, because Equation (3) is not a linear function, we transform it into Equation (4) with an equivalent linear programming for t, $\varphi,\ S^{-*},\ S^b,\ S^g,$ as follows [20]:

$$\begin{gathered} r^* = \text{min}t - \frac{1}{m}\sum_{i=1}^{m}\frac{s_{i0}^-}{x_{io}}, \\ \text{S.T.} \\ t = 1 + \frac{1}{s_1+s_2}(\sum_{r1=1}^{s_1}\frac{S_{r10}^g}{y_{r10}^g} + \sum_{i=1}^{m}\frac{S_{r10}^b}{y_{r20}^b}) \\ x_o t = X\varphi + S_0^- \\ y_0^g t = Y^g\varphi - S_0^g \\ y_0^b t = Y^b\varphi + S_0^b \\ S_0^- \geq 0,\ S_0^g \geq 0,\ S_0^b \geq 0, \varphi \geq 0\ t \geq 0. \end{gathered} \tag{4}$$

With the linear optimal solution of model (4) with variables (t, φ, S^{-*}, S^b, S^g), we can solve the linear program. The efficiency measure includes both economic and the environmental factors; therefore, we could define it as the environmentally adjusted technical efficiency.

A similar idea is found in Tone's model [20]: when fitting the DEA model, it could be interpreted in terms of the inter-relationship between inputs and slacks. Let us define TEI as target energy input, REI as real energy input, and ES as energy slack. Then, the solution to model (Equation (4)) could be re-stated as Equation (5):

$$\textit{\textbf{Energy efficiency}} = \textit{\textbf{TEI/REI}} = (\textit{\textbf{REI}} - \textit{\textbf{ES}})/\textit{\textbf{REI}} = 1 - \textit{\textbf{ES}}/\textit{\textbf{REI}} \quad (5)$$

As the energy slack is estimated with model (Equation (4)), we calculated the environmental energy efficiency for each firm using Equation (5). The advantage of the SBM model is in its ability to calculate the efficiency of specific input, especially energy in this study, with different results [22]. A similar approach is found in Hu and Wang [23], where they estimate the energy efficiency index.

By imposing $\boldsymbol{\lambda} = 1$, $P(x)$ can be constructed with variable returns to scale (VRS) technology [24]. If we calculate the energy efficiency under VRS, we can obtain a pure energy efficiency (PEE) score. For this purpose, Wei et al. [25] decomposed the total energy efficiency obtained from Equation (5), into pure energy efficiency and scale efficiency (SE). Following their approach, environmental energy efficiency (EEE) is decomposed as shown in Equation (6):

$$\textit{\textbf{Energy efficiency}} = \textit{\textbf{PEE}} \times \textit{\textbf{SE}} \quad (6)$$

A scale efficiency of 1 indicates observations are operating at the most productive scale size [21]. Equation (6) is used to determine whether energy inefficiency is caused by inefficient operation and management, disadvantageous scale conditions, or both [25]. If the PEE value is larger than SE, this means the inefficiency mostly stems from the scale condition; if the SE value is larger than PEE, PEE mainly causes the inefficiency.

3. Characteristics of Data and Empirical Results

3.1. Data

In order to analyze the characteristics of the steel industry, we collected data on 20 firms for five years (2011–2015). The reason why we selected the steel industry as a sample is that it is obviously one of the heaviest emitter industries and its share is also large compared to those of all the manufacturing industries covered by the ETS. In addition, these 20 firms in our sample account for 97.6% (the percentage comes from GHG emissions of the steel industry comes from the amount of 102,649,282 CO_2 eq. ton divided the amount of 100,203,359 CO_2 eq. ton emissions of the firms in the sample (source: Greenhouse Gas Inventory and Research Center). This result may stem from the fact that a few large firms hold a larger majority of emissions in the steel industry) of the steel industry total GHG emission amount. Therefore, empirical results derived from these data could substantially reflect the Korean steel industry's situation. Meanwhile, according to Cooper et al. [21], the number of DMUs should be in accordance to the equation below. This means the number of DMUs should be reasonable when it is greater than 15 in this study ($m + s$ is the sum of input and output variables).

$$\boldsymbol{N} \geq max\{3(\boldsymbol{m}+\boldsymbol{s})\}$$

With regard to the output variables, we selected *sales turnover* (T) as the sole desirable output and *greenhouse gas* (G) as an undesirable output. We also selected two basic types of input, *labor* (L) and *capital* (K), and added *energy* (E) as the third input for environmental performance. The data for labor, capital, and turnover were derived from DART (the Data Analysis, Retrieval, and Transfer System). Energy and GHG data were taken from the Greenhouse Gas Inventory and Research Center of Korea. Since there are no individual CO_2 data available for each Korean firm, Choi and Lee [26] substituted

GHG data with the CO_2 data, an approach that we too have followed. The basic data statistics for these firms are shown in Table 2.

Table 2. Descriptive statistics.

Variable	Type	Unit	Mean	Max	Min.
Turnover	Desirable output	Million USD	3281.5	39,171.7	91.3
Carbon	Undesirable output	CO_2 eq. tons	501,786,317	77,124,639	32,533
Capital	Input	Million USD	105	577.2	4.1
Labor	Input	Per person	1968.75	17,877	152
Energy	Input	Tera joules (TJ)	53,519.7	863,564	630

Sources: Greenhouse Gas Inventory & Research Center of Korea (http://www.gir.go.kr/); DART: Data Analysis, Retrieval, and Transfer System (http://dart.fss.or.kr/).

Table 3 presents the input and output correlation matrix. The results show that the correlations between the types of input and output are positive. *Capital* and *labor* are significantly related with desirable output, and *energy* influences *carbon* significantly. Thus, an overall increase in input causes an increase in output, which strongly suggests that our approach is feasible for an empirical study.

Table 3. Input and output correlation matrix.

Variable	*Energy*	*Capital*	*Labor*	*Turnover*	*GHG*
Energy	1				
Capital	0.647 *	1			
Labor	0.944 *	0.752 *	1		
Turnover	0.970 *	0.731 *	0.981 *	1	
GHG	0.940 *	0.595 *	0.951 *	0.964 *	1

* Statistically significant at the 95% confidence level.

3.2. Efficiency Results

Based on Equation (1) and the related approaches explained above, we can obtain the comparative results for EEE (Environment Energy Efficiency) and TEE (Traditional Energy Efficiency), as shown in Table 4. EEE means efficiency that includes undesirable output when evaluating efficiency, and TEE measures the efficiency that excludes undesirable output. We used the MaxDEA software 6.2 (MaxDEA Co.: Beijing, China) for the calculation of the empirical tests.

Table 4. Environment energy efficiency (with pollution) and traditional energy efficiency (without pollution) by SBM.

	2011		2012		2013		2014		2015	
	EEE	TEE	EEE	TEE	EEE	TEE	EEE	TEE	EEE	TEE
SIMPAC	0.251	0.322	0.250	0.318	0.175	0.222	0.182	0.231	0.144	0.181
SeAH Besteel	0.314	0.377	0.269	0.320	0.269	0.321	0.279	0.336	0.222	0.265
SeAH Steel	1.000	1.000	1.000	1.000	0.859	0.869	1.000	1.000	0.796	0.733
KISWIRE	0.375	0.404	0.342	0.365	0.334	0.359	0.359	0.386	0.294	0.308
DAEHAN Steel	0.411	0.503	0.430	0.528	0.432	0.528	0.463	0.567	0.363	0.442
DONGKUK Steel	1.000	1.000	0.566	0.623	0.373	0.473	0.357	0.435	0.309	0.391
DONGBU Steel	0.436	0.503	0.396	0.456	0.374	0.436	0.526	0.573	0.502	0.529
DONGIL	0.459	0.579	0.396	0.502	0.354	0.447	0.346	0.438	0.287	0.360
YEONGHWA Metal	0.146	0.169	0.138	0.159	0.140	0.161	0.176	0.195	0.164	0.182
DONGBU Metal	0.375	0.487	0.335	0.435	0.319	0.414	0.307	0.399	0.241	0.313
POSCO	1.000	1.000	0.594	0.735	0.473	0.620	0.484	0.637	0.444	0.584
POSCO C&C	1.000	1.000	0.785	0.804	0.787	0.808	0.803	0.818	0.592	0.625
KISCO	0.311	0.378	0.309	0.375	0.305	0.373	0.288	0.351	0.243	0.296
HYUNDAI BNG Steel	0.563	0.552	0.495	0.480	0.495	0.480	0.515	0.497	0.486	0.457
HYUNDAI Steel	0.488	0.618	0.455	0.575	0.341	0.427	0.433	0.546	0.332	0.417
HWANYOUNG Steel	0.359	0.442	0.322	0.396	0.295	0.362	0.253	0.308	0.230	0.281
YK Steel	1.000	1.000	0.883	0.912	0.862	0.898	0.765	0.824	0.494	0.607
KOSTEEL	0.534	0.578	0.436	0.470	0.404	0.430	0.375	0.390	0.297	0.292
DONGKUK Industry	0.558	0.507	0.515	0.463	0.441	0.399	0.445	0.389	0.413	0.360
Kiswire	0.510	0.554	0.342	0.407	0.340	0.404	0.332	0.389	0.289	0.335
Average	*0.554*	*0.599*	*0.463*	*0.516*	*0.419*	*0.471*	*0.434*	*0.485*	*0.357*	*0.398*

First of all, as shown in Figure 1, the steel industry has experienced not only a decreasing trend in its sales volume, but also in its production efficiency in general. Nonetheless, this decreasing trend in efficiency does not stem from the environmental regulation because both EEE and TEE have a similar trend and, thus, the environmental regulation does not seem to severely distort traditional production efficiency. Second, EE scores are always higher than EEE, implying that the environmental regulation certainly showed negative effects on efficiency. Third, nonetheless, the EEE scores show an average of 0.357 to 0.554 for five years. This implies that there is great potential for the steel industry to increase its environmental efficiency toward the frontier of environmental production technology. The maximum value can be accomplished by the learning effect from the firm with efficiency value of "1" by benchmark, to control its input and output slacks. In this result, the DMU of SeAH Steel, DONGKUK Steel, POSCO, POSCO C and C, and YK Steel were reported as DMUs efficient as benchmark firms in 2011. However, all the other efficiencies decrease, but only SeAH Steel maintains more efficient value even in 2015. The reason for reporting SeAH Steel as the best reference set in this study will be analyzed in the following benchmark chapter. In addition, we can see that the efficiency value decreases over time. As mentioned in the introduction, the volume of GHG emissions as an undesirable output in the study does not show a significant change, whereas revenue, which is desirable output, drastically decreases. This explains the main reason for the decreasing efficiency value over time. Firms need to find a way to enhance their revenue through their activity, such as restructuring intra-company governance and changing technical innovation. In addition, strong regulation is needed to enhance efficiency. Due to the loose environmental regulation, TEE and EEE did not significantly change their trends. If there is strong regulation, then certainly these two trends should meet or narrow their gap due to the promoting effect of regulation policies. According to Zhang et al. [22], the Chinese environmental energy efficiency had shown a downward trend but, due to regulation, it turned into an uptrend and proved the Porter hypothesis. This implies that it may also be possible that the Korean steel industry also shows an uptrend if a sustainable regulation policy is implemented more tightly.

TEE, which excludes undesirable output, did not show a large difference with EEE, although it seems to be a little higher. This fact implies that GHG is not the sole reason for the decreasing efficiency. Therefore, every firm in the steel industry should pay attention to governance inside the company, technical innovation, and the overall manufacturing system.

Meanwhile, since the EEE and TEE values did not show a large difference, we conducted a Mann-Whitney test to check the null hypothesis of no group difference. As shown in Table 5 and Figure 3, the M-W test statistic shows a p-value of 0.011, and we can reject the null hypothesis, concluding a significant group difference between TEE and EEE. This result means that TEE overestimates its real efficiency, including the environmental pollution effect, since emitting GHG is inevitable in production. Thus, in E and E studies, it is meaningful to consider undesirable output in order to obtain an unbiased sustainable efficiency value.

Meanwhile, this study also evaluates the difference in efficiency measurement between the radial DDF and non-radial approaches. With the same data, the results of radial DDF efficiency are shown in Table 6. Compared to non-radial SBM efficiency, we can see that the efficiency calculated by the radial DDF in Table 6 is much higher than the non-radial SBM efficiency in Table 4. Thus, we could deduce that the radial DDF result is surely an overestimation when compared to the result from SBM. The reason for this overestimation stems from the characteristics of the non-radial approach of SBM and, thus, it could be better to obtain the unbiased potentials from the non-radial SBM.

Table 5. Result of the Mann-Whitney test.

Test	Null Hypothesis	Test Statistic	p-Value
Wilcoxon-Mann-Whitney	Mean (EEE) = Mean (TEE)	4731	0.011

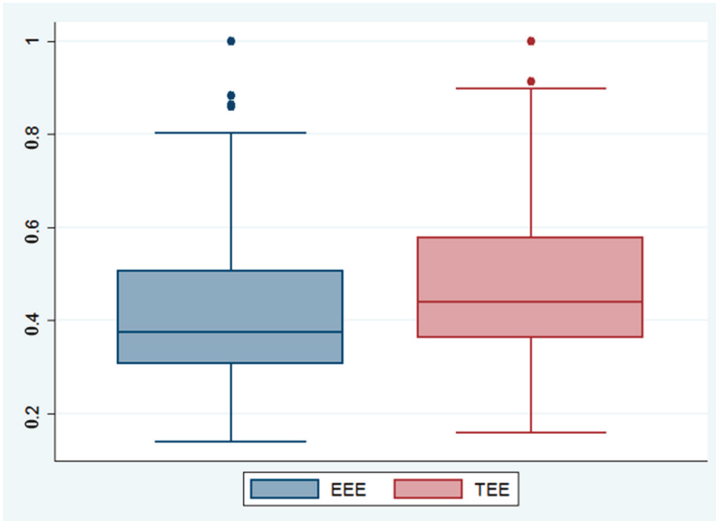

Figure 3. Box plot of EEE vs. TEE.

Table 6. Environment energy efficiency (with pollution) using a radial DDF.

	2011	2012	2013	2014	2015
SIMPAC	0.470	0.458	0.316	0.337	0.258
SeAH Besteel	0.597	0.504	0.508	0.538	0.419
SeAH Steel	1.000	1.000	0.899	1.000	0.955
KISWIRE	0.584	0.517	0.524	0.558	0.408
DAEHAN Steel	0.725	0.755	0.742	0.820	0.635
DONGKUK Steel	1.000	0.853	0.704	0.706	0.584
DONGBU Steel	0.781	0.716	0.686	0.852	0.837
DONGIL	0.858	0.760	0.671	0.657	0.543
YEONGHWA Metal	0.236	0.231	0.235	0.256	0.237
DONGBU Metal	0.676	0.607	0.584	0.573	0.497
POSCO	1.000	0.897	0.792	0.840	0.696
POSCO C&C	1.000	0.919	0.925	0.929	0.819
KISCO	0.570	0.574	0.591	0.558	0.471
HYUNDAI BNG Steel	0.792	0.692	0.697	0.714	0.675
HYUNDAI Steel	0.768	0.669	0.512	0.660	0.520
HWANYOUNG Steel	0.735	0.660	0.605	0.508	0.468
YK Steel	1.000	0.970	0.978	0.920	0.777
KOSTEEL	0.836	0.671	0.585	0.533	0.401
DONGKUK Industry	0.718	0.673	0.570	0.613	0.570
Kiswire	0.888	0.638	0.638	0.552	0.537
Average	**0.762**	**0.688**	**0.638**	**0.660**	**0.565**

Figure 4 shows the graphs of the 3 efficiencies (EEE, TEE, and radial DDF efficiency). As mentioned, TEE, which does not consider undesirable output overestimates the efficiency value compared to EEE, which contains undesirable output. The radial DDF efficiency is higher than both TEE and EEE, implying an overly overestimated efficiency with much less potential.

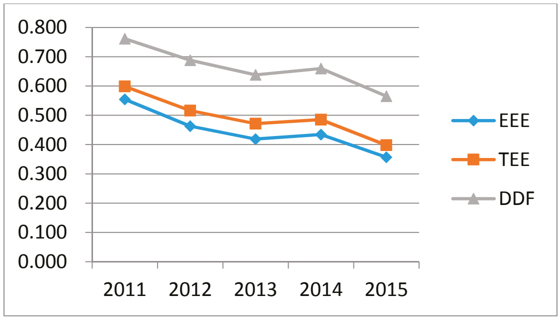

Figure 4. Trend of the three efficiencies.

3.3. Efficiency Decomposition

In this chapter, on the basis of Equation (6), we decompose EEE into PEE and SE. As explained above, PEE is the efficiency obtained from the VRS condition. SE (scale efficiency) is the ratio between energy efficiency under the CRS and VRS conditions. From this process, we could the classify DMUs' returns to scale status. The result is shown in Table 7.

Table 7. Pure technical efficiency score (VRS) and scale efficiency using SBM.

	2011		2012		2013		2014		2015	
	PEE	**SE**	**PEE**	**SE**	**PEE**	**SE**	**PEE**	**SE**	**PEE**	**SE**
SIMPAC	1.000	0.251	1.000	0.250	0.748	0.234	1.000	0.182	1.000	0.144
SeAH Besteel	0.426	0.739	0.314	0.856	0.309	0.869	0.351	0.796	0.225	0.990
SeAH Steel	1.000	1.000	1.000	1.000	0.872	0.985	1.000	1.000	1.000	0.796
KISWIRE	0.485	0.773	0.421	0.812	0.409	0.817	0.440	0.816	0.343	0.857
DAEHAN Steel	0.504	0.816	0.543	0.793	0.539	0.801	0.575	0.804	0.432	0.840
DONGKUK Steel	1.000	1.000	0.797	0.710	0.631	0.590	0.541	0.659	0.577	0.536
DONGBU Steel	0.837	0.520	0.720	0.550	0.647	0.578	0.630	0.835	0.505	0.995
DONGIL	1.000	0.459	0.839	0.473	0.742	0.477	0.709	0.488	0.627	0.457
YEONGHWA Metal	1.000	0.146	0.384	0.359	1.000	0.140	0.385	0.456	0.343	0.478
DONGBU Metal	0.480	0.780	0.431	0.778	0.418	0.764	0.412	0.746	0.330	0.729
POSCO	1.000	1.000	0.916	0.648	0.837	0.565	1.000	0.484	0.838	0.530
POSCO C&C	1.000	1.000	0.909	0.864	0.905	0.870	0.917	0.876	0.803	0.738
KISCO	0.395	0.789	0.330	0.936	0.342	0.893	0.322	0.894	0.271	0.896
HYUNDAI BNG Steel	0.712	0.791	0.623	0.794	0.636	0.778	0.653	0.789	0.628	0.774
HYUNDAI Steel	1.000	0.488	0.896	0.508	0.721	0.474	1.000	0.433	0.681	0.488
HWANYOUNG Steel	0.479	0.748	0.423	0.762	0.394	0.749	0.341	0.744	0.307	0.747
YK Steel	1.000	1.000	0.941	0.939	1.000	0.862	0.982	0.779	1.000	0.494
KOSTEEL	1.000	0.534	0.805	0.542	0.694	0.582	0.842	0.445	1.000	0.297
DONGKUK Industry	1.000	0.558	1.000	0.515	0.739	0.597	0.749	0.594	0.693	0.596
Kiswire	1.000	0.510	0.597	0.573	0.593	0.573	0.595	0.557	1.000	0.289
Average	0.816	0.695	0.694	0.683	0.659	0.660	0.672	0.669	0.630	0.652

In the results, we can see that the average value of PEE, which is derived from VRS, is higher than that of EEE. This result stems from the fact that SE was excluded from EEE. When SE is close to 1, it means that the inefficiency caused by scale decreases, and if SE is close to 0, the inefficiency caused by scale is larger. Therefore, the value of SE is important for the firm when deciding green investment and considering its effectiveness. Although the Korean steel industry's SE did not show a drastic fall, it still shows that 30–40% of the inefficiency can be improved through green investments. To improve each inefficient DMU's efficiency value, it is through checking their RTS that it is possible to delineate a specific plan. RTS, which is classified as CRS, DRS, and IRS, is obtained from the following step.

All DMUs could be evaluated with their initial stage of CRS by linear programming. Assume that there are j $(j = 1, 2, \ldots, n)$ DMUs, and each DMU uses i $(i = 1, 2, \ldots, m)$ as its inputs to produce

r $(r = 1, 2, \ldots, s)$ as its outputs. Then, the efficiency from the production scale could be defined in its linear form:

$$\min\theta \; S.T. \; : \; \theta x^i - X\lambda \; \geq 0, \; \theta y^i - Y\lambda \; \leq 0, \; \lambda \geq 0$$

In this equation, each x and y is the vector of DMU's inputs and outputs. λ is the weights vector. The function's value of θ is the EEE. When θ = 1, this means the DMU is efficient; when θ < 1, this means an inefficient DMU that uses more input $(1 - \theta)$ compared to the other DMUs. In addition, it is possible to check RTS by using the sum of λ values calculated from the above equation. If $\Sigma\lambda = 1$, DMU is on CRS (constant returns to scale), and this means both EEE and PEE are 1. Hence, firms showing CRS have an efficient input and output structure. On the other hand, if the firms' scale efficiency is less than 1, this means that the firms' input and output structure has not achieved full scale efficiency. In this case, when $\Sigma\lambda < 1$, DMUs are on decreasing returns to scale (DRS), whereas when $\Sigma\lambda > 1$, DMUs are on increasing returns to scale (IRS). Results of the RTS of the steel industry for five years are shown in Table 8.

In the Korean steel industry, the firms with IRS comprise a large majority. The number of firms with DRS is 3–5 in each year. IRS means that the rate of increased output is higher than that of input, implying that the increasing scale could enhance the DMU's efficiency value. On the other hand, firms showing DRS can increase their efficiency by reducing their input structure or facilities. Since most Korean steel firms show IRS, the Korean government should promote green investments with incentives for the steel firms to increase their efficiency through expanding their scale.

Table 8. RTS for DMU.

	2011	2012	2013	2014	2015
RTS status	Constant = 5 Decreasing = 3 Increasing = 12	Constant = 1 Decreasing = 5 Increasing = 14	Constant = 0 Decreasing = 5 Increasing = 15	Constant = 1 Decreasing = 5 Increasing = 14	Constant = 0 Decreasing = 3 Increasing = 17
Cause of inefficiency	PEE:7 SE:8	PEE:8 SE:11	PEE:9 SE:11	PEE:10 SE:9	PEE:11 SE:9

3.4. Benchmark for Ineffective Firms

Since it is not easy for the steel industry to further reduce its GHG emissions, the Korean government should support the firms' learning more from the industry's benchmark cases among the firms on the production frontier to overcome the challenge of emissions reduction. Regarding the causes of inefficiency, since PEE and SE are evenly distributed, both the scale condition and intra-firm operation should be examined in more detail for the inefficient firms of the steel industry. To enhance individual firms' performance, the result of benchmark cases could provide valuable information regarding each firm's input target. As mentioned above, SBM-DEA provides the benchmark information for ineffective DMUs that do not show a "constant returns to scale" status. These firms can learn from the detailed information of efficient DMUs: each inefficient DMUs can take the learning effect from matching efficient DMU called the "reference set". This reference set is allocated to inefficient DMUs when they have similar input and output structure. For an inefficient DMU to enhance its efficiency, its input target should achieve the value derived from Equation (7). The λ value could be defined as the level of influence of how much efficient DMUs give to each inefficient DMU. All the firms with EEE less than 1 can obtain benchmark information using Equation (7). Each projection target of an inefficient firm can be from the Equation (7). For example, SeAH Besteel's target value the can come from the input value of SeAH Steel: 12 $\times$ 1.320007; by the same token, KOSTEEL's target value can result from POSCO C and C: 11 $\times$ 0.065857 + SeAH Steel 12's input value $\times$ 0.189196. The result of the benchmark information is derived in Table 9 under the CRS condition.

$$\textbf{Reference set's input} \times \boldsymbol{\lambda} = \textbf{inefficient DMU's input target} \qquad (7)$$

Table 9. Firms for benchmark (2011 case).

Efficient DMU (Number of Reference Sets)	DMU	Efficiency	Benchmark (Lambda Value)
DONGKUK Steel 11 (2) POSCO 11 (1) POSCO C&C 11 (17) YK Steel 11 (5) SeAH Steel 11 (5) SeAH Steel 12 (56) SeAH Steel 14 (29)	SIMPAC	0.251	SeAH Steel 14 (0.168860)
	SeAH Besteel	0.314	SeAH Steel 12 (1.320007)
	SeAH Steel	1.000	SeAH Steel 11(1.000000)
	KISWIRE	0.375	SeAH Steel 12 (0.433333)
	DAEHAN Steel	0.411	SeAH Steel 12 (0.624573)
	DONGKUK Steel	1.000	DONGKUK Steel 11 (1.000000)
	DONGBU Steel	0.436	POSCO C&C 11 (0.168500) SeAH Steel 12 (1.986135)
	DONGIL	0.459	SeAH Steel 14 (0.282895)
	YEONGHWA Metal	0.146	SeAH Steel 12 (0.230944)
	DONGBU Metal	0.375	SeAH Steel 14 (0.491228)
	POSCO	1.000	POSCO 11 (1.000000)
	POSCO C&C	1.000	POSCO C&C 11 (1.000000)
	KISCO	0.311	SeAH Steel 12 (0.542191)
	HYUNDAI BNG Steel	0.563	SeAH Steel 12 (0.513083)
	HYUNDAI Steel	0.488	POSCO C&C 11 (12.422546) SeAH Steel 12 (1.796534)
	HWANYOUNG Steel	0.359	SeAH Steel 12 (0.321957)
	YK Steel	1.000	YK Steel 11 (1.000000)
	KOSTEEL	0.534	POSCO C&C 11 (0.065857); SeAH Steel 12 (0.189196)
	DONGKUK Industry	0.558	SeAH Steel 11 (0.308831)
	Kiswire	0.510	SeAH Steel 12 (0.034409)

Benchmark information is calculated based on 2011, because the efficient DMUs are very biased in 2011 and the average efficiency is also higher than that of the next four years. In the result, we can see that DONGKUK Steel, POSCO, POSCO C and C, YK steel, and SeAH Steel are the efficient DMUs among 20 firms, and SeAH Steel is the best DMU in that it appears 90 times as a reference set. This is because among the 20 firms in the sample of this study, SeAH Steel's input and output structure would be similar to that of other inefficient DMUs. On the other hand, efficient DMUs that are not reported as a reference set as much as SeAH Steel means that their input and output structure is more different from that of other inefficient DMUs. Hence, from the benchmark information, inefficient DMUs should follow the structure of the reference set benchmark firm to enhance their efficiency, through the learning effect based on their allocated reference set.

Meanwhile, it could be speculated that the reason SeAH Steel is an exemplary DMU stems from the high demand for steel pipes. In 2011, in accordance with the expanding LNG market in the U.S, the demand for steel pipes had drastically increased and SeAH Steel, which has 12% of the domestic share of steel pipes, realized a large profit, and that may have affected its enhanced efficiency as a reference set.

4. Conclusions

In this study, we analyzed the efficiency of the Korean steel industry while considering undesirable output. We calculated diverse types of efficiencies and a series of empirical results for five years with 20 firms covered by Korea's ETS. It is noteworthy that the enforcement of ETS policies is too loose to capture the regulation effects. Nonetheless, the paper sheds light on the appropriateness of the diverse approaches and the implications of these approaches. The SBM model with undesirable outputs is the core model for the comparison of the feasibility, and undesirable-DDF models were added for practical implications. We draw the results of diverse efficiencies, such as TEE, EEE, and EEE by radial DDF, with flexible mechanisms on returns to scale status and benchmark information for a catch-up effect. Major findings with practical implications from this study are summarized below.

First, we found that the EEE of 20 steel firms exhibits a decreasing trend across the span of five years. Even if there has been a short upturn in 2014 due to the exchange rate fluctuation coming from the global economic crisis, the trend, in general, clearly shows a downturn of the EEE. Since the Porter hypothesis strongly supports the regulation policies for enhancing efficiency, our results imply that government regulation is not enough for the firms to react in addition to the regulation. For example, Samsung Electronics Co., the most representative Korean company, paid millions of dollars in penalties for three years since the inauguration of the ETS in 2015. The relaxed target of 100% allowances for the participating companies in the first stage of the ETS could not encourage the covered companies to invest in green technology. Therefore, it seems that strong regulation is needed to enhance the sustainable performance of ETS, according to the Porter hypothesis. TEE always exhibits a higher value than EEE because TEE does not consider undesirable output of GHGs. Thus, it is reasonable to include undesirable output in a more systematic way to prevent this kind of overestimated bias. On the other hand, there is no systematic relationship between TEE and EEE, implying that GHGs are not the sole reason causing the firms' higher inefficiency. Therefore, changes in intra-company governance, production structure, and technical innovation are required for firms to overcome the aggravating inefficiency in the steel industry over time.

Second, from the perspective of returns to scale, almost all firms show IRS, implying that the Korean steel industry has room to increase its overall industrial efficiency through an increase in scale. Therefore, it is certain that the potential efficiency shall increase if there is enough green investment. Meanwhile, as you can see in the SeAH Steel case, if a firm is competitive on its own, it may maintain a high efficiency regardless of regulation. Thus, each firm should make efforts to enhance their own competitiveness for their sustainable performance. Of course, this kind of scale upgrading may require higher emissions targets and, thus, the government should promote a balanced green investment of the covered companies between enhanced efficiency and newly-added responsibility [26]. It is noteworthy that upgrading the scale may not only arise from green investment, but also from organizational culture and/or behavioral changes in the private sectors. For this purpose, this paper showed the optimal leaning path of the inefficient firms toward their individual benchmark reference sets. Well-provided benchmark information can be helpful for guiding the efficiency enhancement of inefficient firms. Thus, each inefficient firm needs to refer to its unique benchmark reference set for its sustainable performance. Most of all, the covered companies should participate in the ETS not with a passive, critical, cost-saving attitude, but with a more proactive partnership, to lead the new international norms of sustainable development.

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

Appendix

Table A1. The industries and the number of covered companies in the Korean ETS.

Industry	Number of Companies	Industry	Number of Companies
Construction	40	Textiles	15
Mining	2	Water	3
Machinery	19	Cement	25
Wood processing	7	Glass	24
Electronic, displays, and semiconductors	45	Food and drink	23
Power and energy	38	Car manufacturing	24
Nonmetallic	24	Oil refining	4
Petrochemical	85	Paper	44
Shipbuilding	8	Steel	40
Telecommunications	6	Waste	44
Aviation	5	Total	525

Table A2. Carbon allocation for each industry in the Korean ETS.

Sector	Industry		Commitment Period 2015	2016	2017	Three-Year Total
Total amount of emissions			573,460,132	562,183,138	550,906,142	1,686,549,412
Pre-allocated quota			543,227,433	532,575,917	521,924,398	1,597,727,748
Reserve			88,821,664			
Electricity	Power & Energy		250,189,874	245,284,190	240,378,507	735,852,571
Industry	Mining		245,386	240,575	235,763	721,724
	Food and drink		2,534,679	2,484,980	2,435,280	7,454,939
	Textile		4,701,454	4,609,269	4,517,084	13,827,807
	Wood		384,051	376,521	368,990	1,129,562
	Paper		7,630,496	7,480,879	7,331,261	22,442,636
	Oil refining		19,153,420	18,777,862	18,402,305	56,333,587
	Petro-chemical		48,857,291	47,899,305	46,941,318	143,697,914
	Glass		6,263,680	6,140,863	6,018,046	18,422,589
	Cement		43,518,651	42,665,344	41,812,037	127,996,032
	Steel	General	103,284,517	101,259,331	99,234,144	303,777,992
		F-gas products	675,361	662,119	648,877	1,986,357
	Non-ferrous		6,888,332	6,753,266	6,618,201	20,259,799
	Machine		1,416,225	1,388,456	1,360,687	4,165,368
	Semi Con.	General	8,252,756	8,090,937	7,929,118	24,272,811
		F-gas products	2,202,049	2,158,871	2,115,694	6,476,614
	Display	General	6,705,480	6,574,000	6,442,520	19,722,000
		F-gas products	2,438,238	2,390,430	2,342,621	7,171,289
	Electronics		2,877,479	2,821,058	2,764,637	8,463,174
	Cars		4,242,789	4,159,597	4,076,405	12,478,791
	Ship-building		2,683,132	2,630,522	2,577,911	7,891,565
Building	Building	4,017,219	3,938,450	3,859,681	11,815,350	
	Telecommunication		3,089,243	3,028,670	2,968,096	9,086,009
Transportation	Air transportation		1,289,780	1,264,490	1,239,201	3,793,471
Public & waste	Water		766,351	751,324	736,298	2,253,973
	Waste		8,919,500	8,744,608	8,569,716	26,233,824

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Analysis of Total Factor Energy Efficiency and Its Influencing Factors on Key Energy-Intensive Industries in the Beijing-Tianjin-Hebei Region

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Abstract: In order to realize the synergistic optimization management of energy efficiency in the key energy-intensive industries of the Beijing-Tianjin-Hebei (Jing-Jin-Ji) region, this paper calculates the total factor energy efficiency (TFEE) of 27 industries in the Jing-Jin-Ji region. We discover that the manufacturing of raw chemical materials and chemical products, the smelting and processing of ferrous metals, and the production and supply of electric power and heat power are key industries, considering their economic output ratio, energy consumption ratio, and energy efficiency. Then, the Malmquist index is used to decompose the TFEE of key energy-intensive industries. The results show that the TFEE changes in the three major industries in the Jing-Jin-Ji region are caused by technological progress. Hebei has the highest total factor average energy efficiency in the production and supply of electric power and heat power industry, the main reason for this being the spillover effect from Beijing enterprises that have led to significant technological changes in Hebei. Due to similar technological advancements, Tianjin has the highest total factor average energy efficiency in the manufacturing of raw chemical materials and chemical products and the smelting and processing of ferrous metals. Therefore, the Jing-Jin-Ji region should work to increase its technological innovation and enhance its core competitiveness. We should optimize the allocation of resources in specific industries to improve the scale efficiency.

Keywords: Beijing-Tianjin-Hebei region; industrial industries; TFP; DEA; Malmquist index

1. Introduction

The Jing-Jin-Ji region is part of China's capital region and, as such, holds an important strategic position. At the end of 2015, the total population of the region exceeded 100 million, accounting for 8.11% of the total Chinese population. Total energy consumption reached 452.58 million tons of standard coal, accounting for 10.95% of the national total energy consumption, and the regional gross domestic product (GDP) reached 6935.889 billion Renminbi (RMB), accounting for 9.60% of China's GDP. Moreover, during the 12th Five Year Plan (FYP) period, the economy of the Jing-Jin-Ji region was strong, with an average GDP growth rate of 7.4%, while total energy consumption growth slowed down to an average growth rate of 0.68%. However, due to the large total consumption of energy, there is still a significant impact on the ecological environment. In 2015, the Jing-Jin-Ji region accounted for nine out of 10 of the cities with the most severe smog and haze occurrences in China. While the environment is deteriorating, the energy shortage in the Jing-Jin-Ji region is still unresolved. In 2015, primary energy production accounted for only 17.79% of total consumption. Faced with the dual challenges of energy shortage and environmental pollution, energy efficiency management has become an important solution. At present, the Beijing, Tianjin, and Hebei provinces have great differences in the effectiveness of their energy efficiency management. In 2015, the energy consumption reduction rate per 10,000 RMB gross regional product in the Beijing, Tianjin, and Hebei provinces was 6.17% (Beijing), 7.21% (Tianjin), and 6.14% (Hebei). The differences between the three industries' reduction rates of 10,000-yuan industrial added value of energy consumption were even more striking, with rates of 8.16%, 13.25%, and 6.02%, respectively. Therefore, identifying the differences in energy efficiency between the three provinces and exchanging energy utilization experience will be conducive to lessening the industry energy efficiency differences in the Jing-Jin-Ji region. This should improve the overall energy efficiency of the Jing-Jin-Ji region and achieve coordinated development. Meanwhile, there were some changes of industrial energy consumption proportion in Beijing, Tianjin, and Hebei between 2005 and 2015. The detailed proportions are shown in Figure 1. The internal ring shows the industrial energy consumption of 27 industries in the Beijing-Tianjin-Hebei (BTH) area in 2005, while the outer ring shows the industrial energy consumption of 27 industries in the BTH area in 2015. Several signs indicate the trend of many Beijing factories being relocated to the city boundary, especially to Hebei Province. For example, the proportion of energy consumption by the manufacture of raw chemical materials and chemical products in Beijing declined from 7.81% in 2005 to 5.28% in 2015. However, this proportion in Tianjin rose to 32.08% in 2015 from 23.63% in 2005, and the proportion in Hebei reached 8.10% in 2015, an increase of 1.32% over 2005. We aim to analyze whether this shift in industry location is beneficial to the industrial total factor energy efficiency. Thus, in this paper we present a study of the total factor energy efficiency and its influencing factors in many key energy-intensive industries in the Beijing-Tianjin-Hebei region.

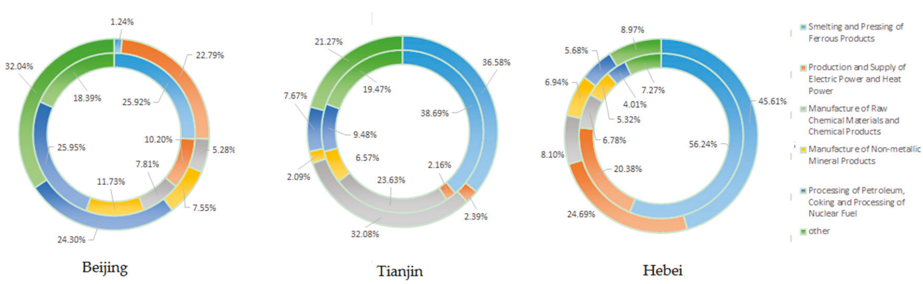

Figure 1. The change of industrial energy consumption proportions.

The second part of this paper serves as a literature review, summarizing existing research methods and measurement indicators. The third part introduces the technical route and the total factor energy efficiency indicators' calculation methods and models. The fourth part measures the total factor energy efficiency (TFEE) of 27 industries in the Jing-Jin-Ji region. In the fifth part, three key industries are selected and the Malmquist index is used to decompose the energy efficiency of the Jing-Jin-Ji region. Finally, the sixth part offers conclusions and policy suggestions.

2. Literature Review

Energy efficiency has been extensively researched by academics, both internationally and domestically. Energy intensity is a single factor efficiency index, which has some apparent flaws. TFEE appears more advantageous, particularly in certain circumstances such as revealing the impact of regional resource endowments on energy efficiency. Accordingly, in recent years, scholars have turned more towards energy efficiency research under a total factor framework. The most common method of TFEE is data envelopment analysis. Specific examples in the literature are shown in Table 1.

Table 1. Research on total factor energy efficiency.

Authors	Evaluation Object	Indexes	Method
Zhang et al. (2011) [1]	Yangtze River Delta	Energy, Labor, Capital Stock, GDP, Exhaust gas	Super Efficiency–Data Envelopment Analysis (SE-DEA), Malmquist-Luenberger (ML) productivity index
Feng et al. (2015) [2]	Beijing-Tianjin-Hebei metropolitan region	Energy, Labor, Capital Stock, GDP, CO_2, SO_2, Inhalable particles	Slack Based Model (SBM model), Tobit model
Ma et al. (2011) [3]	Yangtze River Delta, Peral River Delta, Bohai Zone	Energy, Labor, Capital Stock, Number of patent authorizations, GDP	SE-DEA, ML productivity index
Zhao et al. (2013) [4]	29 provinces in China	Energy, Labor, Capital Stock, GDP	Stochastic Frontier Analysis (SFA) model
Wang et al. (2014) [5]	Industrial sector of 30 Chinese major cities	Energy, Labor, Capital Stock, Value-added of industrial enterprises, CO_2, SO_2	Data Envelopment Analysis
Zhang and Choi (2013) [6]	30 provinces in China	Energy, Labor, Capital Stock, GDP, CO_2, SO_2, COD	SBM-DEA
Apergis et al. (2015) [7]	20 Organization For Economic Cooperation And Development (OECD) countries	Productive capital stock, Labor, Renewable and non-renewable energy	SBM model
Wu et al. (2014) [8]	China's industry	Fixed assets of industry, Electricity, GRP in industry, NO_2	Data Envelopment Analysis
Wang et al. (2013) [9]	30 regions in China	Energy, Labor, Capital Stock, GDP, CO_2	Range Adjusted Measure–Data Envelopment Analysis (RAM-DEA)
Long et al. (2013) [10]	31 provinces in China	Capital, Labor, Coal, GRP, SO_2	Directional distance function
Wang and Chen (2010) [11]	25 industries in China	Energy, Labor, Capital Stock, Value-added of industrial	DEA, Tobit model
Chen(2014) [12]	30 industries in China	Coal, Electricity, Oil, Labor, Capital Stock, Value-added of industrial	Stochastic frontier analysis (SFA)
Huang et al. (2014) [13]	30 provinces in China	Energy, Labor, Capital Stock, Land input, GDP, Environment pollutants	Undesirable output, super efficiency and SBM (US-SBM)
Fan et al. (2015) [14]	32 industrial sub-sectors in Shanghai	Energy consumption, Labor force, Capital stock, Gross industrial output, CO_2	Geography Markup Language (GML) index
Rohdina et al. (2007) [15]	The Swedish foundry industry	Capital, Technical risk, Long-term energy strategy, People with real ambition et al.	A case study, a questionnaire
Saygin et al. (2012) [16]	The German basic chemical industry	Energy coverage, Energy efficiency improvements,	The Process Industries–Inventory Energy Use Plus model (PIE-Plus)
Wu et al. (2007) [17]	The steel industry of Taiwan	Process equipment, Operation method, Energy category, Raw material, System management, Energy saving activity, Utilization of production capability	Taylor series expansion
Hassan et al. (2017) [18]	Small and medium-sized manufacturing enterprises in Pakistan	Access to capital, Risk and hidden cost, Government and state policies	Semi-structured questionnaires and interviews
Honma et al. (2014) [19]	The industries in Japan and 14 developed countries	Labor, Capital stock, Energy and non-energy intermediate inputs	DEA methodology, Sensitivity analyses
Zhou et al. (2010) [20]	18 top CO_2 emitters of the world	Energy, Labor, Capital stock, GDP, CO_2	Malmquist CO_2 Emission Performance Index (MCPI) index, Bootstrapping MCPI index, DEA
Sueyoshi et al. (2017) [21]	30 municipalities and provinces in China	GRP, CO_2, SO_2, Dust, Waste water, Ammonia nitrogen, Energy, Labor, Capital	DEA ML Productivity index
Zhang et al. (2015) [22]	CO_2 emission in Chinese transportation industry	Energy, Labor, Capital Stock, GDP, CO_2	Non-Radial Malmquist CO_2 Emission Performance Index (NMCPI) Bootstrapping approach
Zhou et al. (2012) [23]	OECD countries	Capital stock, Labor force, Energy, GDP	DEA, SFA
Sueyoshi et al. (2017) [24]	30 industries in China	GRP, CO_2, SO_2, Smoke and Dust, Waste Water, COD, Ammonia Nitrogen, Capital, Labor, Energy	DEA, Radial approach non-radial approach
Sueyoshi et al. (2016) [25]	30 municipalities and provinces	GRP, Primary industry, Secondary industry, Tertiary industry, PM_{10}, SO_2, NO_2, Investment, Coal, Oil, Natural gas, Electricity	Radial model: Returns to Damage (RTD) and Damages to Return (DTR) under congestions

3. Model and Estimation Methods

3.1. Research Route

The technical route is shown in Figure 2.

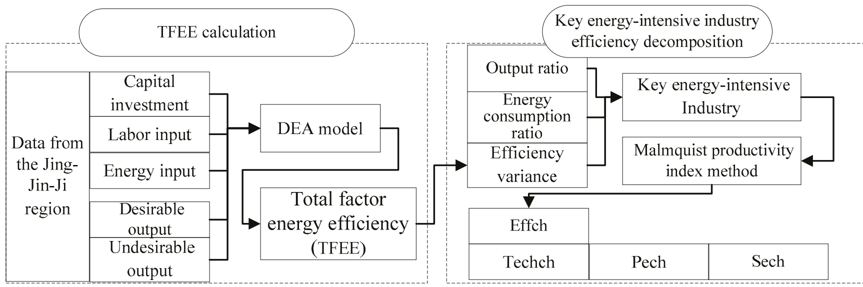

Figure 2. Research technical route.

3.2. Model Method

3.2.1. Total-Factor Energy Efficiency

Hu and Wang [26] defined total-factor energy efficiency (TFEE) since the index is established based on the viewpoint of total factor productivity. Index TFEE is also employed to analyze energy efficiency in an industry; Industry α's TFEE at time t is:

$$\text{TFEE}(\alpha) = \frac{\sum \text{Target Energy Input}(t)}{\sum \text{Actual Energy Input}(t)} \tag{1}$$

Here, Equation (1) shows that the TFEE in an industry is calculated by dividing the summation of target energy inputs by the total actual energy inputs of the industry.

3.2.2. DEA Model

Data envelopment analysis (DEA) was proposed by American operational researchers Charnes, Cooper, and Rhodes in 1978; accordingly named the CCR model, it uses mathematical programming and statistical data to identify the relatively efficient production frontier. The decision-making unit is projected onto the production frontier and then their relative validity is evaluated by comparing the extent to which decision-making units deviate from the production frontier. The DEA method has its unique advantages. Firstly, it is suitable for evaluating the validity of multiple-input and multiple-output. Secondly, there is no need for non-dimensional data processing when applying this method. Finally, it eliminates many subjective factors without any weight assumption.

The CCR model is the most classic DEA model and is based on the assumption of constant returns to scale, although this assumption does not match reality. To this end, Banker et al. (1984) added variable returns to the scale based on the CCR model and proposed the Banker, Charnes, and Cooper (BCC) model. Not only is this model more in line with the actual production experience, but it can examine the technical efficiency and scale effectiveness of decision-making units. Its specific form is:

$$\begin{aligned} & Min\theta \\ s.t. \quad & \sum_{j=1}^{n} \lambda_j x_j \leq \theta x_0 \\ & \sum_{j=1}^{n} \lambda_j y_j \geq y_0 \\ & \sum \lambda_j = 1; \lambda_j \geq 0, j = 1, \ldots, n \end{aligned} \tag{2}$$

where θ is the effective value of the evaluation unit, s^+ and s^- are the slack variables, λ_j is the combination ratio of the original decision unit, and the corresponding reconstructed decision unit.

The efficiency value (TIE) calculated by the CCR model can be decomposed into the product of the scale efficiency (SE) and pure technical efficiency (PTE), namely, technical efficiency = pure technical efficiency $\times$ scale efficiency, and pure technical efficiency is the efficiency value required for the BCC model. Then we can determine the returns to scale of decision-making units according to the value of $\sum \lambda_j$:$\sum \lambda_j > 1$, which indicates a diminishing returns to scale. $\sum \lambda_j = 1$ means the returns to scale reaches the best point of return, while $\sum \lambda_j < 1$ indicates an increasing returns to scale.

3.2.3. Unified Efficiency DEA Model

To deal with the undesirable outputs in assessing the operational and environmental performance of energy firms, Fare [27] proposed the following directional distance function:

$$Max\{\theta | (G + \beta\zeta_g, B - \beta\zeta_b) \in P(X)\} \quad (3)$$

Here, $P(X)$ = {(G, B): X can produce (G, B)}. The $P(X)$ indicates a production possibility set, which has a column vector of inputs (X) that can produce not only a column vector of desirable outputs (G) but also a column vector of undesirable outputs (B). $\zeta = (\zeta_g, -\zeta_b)$ is suggested as (1, 1, ..., 1, -1, -1, . . . , $-1)^T$, which contains $s + h$ components.

Mandal and Madheswaran [28] assumed that if the firm's objective is to simultaneously expand the desirable outputs and reduce the undesirable ones by the same proportion without increasing the inputs, the directional technology distance function becomes:

$$\vec{D}_T(x, y, b; 0, y, -b) = \sup[\beta : [(1 + \beta)y, (1 - \beta)b] \in P(x)] \quad (4)$$

The value β represents technical inefficiency. The direction vector $g = (g_x, g_y, -g_b) = (0, y, -b)$ determines the direction in which efficiency is measured. Given the technology and direction vector, the directional distance function measures the maximum feasible expansion of desirable output and the directional distance function β is zero. The directional distance function β is obtained by solving the maximization problem in Model (5).

$$\begin{aligned} & Max\beta \\ s.t. \quad & \sum_{j=1}^{n} x_{ij}\lambda_j \leq x_{ik} \qquad (i = 1, \ldots.) \\ & \sum_{j=1}^{n} g_{rj}\lambda_j \geq grk + \beta g_{rk} \quad (r = 1, \ldots.) \\ & \sum_{j=1}^{n} b_{fj}\lambda_j \leq b_{fk} - \beta b_{fk} \quad (f = 1, \ldots.) \\ & \sum_{j=1}^{n} \lambda_j = 1 \\ & \beta \geq 0, \lambda_j \geq 0 \quad (j = 1, \ldots.) \end{aligned} \quad (5)$$

Here, the outputs regarding the jth decision making unit (DMU) are separated into desirable outputs (g_{rk}) and undesirable outputs (b_{fk}). This model can measure the efficiency by $\theta = 1 - \beta$, where β is obtained from the optimality of Model (5).

In addition to Model (5), Zhou and Ang [29] proposed the following model to measure the unified efficiency of the energy firms:

$$\begin{array}{lll} & Min\theta & \\ s.t. & \sum_{j=1}^{n} x_{ij}\lambda_j \leq x_{ik} & (i = 1, \ldots.) \\ & \sum_{j=1}^{n} e_{qj}\lambda_j \leq \theta e_{qk} & (q = 1, \ldots.) \\ & \sum_{j=1}^{n} g_{rj}\lambda_j \geq g_{rk} & (r = 1, \ldots.) \\ & \sum_{j=1}^{n} b_{fj}\lambda_j = b_{fk} & (f = 1, \ldots.) \\ & \theta \geq 0 and \lambda_j \geq 0 & (j = 1, \ldots.) \end{array} \quad (6)$$

Here, inputs regarding the *j*th DMU are separated into non-energy (x_{ij}: i = 1) and energy-related inputs (e_{ij}: q = 1, …). Model (6) can be considered as an extension of CCR (Charnes-Cooper-Rhods) and the production possibility set of Model (6) is shaped by constant RTS (returns to scale).

3.2.4. Clustering Analysis

Clustering analysis is a kind of statistical method used to classify the research objects corresponding to the data. Through clustering analysis, we can measure the distance between different combinations, adopt different measuring distance methods, combine the two closest combinations in all combinations into one, and repeat the operation. Therefore, the final result will show the most similar samples gathered together; this plays an important role in statistical analysis.

3.2.5. Principal Component Analysis

Principal component analysis is a statistical analysis method that simplifies multiple indicators into a small number of comprehensive indicators, using a small number of variables to reflect as much of the original variable's information as possible while ensuring that the original information loss is small. Suppose $X = (X_1, X_2, \ldots, X_P)'$ is a p-dimensional random vector whose linear variation is as follows:

$$\begin{array}{c} PC_1 = \alpha'_1 X = \alpha_{11}X_1 + \alpha_{21}X_2 + \ldots + \alpha_{p1}X_p \\ PC_2 = \alpha'_2 X = \alpha_{12}X_1 + \alpha_{22}X_2 + \ldots + \alpha_{p2}X_p \\ \ldots\ldots\ldots \\ PC_p = \alpha'_p X = \alpha_{1p}X_1 + \alpha_{2p}X_p + \ldots + \alpha_{pp}X_p \end{array}$$

Using the new variable PC_1 to replace the original p variables, $X_1, X_2, \ldots, X_P$, PC_1 should reflect the original variable information as much as possible. If the first principal component is not enough to represent most of the information of the original variable, consider introducing the second principal component PC_2, and so on. The main purpose of principal component analysis is to simplify the data. Therefore, in practical application we will not take p main components; rather, we will usually use m ($m < p$) principal components. Number m of the principal component is finally determined according to the cumulative variance contribution rate of each principal component.

$$\text{Cumulative variance contribution rate} = \sum_{k=1}^{m} \lambda_k / \sum_{i=1}^{p} \lambda_i$$

where λ is the corresponding eigenvalue of each principal component; k is the selected principal component fraction; and i is number of the total principal components.

3.2.6. Malmquist Index

The Malmquist productivity index, originally proposed by Sten Malmquist, constructs the total factor productivity (TFP) index from period t to t + 1. In 1992, Fare combined the DEA model solution with the Malmquist index calculation. The Malmquist productivity index (TFPCH) can be decomposed into the technical efficiency change index (EFFCH) and the technical change index (TECHCH). The transformation of the Malmquist index is as follows:

$$M(x^{t+1}, y^{t+1}, x^t, y^t) = \frac{D^{t+1}(x^{t+1}, y^{t+1})}{D^t(x^t, y^t)} \times \left[\frac{D^t(x^{t+1}, y^{t+1})}{D^{t+1}(x^{t+1}, y^{t+1})} \times \frac{D^t(x^t, y^t)}{D^{t+1}(x^t, y^t)}\right] = \mathrm{EFFCH} \times \mathrm{TECHCH} \quad (7)$$

When the returns to scale change, the technical efficiency change index can be further decomposed into pure technical efficiency change (PECH) and scale efficiency change (SECH).

$$\frac{D^{t+1}(x^{t+1}, y^{t+1})}{D^t(x^t, y^t)} = \frac{D^{t+1}(x^{t+1}, y^{t+1}/V)}{D^t(x^t, y^t/V)} \times \frac{S^{t+1}(x^{t+1}, y^{t+1})}{S^t(x^t, y^t)} = \mathrm{PECH} \times \mathrm{SECH} \quad (8)$$

The final transformation of the Malmquist index is as follows:

$$M(x^{t+1}, y^{t+1}, x^t, y^t) = \mathrm{EFFCH} \times \mathrm{TECHCH} = \mathrm{PECH} \times \mathrm{SECH} \times \mathrm{TECHCH} \quad (9)$$

$M(x^{t+1}, y^{t+1}, x^t, y^t)$ represents the variation of the TFP level. If EFFCH > 1, it indicates that the relative technical efficiency of t and $t + 1$ period is increased, whereas, in the contrary, it is the reverse. If TECHCH > 1, it indicates that $t + 1$ period has technological progress compared to t period, whereas, in the contrary, it is the reverse. PECH indicates whether the technology is fully utilized; if it is larger than 1, it indicates that the resource allocation is reasonable, whereas, in the contrary, it is the reverse. SECH expresses the index of the change of scale efficiency in two periods; if it is larger than 1, it means that the scale efficiency is optimized, whereas, in the contrary, it is the reverse.

4. Jing-Jin-Ji Region Key Energy-Intensive Industries Analysis

4.1. Jing-Jin-Ji Region Industrial Industries TFP Measurement

This paper selects the industrial energy input and output indicators of the 27 industries above designated size in the Jing-Jin-Ji region from 2005 to 2015. The indicators are defined as follows:

Capital investment. Capital investment is expressed as the "total fixed investment" of the industries above the designated size in the Jing-Jin-Ji region, and the actual value of the corresponding year is reduced by the fixed-asset investment price index (2005 = 100).

Labor input. Select the Jing-Jin-Ji region above the designated size industrial "average number of years of employment" as a labor input index.

Energy input. Select the Jing-Jin-Ji region above the designated size industrial energy total consumption as the energy input.

Desirable output. Select the Jing-Jin-Ji region above the designated size total industrial output as the desirable output, and the actual value of the corresponding year is reduced by the industrial production price index (2005 = 100).

Undesirable output. Calculate the CO_2 emissions of 27 industries in 2005–2015 according to the 2006 Intergovernmental Panel on Climate Change (IPCC) Guidelines for National Greenhouse Gas Inventories. The above data is sourced from the Beijing Statistical Yearbook, Tianjin Statistical Yearbook, Hebei Economic Yearbook, China Industrial Economy Yearbook, and China Population and Employment Statistics Yearbook from 2006 to 2016 calendar years.

Descriptive statistics of TFEE measurement indicators are shown in Table 2.

Table 2. Descriptive statistics of TFEE measurement indicators of the Jing-Jin-Ji region.

Variables	Unit	Quantity	Expected Value	Variance	Maximum Value	Minimum Value
Capital	10,000 yuan Renminbi (RMB)	891	1,925,008.5	1006.227	48,598,069	719.7662
Labor	10,000 people	891	4.27	5.12	42.8	0.25
Energy	10,000 tons of standard coal	891	251.4162	1003.602	10,765.11	0.32
Desirable output	10,000 yuan RMB	891	5,135,763.6	9,995,731.7	119,232,787	17,693.821
Undesirable output	10,000 tons	891	648.7856	2474.223	26,446.65	0.029884

4.2. TFEE Measurement Results

The DEA model is used to calculate the TFEE results of the Jing-Jin-Ji region in 27 industries in Beijing, Tianjin, and Hebei from 2005 to 2015. The descriptive statistics of the TFEE results are shown in Table 3.

Table 3. TFEE measurement results of the Jing-Jin-Ji region.

Number	Industrial Industries	Beijing		Tianjin		Hebei	
		Average	Median	Average	Median	Average	Median
1	Processing of Food from Agricultural Products	0.526	0.244	0.449	0.119	0.381	1.000
2	Manufacture of Foods	0.291	0.149	0.310	0.074	0.298	0.064
3	Manufacture of Beverages	0.270	0.188	0.203	0.035	0.247	0.047
4	Manufacture of Textile	0.343	0.110	0.168	0.023	0.310	0.985
5	Manufacture of Textile Wearing Apparel and Accessories	0.410	0.103	0.651	0.207	0.729	0.100
6	Manufacture of Leather, Fur, Feathers, and Related Products	0.713	0.151	0.379	0.136	0.763	0.198
7	Manufacture of Timber, Manufacture of Wood, Bamboo, Rattan, Palm, and Straw Products	0.226	0.151	0.325	0.083	0.319	0.065
8	Manufacture of Furniture	0.338	0.121	0.325	0.064	0.371	0.061
9	Manufacture of Paper and Paper Products	0.340	0.233	0.166	0.039	0.212	0.059
10	Printing and Reproduction of Recording Media	0.189	0.115	0.251	0.040	0.425	0.064
11	Manufacture of Articles for Culture, Education, Arts and Crafts, Sport and Entertainment activities	0.357	0.066	0.551	0.088	0.627	0.084
12	Processing of Petroleum, Coking and Processing of Nuclear Fuel	0.908	0.841	0.307	1.000	0.203	0.525
13	Manufacture of Raw Chemical Materials and Chemical Products	0.338	0.279	0.170	1.000	0.181	1.000
14	Manufacture of Medicines	0.348	0.242	0.263	0.040	0.206	0.064
15	Manufacture of Rubber and Plastic Products	0.268	0.141	0.264	0.043	0.285	0.130
16	Manufacture of Non-Metallic Mineral Products	0.281	0.214	0.181	0.043	0.173	1.000
17	Smelting and Pressing of Ferrous Products	0.473	0.400	0.280	1.000	0.265	1.000
18	Smelting and Pressing of Non-Ferrous Products	0.591	0.344	0.713	0.170	0.422	0.058
19	Manufacture of Metal Products	0.368	0.203	0.389	0.295	0.470	0.696
20	Manufacture of General Purpose Machinery	0.424	0.247	0.398	0.122	0.378	0.690
21	Manufacture of Special Purpose Machinery	0.435	0.226	0.377	0.080	0.389	0.058
22	Manufacture of Railway, Ship, Aerospace, and Other Transport Equipment	0.593	0.554	0.522	1.000	0.526	1.000
23	Manufacture of Electrical Machinery and Apparatus	0.656	0.403	0.564	0.138	0.606	0.550
24	Manufacture of Computers, Communication, and Other Electronic Equipment	0.835	0.745	0.975	0.569	0.519	0.071
25	Production and Supply of Electric Power and Heat Power	0.830	0.780	0.230	1.000	0.068	1.000
26	Production and Supply of Gas	0.359	0.412	0.597	0.274	0.389	0.061
27	Production and Supply of Water	0.210	0.095	0.154	0.049	0.142	0.015

The definition and information of these 27 industries can be found in national bureau of statistics of China.

4.3. TFEE Measurement Results and Information Statistics

The DEA model, data of TFEE, average TFEE, variance, proportion of energy consumption in various industrial industries, and economy output ratio in 27 industries in Beijing, Tianjin, and Hebei from 2005 to 2015 are used. The descriptive statistics of upper indicators are shown in Table 4.

Table 4. Descriptive statistics of industry data in the Jing-Jin-Ji region.

Number	Industrial Industries	TFEE Variance	Energy Consumption Ratio	Economy Output Ratio
1	Processing of Food from Agricultural Products	0.219	0.012	0.041
2	Manufacture of Foods	0.162	0.009	0.031
3	Manufacture of Beverages	0.072	0.003	0.010
4	Manufacture of Textile	0.261	0.005	0.022
5	Manufacture of Textile Wearing Apparel and Accessories	0.014	0.001	0.011
6	Manufacture of Leather, Fur, Feathers, and Related Products	0.092	0.001	0.017
7	Manufacture of Timber, Manufacture of Wood, Bamboo, Rattan, Palm, and Straw Products	0.046	0.002	0.004
8	Manufacture of Furniture	0.044	0.001	0.006
9	Manufacture of Paper and Paper Products	0.090	0.006	0.009
10	Printing and Reproduction of Recording Media	0.033	0.002	0.006
11	Manufacture of Articles for Culture, Education, Arts and Crafts, Sport and Entertainment activities	0.027	0.001	0.012
12	Processing of Petroleum, Coking and Processing of Nuclear Fuel	0.200	0.060	0.042
13	Manufacture of Raw Chemical Materials and Chemical Products	0.328	0.107	0.051
14	Manufacture of Medicines	0.148	0.007	0.026
15	Manufacture of Rubber and Plastic Products	0.100	0.006	0.024
16	Manufacture of Non-Metallic Mineral Products	0.262	0.050	0.033
17	Smelting and Pressing of Ferrous Products	0.147	0.493	0.174
18	Smelting and Pressing of Non-Ferrous Products	0.096	0.003	0.018
19	Manufacture of Metal Products	0.114	0.012	0.052
20	Manufacture of General Purpose Machinery	0.123	0.005	0.036
21	Manufacture of Special Purpose Machinery	0.048	0.007	0.036
22	Manufacture of Railway, Ship, Aerospace, and Other Transport Equipment	0.175	0.013	0.133
23	Manufacture of Electrical Machinery and Apparatus	0.198	0.007	0.045
24	Manufacture of Computers, Communication, and Other Electronic Equipment	0.288	0.003	0.061
25	Production and Supply of Electric Power and Heat Power	0.109	0.177	0.091
26	Production and Supply of Gas	0.093	0.005	0.008
27	Production and Supply of Water	0.070	0.002	0.002

4.4. Analysis of Key Energy-Intensive Industry in the Jing-Jin-Ji Region

4.4.1. Clustering Analysis Result

The clustering analysis of 27 industrial industries in Beijing, Tianjin, and Hebei is conducted by using the method of system clustering analysis, according to the three indicators of energy consumption ratio, economy output ratio, and energy efficiency fluctuation. The calculation results are shown in Figure 3.

Through Figure 3, we find that the 27 industries are divided into three categories. The first category is the production and supply of electric power and heat power, raw chemical materials and chemical products, the smelting and processing of ferrous metals, and the oil and gas mining industry. The second category is petroleum processing, the coking and nuclear fuel processing industry, the manufacturing of computers, communication, and other electronic equipment, and the manufacturing of railways, ships, aerospace equipment, and other transport equipment. Finally, the third category is comprised of the remaining industries.

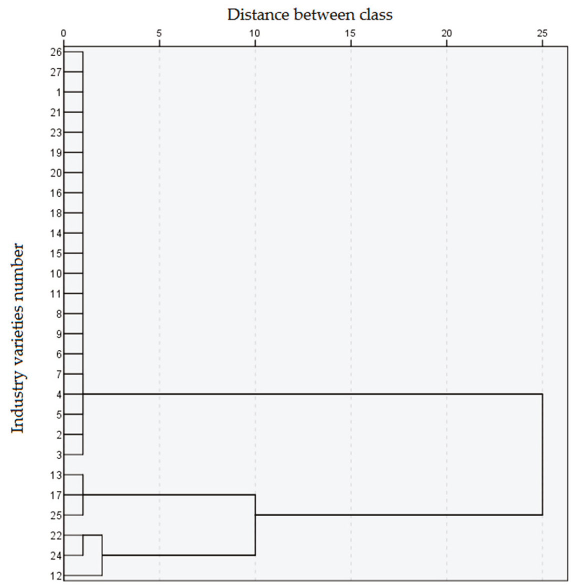

Figure 3. System clustering figure.

4.4.2. Principal Component Analysis Result

Through principal component analysis, we reduce the number of variables, while minimizing the original information loss, to make the research clearer and the categorization more intuitive. The specific results are shown in Figure 4.

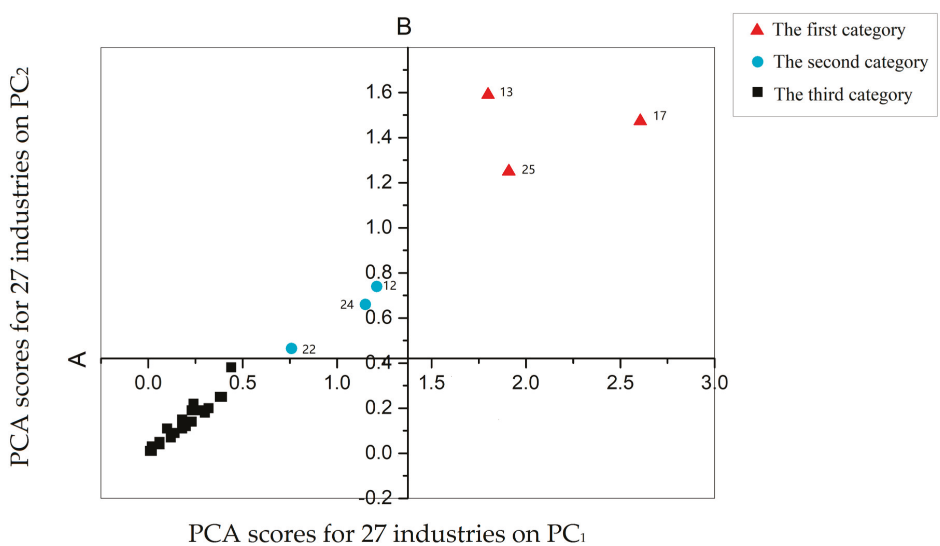

Figure 4. Principal component analysis.

Two principal components are selected. The first principal component predominately reflects the energy consumption information, while the second principal component mainly reflects the output value information. The cumulative variance contribution rate is 97.7%, which is greater than the threshold value of 85%. We find that the production and supply of electric power and heat power, raw chemical materials and chemical products, smelting, and the processing of ferrous metals fall in the positive direction of the first principal component and the second principal component. This indicates that the three industries account for a large proportion of the energy consumption ratio and economic output ratio. The petroleum processing, coking and nuclear fuel processing industry, the manufacturing of computers, communication, and other electronic equipment, and the manufacturing of railways, ships, aerospace equipment, and other transport equipment fall in the second quadrant of the first principal component and the second principal component. This indicates that the three industries account for a larger proportion of output, but a smaller proportion of energy consumption. The remaining industries in the third quadrant indicate low energy consumption and low output.

4.4.3. The Results of Analysis of Key Energy-Intensive Industries in the Jing-Jin-Ji Region

Based on the two methods above, we conduct the following classification system. The specific results are shown in Table 5.

Table 5. Industry classification table.

Classification	Industrial Industries
The first category	Raw Chemical Materials and Chemical Products, Smelting and Processing of Ferrous Metals, Production and Supply of Electric Power and Heat Power
The second category	Petroleum Processing, Coking and Nuclear Fuel Processing Industry, Manufacturing of Computers, Communication, and Other Electronic Equipment, Manufacturing of Railway, Ship, Aerospace, and Other Transport Equipment
The third category	The rest of the department

The above categorization is useful according to clustering analysis and principal component analysis. The industries are classified into three types. The first type has a high GDP, a large amount of energy consumption, and a large difference in energy efficiency between the three provinces. The second type has a relatively high GDP, relatively low energy consumption, and a relatively large difference in energy efficiency between the three provinces. The third type has a small GDP and energy consumption, with energy efficiency differences between the three provinces also proving small. We select the first type of industries as the focus of this study.

5. Analysis of Influencing Factors of the TFEE in Key Energy-Intensive Industries

5.1. Production and Supply of Electric Power and Heat Power

From the overall integrated efficiency change, the average value of the production and supply of electric power and heat power in the Jing-Jin-Ji region is 1.065, of which the average of technical progress changes is 1.090, while the average of comprehensive technical efficiency changes is 1.038. Judging from its decomposition, the pure technical efficiency change index average value is 1.083, and the scale efficiency change index is 0.985. This shows that the Jing-Jin-Ji region has made remarkable achievements in technological innovation. The reason for the low efficiency of integrated technology is the change in scale efficiency, indicating that the optimal industrial scale has not yet been reached.

In terms of differences, Beijing's TFP has been on a downward trend since 2009 and is much lower than that of Tianjin and Hebei in 2015. By contrast, the TFP of industry in Hebei Province is greater than 1 each year, indicating that the industry in Hebei Province has been showing a positive progressive change. At 9%, it has the highest average annual rate of change among the three provinces.

In Tianjin, the average annual rate of change is 6.7% in the industry, but in a few years the TFP changes predict negative growth. The change curves of TFP in the production and supply of electric power and heat power in the Jing-Jin-Ji region are shown in Figure 5.

The average scale efficiency of the industry in Beijing is 0.839, which is lower than the values of 1.005 in Tianjin and 0.965 in Hebei. This is the predominate reason why the TFP of the industry in Beijing is low. The technological progress of the industry in Hebei is 1.1078, higher than the values of 1.0914 in Beijing and 1.0703 in Hebei, which is the primary reason why the TFP of this industry in Hebei Province is the highest among the three provinces. The detailed data of average Malmquist index in the production and supply of electric power and heat power in the Jing-Jin-Ji region, 2005–2015 are shown in Table 6.

In Beijing, in order to realize its overall planning, much of the industry's enterprise had to relocate. Since 2010, Beijing has shut down its original coal-fired thermal power plant represented by the four coal-fired cogeneration plants. Although the city has reduced its consumption of coal by 9.2 million tons, the scale efficiency of the industry in Beijing remains low. Hebei Province, in part, accepts the relocation of Beijing's enterprises from the city. The spillover effect from Beijing enterprises has led to significant technological change in industries in the Hebei Province. At the same time, the efficiency of scale change in the Hebei Province is 0.965, which is not optimal. If the scale benefits are increased and industrial structure changed, the overall technical efficiency of the province can be improved.

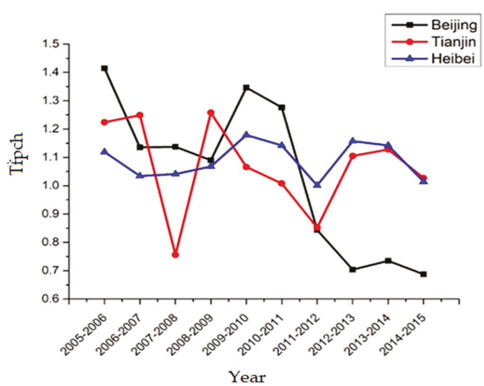

Figure 5. Dynamic change of TFP in the production and supply of electric power and heat power in the Jing-Jin-Ji region, 2005–2015.

Table 6. The average Malmquist index in the production and supply of electric power and heat power in the Jing-Jin-Ji region, 2005–2015.

	Beijing	Tianjin	Hebei
TFPCH	1.036696	1.0673	1.0897
SECH	0.83945	1.0052	0.9649
PECH	1.110767	1.0419	1.1458
TECHCH	1.0914	1.0703	1.1078
EFFCH	0.969428	1.0675	1.0767

5.2. Smelting and Processing of Ferrous Metals

From the overall integrated efficiency change, the average value of ferrous metal smelting and rolling processing industry in the Jing-Jin-Ji region is 1.103, showing progress with the average technical progress changes at 1.144, while the average comprehensive technical efficiency changes are at 0.993. Judging from its decomposition, the pure technical efficiency change index average value is 1.058, while the scale efficiency change index is 0.949. This shows that the Jing-Jin-Ji region has made remarkable progress in technological innovation. The reason for the low efficiency of integrated technology is the change in scale efficiency, indicating that the optimal industrial scale has not yet been reached. The change curves of TFP in the smelting and processing of ferrous metals in the Jing-Jin-Ji region are shown in Figure 6.

In terms of differences, Beijing's TFP presents a sharp decline, followed by a trend of ascending and descending since 2008. In Tianjin, the TFP of the industry shows an upward trend in 2008 or so, followed by a decline and then an increase. Meanwhile, Hebei Province has seen a sharp rise in the industry in 2008, since followed by a declining trend.

In Hebei Province, the average scale efficiency change is rather low at 0.848, compared with 1.054 in Beijing and 0.944 in Tianjin, leading to the conclusion that Hebei's TFP for the industry is low. The average pure technical efficiency change in Tianjin is 1.114, higher than the values of 0.983 in Beijing and 1.077 in Hebei. This is the primary reason why the TFP of the industry in Tianjin is the highest of the three regions. The detailed data of average Malmquist index in the smelting and processing of ferrous metals in the Jing-Jin-Ji region, 2005–2015 are shown in Table 7.

In Beijing, in order to realize its overall planning and undertake the Green Olympics, a number of large-scale enterprises headed by the Beijing ShouGang Group moved out of Beijing in 2008, causing the TFP of the industry in Beijing to plunge. At this time, the surrounding areas of Tianjin and Hebei accepted these enterprises, making the TFP of the surrounding areas rise. As a port city, Tianjin's economy is vulnerable to international trade. In 2011, the impact of the global financial crisis on Tianjin caused the industry to show a downward trend; however, it then rebounded rapidly. Beijing and Hebei provinces should actively study Tianjin's advanced management methods and technical experience in the industry.

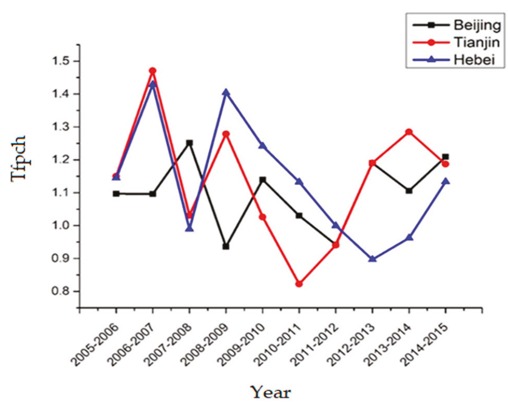

Figure 6. Dynamic change of total factor productivity (TFP) in the smelting and processing of ferrous metals in the Jing-Jin-Ji region, 2005–2015.

Table 7. The average Malmquist index in the smelting and processing of ferrous metals in the Jing-Jin-Ji region, 2005–2015.

	Beijing	Tianjin	Hebei
TFPCH	1.100	1.138	1.098
SECH	1.054	0.944	0.868
PECH	0.983	1.114	1.077
TECHCH	1.091	1.103	1.188
EFFCH	1.015	1.053	0.935

5.3. Manufacture of Raw Chemical Materials and Chemical Products

From the overall integrated efficiency change, the average value of raw chemical materials and chemical products manufactured in the Jing-Jin-Ji region is 1.096, of which the average technical progress changes are 1.062, while the average comprehensive technical efficiency changes are 1.048. Judging from its decomposition, the pure technical efficiency change index average value is 1.060, while the scale efficiency change index is 0.994. This shows that the Jing-Jin-Ji region has made notable achievements in technological innovation. The reason for the low efficiency of integrated technology is the change in scale efficiency, indicating that the optimal industrial scale has not yet been reached.

In terms of differences, the growth of Beijing's industry in 2005–2011 is relatively slow compared with that of Tianjin and Hebei. By 2010, the industry in Beijing dropped sharply, while the industry in Tianjin and Hebei increased during the same period. In Tianjin, in addition to the TFP being less than 1 from 2009–2011, significant progress has also been made in subsequent years. Since 2009, Hebei has shown significant and progressive changes. The change curves of TFP in the manufacturing of raw chemical materials and chemical products in the Jing-Jin-Ji region are shown in Figure 7.

The average TFP of Tianjin in this industry is 1.140, which is considerably higher than the values of 1.062 in Beijing and 1.085 in Hebei. The predominant reason for this is that the technical progress of Tianjin in this industry is 1.132, a figure that is significantly higher than the equivalent 1.023 in Beijing and 1.030 in Hebei. The detailed data of average Malmquist index in the manufacturing of raw chemical materials and chemical products in the Jing-Jin-Ji region, 2005–2015 are shown in Table 8.

In 2005, a fire broke out in Beijing Chemical Plant No. 2, causing an explosion. After the accident, the Beijing government decided to relocate all polluting enterprises, including chemical plants and coking plants, beyond the Fifth Ring Road, while Beijing Chemical Plant No. 2 immediately stopped production. Additionally, 22 enterprises in this industry relocated out of Beijing around 2010, causing the TFP of the industry to decline. At this time, Tianjin and Hebei's peripheral regions accepted these enterprises, resulting in an increase in the TFP in the surrounding areas. Tianjin, as a city with frequent international trade, was hit by the financial crisis in 2008, causing its growth to slow down.

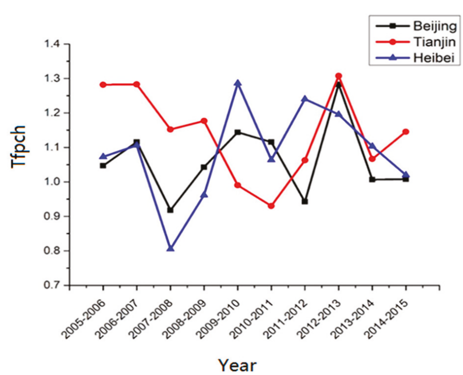

Figure 7. Dynamic change of TFP in the manufacturing of raw chemical materials and chemical products in the Jing-Jin-Ji region, 2005–2015.

Table 8. The average Malmquist index in the manufacturing of raw chemical materials and chemical products in the Jing-Jin-Ji region, 2005–2015.

	Beijing	Tianjin	Hebei
TFPCH	1.062	1.140	1.086
SECH	0.990	1.004	0.989
PECH	1.066	1.031	1.084
TECHCH	1.023	1.132	1.030
EFFCH	1.060	1.020	1.063

6. Conclusions

This paper first uses the DEA model to compare the average efficiency of the 27 industrial industries in Beijing, Tianjin, and Hebei from 2005 to 2015, and highlights three industries with considerable differences in their efficiency and energy consumption. Subsequently, we employ the Malmquist index analysis, which shows that the manufacturing of raw chemical materials and chemical products, the smelting and processing of ferrous metals, and the production and supply of electric power and heat power are rising steadily. However, the efficiency of technological changes in these three major industries is generally low, so the Jing-Jin-Ji region should improve its technological innovation and enhance its core competitiveness. At the same time, the scale efficiency is insufficient, which is reflected in the inefficiency of the allocation of resources. We should optimize the allocation of these resources in specific industries to improve the scale efficiency.

The average value of the overall efficiency change of the three key industries in Beijing, Tianjin, and Hebei is 1.09, which, on the whole, shows a progressive change. The primary reason for this is that the technical changes in the three industries are 1.10, and this is because the three industries themselves have considerable economic strength and a strong ability to import and develop technologies.

We also find that Beijing industries have a tendency to relocate towards the region's peripheries, especially to Hebei Province. By 2015, Beijing had transferred more than 80 industrial projects to Hebei, with a total investment exceeding 120 billion yuan RMB and generating a capacity of 250 billion yuan RMB. Beijing can make use of this opportunity to ease its non-capital function, adjust its economic structure and spatial structure, explore a model for optimizing the intensive development of a densely populated area, and promote harmonious regional development. Hebei Province can take advantage of this opportunity to accelerate the optimization and adjustment of its economic structure and industrial institutions by promoting the upgrade of industrial enterprises equipment and forming a large-scale industry, thereby enhancing industrial energy efficiency.

Thus far, Tianjin is the only free trade zone in the north and has the opportunity of building the "Belt and Road". Tianjin should focus on promoting the international nature of its industries and work to constantly improve its international competitiveness. At the same time, it must also make good use of the opportunity of building a "national advanced manufacturing research and development base" and strive to enhance research and development capability so as to create a well-structured and distinctive industrial system, improve industrial clusters, and build a gathering place with high-end industry, advanced technology, and innovation elements.

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Research and Development Strategy for Fishery Technology Innovation for Sustainable Fishery Resource Management in North-East Asia

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Abstract: The development of fishery technologies supports food sustainability to achieve a steady supply of fish and fishery products. However, the priorities for research and development (R&D) in fishery technologies vary by region due to differences in fish resource availability, environmental concerns, and consumer preferences for fishery products. This study examines trends in fishery technology innovations using data on patents granted as an indicator of changing R&D priorities. To clarify changes in R&D priorities, we apply a decomposition analysis framework that classifies fishery technologies into three types: harvesting, aquaculture, and new products. This study mainly focuses on China, Japan, and Korea as the major fishing countries in the north-east Asia region. The results show that the number of fishery technology patents granted increased between 1993 and 2015; in particular, the number of aquaculture patents granted has grown rapidly since 2012. However, the trend in Japan was the opposite, as the apparent priority given to aquaculture technology innovation decreased between 1993 and 2015. The trends and priority changes for fishery technology inventions vary by country and technology group. This implies that an international policy framework for fishery technology development should recognize that R&D priorities need to reflect diverse characteristics across countries and the technologies employed.

Keywords: aquaculture; decomposition analysis; research and development strategy; fisheries technology; food sustainability; harvesting technology; patent data

1. Introduction

Fish and fishery products are important for maintaining a healthy diet [1] and are a major source of nutrition for hundreds of millions of people worldwide [2]. Marine fishery resources are perishable goods dramatically affected by fishing and storage conditions. Furthermore, fishery is an export-oriented sector, in which information asymmetry plays a fundamental role in relation to product origins [3]. The demands for fish and fishery products are expected to increase in the future due to population expansion in developing countries [4] and to increase per capita consumption driven mainly by developing countries, especially China [5]. This report expects that food fish supply per capita will increase in China, India, and Brazil by 19.5%, 11.7%, and 32.3%, respectively, by 2025, which is the target year for the global improvements in maternal, infant and young child nutrition outlined in the Rome Declaration on Nutrition [5]. This growth is expected to significantly increase worldwide demand for fish and fishery products.

The rapid growth in demand for fish and fishery products increases the risk of stock depletion due to over-exploitation. The Food and Agriculture Organization of the United Nations (FAO) [5] has pointed out that marine fish stocks declined from 1974 to 2011, and the remainder were estimated to be fished at a biologically unsustainable level. To move towards solving the problem of overfishing, recently some indicators of sustainability (e.g., marine ecological footprint, fishprint, primary production required) have been analysed [6] and several types of tools and management strategies (e.g., total allowable catches, marine protected areas, and individual transferable quotas) have been created [7]. Additionally, marine resource management was individually established as goal 14, "Conserve and sustainably use the oceans and marine resources for sustainable development", in the sustainable development goals (SDGs) adopted by the United Nations [8].

Technology development is another important factor in satisfying the future demand for fish and fishery products by improving the catchability of the harvesting sector and preventing resource depletion [9]. Additionally, new aquaculture technology can boost production, supply high-quality fish products, and contribute to the protection of fragile aquatic environments [10]. In addition to fishing and aquaculture technology, new fish product technologies contribute to economic development, e.g., through value-adding processing such as surimi technology [11]. Therefore, fishery technology development plays an important role in achieving sustainable fishery resource management [12].

However, the priority for research and development (R&D) differs based on the type of fishery technology due to differences in the incentives for technology development (e.g., expected profit, policy and regulation, availability of financing). Additionally, R&D strategies for fishery technology differ between countries due to varying dietary cultures and available fish resources. Understanding the diversity of fishery resources and fishery technologies available or under development is an essential step towards obtaining international agreements for fishery resource conservation [13].

To consider the characteristics of fishery technologies, we applied patent data with the fishery technology classification used by the Organisation for Economic Co-operation and Development [14]. By following this classification, we can separate fishery technologies into three types: harvesting technology, aquaculture technology, and new products technology. A description of each technology is provided in Table 1, and a list of patent classifications is introduced in Table S1 in the supplementary material.

Table 1. Description of the aquaculture technology patent groups.

Patent Group	Description of Patent Group
Harvesting technology	Harvesting technologies, such as more effective ways to find or harvest fish; these are typically associated with improvements in catch per unit of effort. The main categories of this patent group are IPC = A01K69 (Stationary catching devices), IPC = A01K77 (Landing-nets; Landing-spoons), and IPC = B63B35/14 (Fishing vessels).
Aquaculture technology	Aquaculture technologies, such as methods to more effectively grow fish in captivity (innovation in feeds, ingredients that improve the health of aquaculture animals, etc.). The main categories of this patent group are IPC = A01K61 (Culture of fish, mussels, crayfish, lobsters, sponges, pearls and the like) and IPC = A01K63 (Receptacles for live fish, e.g., aquaria).
New products technology	New products technologies, such as the development of new fish products (food technologies/processing, such as the development of surimi as a crabmeat substitute) and improvement in processing lines. The main categories of this patent group are IPC = A22C25 (Processing fish; curing of fish; stunning of fish by electric current; investigating fish by optical means) and IPC = A22C29 (Processing shellfish or bivalves and devices therefor; processing lines).

Source: OECD [14].

Patent data analyses are widely applied to evaluate R&D activities in the fields of engineering, economics, and corporate management [15]. Nicol et al. [16] explained the technological development of Antarctic krill products using krill-related patents-granted data. Popp [17] analysed the effect of energy prices on R&D activities using patent data. He considered the share of energy-related patents granted of total patents granted as the proxy variable of R&D priority for energy technology. Fujii [18] uses this R&D priority idea to develop the framework of patent decomposition analysis.

Previous studies on fishery technology innovations do not clearly consider the diversity of countries and technological characteristics (e.g., Ninan et al. [19], Ninan and Sharma [20]). The objective of this study is to clarify R&D strategy changes for fishery technology development using patent data categorized by country and technology type. The novelty of this study is that it is the first to analyse R&D strategy through the use of fishery technology patent innovations and the application of a decomposition analysis framework. By using decomposition analysis, we can identify the factors affecting fishery technology patents, which is key information needed to support an effective R&D development policy.

According to Fujii and Managi [21], technology innovation is induced by future business market expansion. Additionally, fishery technology development is driven by fish resource conservation and environmental protection [22]. As explained above, demand for fish and fishery products will significantly increase, especially in developing countries. Additionally, international treaties and agreements for marine resource management become stricter every year [23]. Under strict harvesting rules for marine resources, fishery companies will need to invest in fishing gear and geographic information systems for marine resource conservation, which will decrease the incentive to continue harvesting activities [2]. Meanwhile, the opportunity for aquaculture business will increase, especially in China [2]. The demand for technology will directly affect the technological development strategy, which is a key factor in R&D activities [21].

To investigate the research objective more clearly, we established two research hypotheses.

Hypothesis 1. *The R&D priority for fishery technology development increased in fishing countries.*

Hypothesis 2. *The R&D priority placed on aquaculture technology development in fishing countries increased more than that placed on harvesting technology development.*

2. Materials and Methods

We employed a decomposition analysis framework to identify changes in the factors involved in fishery technological patents granted. In a decomposition analysis, we use three specific technology groups: harvesting technology, aquaculture technology, and new products technology. To decompose patents granted in the field of fisheries technology, we used three indicators: the priority of the specific fisheries technology (PRIORITY), the importance of fisheries technology in all patents granted (FISHERY), and the scale of R&D activity (SCALE).

We define the PRIORITY indicator as the number of each specific group of fishery technology patents granted divided by the total number of fishery technology patents granted, which gives us the share of specific fishery technology patents granted within the total. This indicator will increase if the number of specific fishery technology patents granted increases more quickly than the total number of fishery technology patents granted, indicating that inventors are concentrating their research resources on these specific technology areas.

Similarly, the FISHERY indicator is defined as the total number of fishery technology patents granted divided by the total number of all patents granted, which gives the share of total fishery technology patents granted within the total. This indicator will increase if the number of total fishery technology patents granted increases more quickly than the number of all patents granted, thus indicating that inventors are concentrating their research resources on fishery technology innovations.

Finally, the SCALE indicator is defined as the total number of all patents granted, which represents the scale of R&D activities. SCALE increases if the total number of all patents granted increases. The number of patents granted for fishery technologies increases due to an increase in overall R&D activities if the SCALE score increases.

Here, we introduce the decomposition approach using the harvesting technology patent group as the specific fisheries technology patents granted (see Table 1). This follows the methodology introduced by Ang et al. [24] to calculate a logarithmic mean divisia index (LMDI). The number of harvesting technology patents granted (HARVEST) is decomposed using the total fisheries technology patents granted (FTECH) and total patents granted (TOTAL), as in Equation (1).

$$\text{HARVEST} = \frac{\text{HARVEST}}{\text{FTECH}} \times \frac{\text{FTECH}}{\text{TOTAL}} \times \text{TOTAL} = \text{PRIORITY} \times \text{FISHERY} \times \text{SCALE} \quad (1)$$

Following Ang et al. [24], we obtained Equation (2) by using logarithmic function. where $\omega_i^t = \left(\text{HARVEST}^t - \text{HARVEST}^{t-1}\right) / \left(\ln\text{HARVEST}^t - \ln\text{HARVEST}^{t-1}\right)$.

$$\begin{aligned} \text{HARVEST}^t - \text{HARVEST}^{t-1} &= \Delta\text{HARVEST}^{t,t-1} \\ &= \omega_i^t \ln\left(\frac{\text{PRIORITY}^t}{\text{PRIORITY}^{t-1}}\right) + \omega_i^t \ln\left(\frac{\text{FISHERY}^t}{\text{FISHERY}^{t-1}}\right) + \omega_i^t \ln\left(\frac{\text{SCALE}^t}{\text{SCALE}^{t-1}}\right) \end{aligned} \quad (2)$$

Therefore, the changes in the number of patents granted for harvesting technologies (ΔHARVEST) are decomposed by changes in PRIORITY (first term), FISHERY (second term) and SCALE (third term). The term ω_i^t operates as an additive weight for the estimated number of patents granted for harvesting technologies.

In this study, we apply a further transformation of the LMDI to clarify the change ratio of patents granted. We define this ratio as the percentage of change in the number of patents granted in comparison with the base year (t_0). To decompose the change ratio, we transform Equation (2) to (3).

$$\begin{aligned} \textit{Change ratio}_{HARVEST}^{t,t_0} &= \frac{\text{HARVEST}^t - \text{HARVEST}^{t_0}}{\text{HARVEST}^{t_0}} = \frac{\Delta\text{HARVEST}^{t,t_0}}{\text{HARVEST}^{t_0}} \\ &= \omega_i^t ln\left(\frac{\text{PRIORITY}^t}{\text{PRIORITY}^{t-1}}\right) \times \frac{1}{\text{HARVEST}^{t_0}} \\ &+ \omega_i^t ln\left(\frac{\text{FISHERY}^t}{\text{FISHERY}^{t-1}}\right) \times \frac{1}{\text{HARVEST}^{t_0}} \\ &+ \omega_i^t ln\left(\frac{\text{SCALE}^t}{\text{SCALE}^{t-1}}\right) \times \frac{1}{\text{HARVEST}^{t_0}} \end{aligned} \quad (3)$$

One advantage of using the change ratio is that decomposition analysis results can reveal the relative change in different time periods. In this study, we propose a patent decomposition framework to distinguish the change in the priority placed on specific fishery technology innovations from that placed on total fishery technology innovations.

3. Data

We used patents granted data from PATENTSCOPE provided by the World Intellectual Property Organization (WIPO). The PATENTSCOPE database covers more than 56 million patents granted from 1978 to 2015. Data coverage by country and period is shown in Table S2 in the supplementary materials. We specified fishery technology patents based on the Organisation for Economic Co-operation and Development (OECD) [14] classification.

Since PATENTSCOPE data coverage for Japan, which is a major fishery technology innovator, started after 1993, we used a patent dataset from 1993 to 2015 (see Table S2). Following Fujii [18] and Fujii and Managi [21], we used only the primary international patent classification (IPC) code to categorize the technology group to avoid the double counting of patent data in each technology group. The limitations of patent data availability should be noted. Patent data are available only if the target country has constructed a patent registration system, which is not the case for all developing countries. Patent data analysis will therefore not be an appropriate methodology to evaluate the technology development in these countries.

4. Results and Discussion

4.1. Trend in Fishery Technology Patents Granted

In China, 50,914 fishery technology patents were granted by the state intellectual property office of the People's Republic of China (see Table 2). China, Korea, and Japan represent 67.75% of fishery technology patents granted worldwide, and China in particular has a large share (42%). Country characteristics strongly affected the patents granted trend. The share of harvesting patents is greater than 50% in Korea and Japan, while China has a large share of aquaculture technology patents.

Table 2. Fishery technology patents granted in north-east Asian countries from 1993 to 2015.

Country and Region	Fisheries Technology Patents		Breakdown by Technology Type (%)		
	Number of Patent Granted (Item)	Share (%)	Harvesting	Aquaculture	Products
China	50,914	42.06%	22%	74%	3%
Korea, Republic of	15,879	13.12%	56%	40%	4%
Japan	15,212	12.57%	50%	46%	4%
World [1]	121,059	100.00%	35%	61%	4%

Note: [1] "World" indicates the summation of patents granted in all countries and regions listed in Table S2.

The number of fishery technology patents granted increased rapidly in all three technological groups (See Table 3). This rapid growth was caused by an increase in patents granted in China; in particular, aquaculture patents granted have significantly increased in the last decade. One interpretation of this result is that Chinese patent application law was revised in 2001 and 2009, making patent applications easier for Chinese companies through a subsidised programme. Additionally, the Chinese government tried to increase international market competitiveness though patents granted after China became a World Trade Organization (WTO) member in 2001 [25]. Hu et al. [26] investigated the relationship between patent applications and two economic indicators (labour productivity and R&D expenditure). They concluded that there is no significant relationship between the applicant's internal factors and patent application behaviour, which means that a rapid increase in patent applications is mainly caused by external factors, such as a revision of patent law and a new subsidy system. Based on these points, the revision of the Chinese patent application system contributed by increasing all patent applications in China, which affected the growth of fishery technology patents.

Table 3. Trend in fishery technology patents granted by industry type.

Technology	Country	1993–1997	1998–2002	2003–2007	2008–2012	2013–2015
Harvest	China	184	929	1801	3363	5293
	Korea	759	2977	2317	1786	1463
	Japan	845	1056	2690	2166	1156
	World	3427	6207	8552	8167	10,336
Aquaculture	China	525	1180	3149	10,635	22,690
	Korea	376	1485	1648	1713	1353
	Japan	1083	1214	2522	1396	1124
	World	3472	5942	11,735	14,945	28,321
Product	China	27	37	105	552	912
	Korea	38	140	183	124	123
	Japan	247	134	129	81	87
	World	536	519	611	774	1384

4.2. Results of Decomposition Analysis

The results of a decomposition analysis for specific fishery technology patents granted are described in Figures 1–3. The figures show the differences in the factors driving patents granted according to the type of fishery technology. In Figures 1–3, the vertical axis represents the change ratios of harvesting technology patents granted based on the year 1993. The plotted line shows the change ratio of harvesting technology patents granted, and the bar chart shows the effects of three decomposed factors on the change ratio of patents granted for harvesting technologies. The sum of the bars is equivalent to the value of the plotted line.

The results of the decomposition analysis by country are described in Tables 4–6. Additionally, the patent portfolios are represented in Figures S1–S3 in the supplementary material. This study then examined whether the pattern of technology development varied across the countries and time periods.

4.2.1. Harvesting Technology

The results of a decomposition analysis of patents granted for harvesting technologies are described in Figure 1. Harvest patents increased from 1997 to 2004, were relatively stable until 2011, and then increased rapidly afterwards. The decomposition analysis indicates that the main driver of the increase in harvest patents from 1997 to 2004 was an increase in the priority of fishery technologies and the scaling up of R&D activity (see bar chart in Figure 1). During this period, harvest patents increased rapidly in Korea (see Table 3). Meanwhile, the priority of harvesting technologies was relatively unchanged compared with the other two decomposed factors. This result suggests that the patents granted for harvesting technologies show a similar trend to the total fisheries technology patents granted (i.e., HARVEST/FTECH is relatively stable).

From 2004 to 2012, the change ratio is stable, while the driving factors of harvest technology patent invention fluctuate, especially from 2009 to 2011. After 2009, the priority placed on harvesting technology decreased, while the priority placed on fishery technologies increased, which indicates that R&D priorities shifted from harvesting technologies to other fishery technologies. This trend became stronger after 2012. It should be noted that these structural changes in the priority and scale factors can be observed using a decomposition approach.

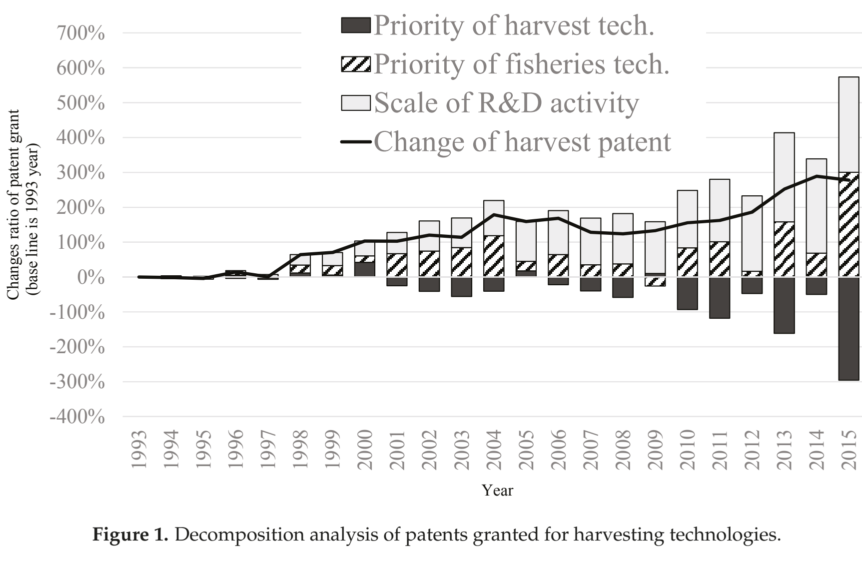

Figure 1. Decomposition analysis of patents granted for harvesting technologies.

The results for China and the world in Table 4 show that summing the priority of harvesting technology and the priority of fishery technology gives a value close to zero. This indicates that the rate of growth for harvest patents granted is similar to that for all patents granted. Therefore, the increase in harvest patents granted was most likely due to the expansion in the scale of R&D in China and the world.

Table 4. Decomposition analysis of harvesting patents granted from 1993 to 2015.

	Change in Harvesting Tech.	Decomposed Factors			Most Increased Patent Technology (IPC)
		Priority of Harvesting Tech.	Priority of Fisheries Tech.	Scale	
China	1841	−1201	1125	1917	Accessories for angling (A01K97)
Korea	115	−214	−102	431	Accessories for angling (A01K97)
Japan	97	128	163	−194	Reels (A01K89)
World	2327	−2477	2516	2287	Systems using the reflection of acoustic waves (G01S15)

Another finding is that opposite trends of decomposition factors can be observed between Korea and Japan. Harvest patents granted in Japan increased due to priority growth and the shrinking scale of R&D contributed to the decrease. Meanwhile, Korea increased its harvest patents granted due to an R&D scale expansion, and both priorities decreased.

These results can be interpreted by focusing on the economic situation in other industries. R&D activity in Japan continued to shrink after 1990 with persistent economic sluggishness [21], while Korea achieved rapid economic growth in the 1990s and 2000s due to increasing product competitiveness in the electronics and semi-conductor markets [27]. In this period, patent activity in Korea increased, especially for technologies from large electronics companies (e.g., Samsung and LG electronics) [28]. Therefore, active innovation, as captured by patents in other technologies, decreased the relative R&D priority for harvest and fishery technologies in Korea.

It can be seen that the patent portfolios in world were largely unchanged, while the patent portfolios for China increased the share of accessories for angling and reel technology (see Figure S1). In Japan, the patent share of reels increased and accessories for angling was declined. Finally, Korea increased other catching devices and systems using the reflection more than the other two technologies.

4.2.2. Aquaculture Technology

The number of patents granted for aquaculture technology increased starting in 2009 and showed particularly rapid growth from 2014 to 2015 due to an increase in priority for both aquaculture technology and fishery technology (see Figure 2). The number of patents granted for aquaculture technology increased dramatically starting in 2008. Most of this increase was attributable to China, particularly from 2009 (see Table 5).

It should be noted that approximately half of the aquaculture technology patents granted in China were attained by Chinese universities. This characteristic is unique to China, as private companies are the main patent applicants in other countries. This trend is observed in other technology fields as well (e.g., nanotechnology (see Huang and Wu [29]). Fong et al. [30] note that "China's National Medium and Long Term Science and Technology Development Planning (2006–2020)" significantly promoted technology transfer for Chinese universities. Furthermore, they conclude that royalties and economic incentives are key factors increasing patenting by Chinese universities.

Additionally, the Chinese government set a high priority on aquaculture technology development in the 13th Five Year Plan (2016–2020) for national progress. This plan promotes the development of new aquaculture technologies among research institutes and universities. Furthermore, technology development for preventing water pollution caused by feed for aquaculture was promoted for environmental protection in China's 12th Five-Year Plan (2011–2015). These governmental targets can be noted as key factors in the increased priority of aquaculture technology in China starting in 2010.

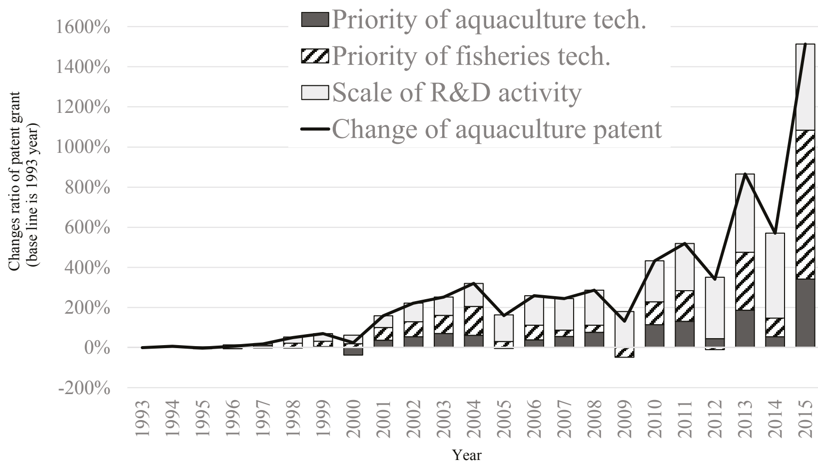

Figure 2. Decomposition analysis of patents granted for aquaculture technology.

Table 5. Decomposition analysis of aquaculture patents granted from 1993 to 2015.

	Change in Aquaculture Tech.	Decomposed Factors			Most Increased Patent Technology (IPC)
		Priority of Aquaculture Tech.	Priority of Fisheries Tech.	Scale	
China	11,736	1441	4949	5346	Animal feeding stuffs for aquatic animals (A23K1)
Korea	231	192	−164	202	Culture of fish, mussels, crayfish, lobsters, sponges, pearls or the like (A01K61)
Japan	82	−46	278	−149	Rearing or breeding animals not otherwise provided for (A01K67)
World	12,769	2884	6262	3623	Animal feeding stuffs for aquatic animals (A23K1)

A total of 90% of the increase in aquaculture technology patents in the world from 1993 to 2015 was due to patents granted in the Chinese patent office (see Table 5). Japan is unique, as it was the only country to decrease the priority of aquaculture technology. This trend is completely opposite to the trend in the other two major fishing countries.

One interpretation of this result is the biased structure of the aquaculture industry in Japan. According to the Ministry of Agriculture, Forestry and Fisheries [31], 75% of inland water aquaculture entities were individually operated in Japan in 2013. Additionally, the average number of workers per entity is 3.3 persons in the inland aquaculture industry, and most of these entities target domestic markets. This type of management entity offers an interpretation for the decrease of R&D priority in Japan, because R&D expenditure and the maintenance of patent protection is costly for small-scale fish farmers [32].

Another reason is that Japanese consumers view aquaculture fish products negatively relative to wild-caught products. Uchida et al. [33], using 3370 questionnaires, found that wild-caught fish products are significantly preferred over farmed fish products by Japanese consumers. Meanwhile, the FAO [34] notes that market competitiveness between farmed and wild fish products is more variable in the U.S. and EU regions. Therefore, the relative market competitiveness of farmed fish products is lower in the Japanese market than in other countries, which decreases the incentive for aquaculture technology patents granted in Japan.

Finally, the share of rearing or breeding animals expanded and that of animal feedstuffs decreased from the 1990s to the 2000s in three countries (see Figure S2). Meanwhile, the share of culture and receptacle technologies is diverse across countries.

4.2.3. New Products Technology

New fishery product technologies largely did not change from 1993 to 2008, in contrast with the trends for harvest and aquaculture technology (Figure 3). In this period, the priority of product technologies steadily decreased. However, this negative effect was cancelled out by an increase in both the priority of fishery technologies and R&D scale factors.

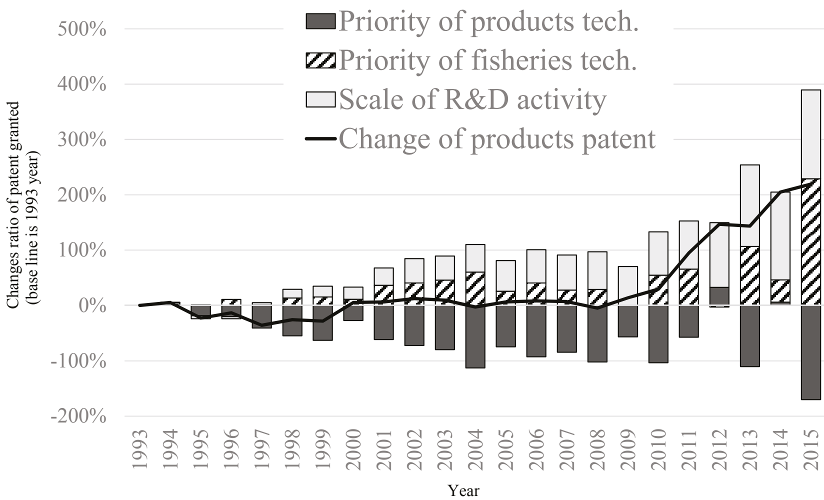

Figure 3. Decomposition analysis of patents granted for new product technology.

From 2009, patents granted in product technologies increased due to the growth in both the priority of fishery technology and the scale of R&D activities. This trend is similar to that of harvesting technology (see Figure 1). One interpretation of this result is that developing technology to maintain the freshness of fish caught by marine harvesting directly contributes to an increase in market competitiveness [35]. The multilateralization of harvesting technology under the pressure of marine resource conservation provides an incentive to develop new technologies for appropriate quality maintenance and value-added processing.

Two countries, except Korea, decreased the priority of product technologies from 1993 to 2015 (see Table 6). Additionally, Japan decreased the number of patents granted for both fish and shellfish processing technologies. One interpretation of this result is changing dietary habits in Japan. According to the Fisheries Agency of Japan [36], the annual per capita consumption volume of fish and fishery products declined from 37.5 kilograms per capita in 1993 to 27.0 kilograms per capita in 2013. Fisheries of Japan [36] also noted that fish consumption is decreasing due to the difficulty of educating children about diet at home. The shrinking fish products market thus decreases new product innovation by private companies in Japan.

Meanwhile, fish meal consumption is predicted to increase in Korea and China [2]. Therefore, private companies in these countries are strongly motivated to develop fish product technologies to gain market competitiveness in an expanded fish meal market. These dramatically changed the patent portfolio in China from the 1990s to the 2000s (see Figure S3). One reason for this change is that fish meal became more popular in China [37]. From the 2000s to the 2010s, the patent share of processing for shellfish or bivalves increased in China, Korea, and Japan.

Table 6. Decomposition analysis of product innovation patents granted from 1993 to 2015.

	Change in Products Technology	Decomposed Factors			Most Increased Patent Technology (IPC)
		Priority of Products Technology	Priority of Fisheries Technology	Scale	
China	345	−116	213	248	Processing fish (A22C25)
Korea	26	16	−10	20	Processing fish (A22C25)
Japan	−57	−77	33	−12	Both technology groups decreased
World	318	−247	332	232	Processing shellfish or bivalves (A22C29)

4.3. Investigation of Research Hypotheses

Based on the above analysis, we consider the two research hypotheses explained in the introduction. From the results of the decomposition analysis, we identified that the main contributor to fishery technology patent growth is the expansion of patents granted in China due to a scaling up of R&D activity. Additionally, China and Japan increased the relative priority of fishery technology innovations. However, we observe that in the Korea, the relative priority of fishery technologies declined from 1993 to 2015. Thus, we can partially support Hypothesis 1: "The R&D priority for fishery technology development increased in fishing countries".

For Hypothesis 2, surprisingly, we observed that the priority of aquaculture technologies declined in Japan from 1993 to 2015, even though the priority of harvesting technologies increased. By contrast, aquaculture technologies had greater priority than harvesting technologies in the other two fishing countries. Therefore, we can partially support Hypothesis 2: "The R&D priority placed on aquaculture technology development increased in fishing countries more than that placed on harvesting technology development".

5. Conclusions

This study examined the trend and priority changes in fishery technologies using patents granted data from 1993 to 2015. We focused on the following three technologies: (1) harvesting technologies, (2) aquaculture technologies, and (3) new products technologies. We clarified priority shifts, as reflected in the patents covering innovations in these three technologies, by applying the LMDI decomposition analysis. We obtained the following results.

First, the number of fishery technology patents granted increased from 1993 to 2015; in particular, there was rapid growth in aquaculture patents granted starting in 2012. The main driver of this growth was expansion in the scale of R&D activity and an increase in the priority of fishery technology innovation in China. The revision of the patent application law and subsidy system in China are noted as external factors promoting R&D activity among Chinese innovators.

Second, the priority placed on aquaculture technology innovation decreased only in Japan from 1993 to 2015. This result for the R&D strategy of fishery technologies is unexpected, because Japan is one of the major fish consuming countries [38]. This information sends a key message to the Japanese government to recognize the necessity of promoting aquaculture technology development in Japan.

Finally, we observe that the priority change for fishery technology innovation is diverse across countries and technology groups. This result has important implications for fishery technology development strategy by inter-governmental activities. For example, the target set in the SDGs was to "Increase scientific knowledge, develop research capacities and transfer marine technology taking into account the Intergovernmental Oceanographic Commission Criteria and Guidelines on the Transfer of Marine Technology" (target 14.a., United Nations [8]). The differences in fishery technology characteristics provide useful information for clarifying the technological advantage and high-priority technology type in each country, which is key information for promoting inter-governmental agreement to achieve SDG targets.

Supplementary Materials: The following are available online at www.mdpi.com/2071-1050/10/1/59/s1, Table S1: A list of patent classifications related to fishery technologies, Table S2: Patent data collection period in PATENTSCOPE database by country, Figure S1: Patent portfolio of harvesting technologies from 1993 to 2015, Figure S2: Patent portfolio of aquaculture technologies from 1993 to 2015, Figure S3. Patent portfolio of product technologies from 1993 through 2015.

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Author Contributions: H.F. designed the study, analysed the data, and wrote the manuscript. Y.S., A.H., J.B., K.S., and Y.M. assisted in writing the manuscript.

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

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Promoting Profit Model Innovation in Animation Project in Northeast Asia: Case Study on Chinese Cultural and Creative Industry

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Abstract: Building on a case study of three animation companies in the Chinese cultural and creative industry, this study aims to understand how profit model innovation is promoted. Due to the rapidly changing environments and resource scarcity, cultural and creative companies need to select the appropriate profit model according to their own key resources. The study uncovers two critical factors that promote profit model innovation in animation projects: the quantity of consumers and their consumption intention. According to these two dimensions, the authors' analysis shows profit model innovation in animation projects can be divided into Fans mode, Popular mode, Placement mode, and Failure mode, respectively. This study provides an empirical basis for advocating profit model innovation and discusses the resource requirements of Fan mode, Popular model, and Placement mode in China's cultural and creative industry. The authors' research also has managerial implications that might help firms promote profit model innovation. Finally, learning and promoting the profit model of China's animation industry in the Northeast Asia area will be conducive to Northeast Asia's cooperation and sustainable development.

Keywords: profit model innovation; animation project; cultural and creative industry; China

1. Introduction

The development of cultural and creative industries in Northeast Asia plays an important role in promoting the sustainable development of the entire region [1]. China is typically an important part of Northeast Asia. Since 2002, the Chinese government has issued a series of policies to promote the development of the cultural and creative industry, especially the animation industry [2,3]. The industrial chain of the animation industry has been taking shape gradually since then. Under such market opportunities and preferential policies, more and more companies have begun to get involved in the animation industry. Through summarizing and drawing on some good models of China's animation industry, and promoting it in Northeast Asia, it can promote regional cooperation and sustainable development. Therefore, this article makes an in-depth study of the profit model of animation projects in China's cultural and creative industries.

According to the experience of the United States of America (U.S.A.) and Japan, the market value of the animation industry is remarkably large. The growing number and variety of types of animation companies show the booming trend in China. Since Chinese culture is low-cost, low-energy, and high value-added, which is the foundation of the creative idea of animation, China's animation industry captures the world's attention [4]. The Chinese market has great potential for development. It is conducive to make better use of the Chinese market in Northeast Asia to achieve the management and sustainable development of the cultural and creative industries in the entire region, through the exploration of the profit model of China's animation industry.

When compared to Japan and Korea, the domestic consumer market of the animation industry in China is not mature enough, and the animation companies are late-comers [5,6]. Some successful animation companies illustrate a variety of modes in communication channels, profit models, and other aspects. It is an important issue to find out the general factor of the profit model in these existing successful cases, which will help to promote the balanced development of cultural and creative industries in Northeast Asia. The successful application of the animation industry profit model will also be conducive to the economic development of Northeast Asia to promote the sustainable development of the entire region.

Therefore, this paper tries to analyze the communication channel and profit model of three successful animation companies, and summarizes successful profit models in the animation industry. The research could provide implications for practices of Chinese animation companies. Consequently, summarizing the profit model in animation industry has great meaning.

2. Literature Review

2.1. An Overview of the Cultural and Creative Industry

Many scholars focus on the development of the cultural and creative industry. Zeng et al. [3] compare the efficiency differences in different areas of the world and hold the opinion that the cultural industry in China is relatively inefficient [4]. Liu and Chiu [7] emphasize the core position of the cultural and creative industry in cities, and explain how they enhance a city's competitiveness. Bai [8] introduces four essential factors for studying the cultural and creative industries in three different countries, including economic environment, creativity, communication, and technology.

When considering that the animation industry is an important part of the cultural and creative industry, scholars try to find the implications for the Chinese animation industry. Zhou and He [9] analyze the basic documents for the development of the Chinese animation industry, and provide the basis for further research. Xu and Schirato [5] analyze the impact of the Chinese animation industry from three aspects: politics, economy, and culture. Based on the research, Liu [10] explores animation production, communication media, and other processes in the Chinese animation industrial chain, and summarizes three development models, which are essentially driven by TV, driven by derivative products, and pushed by animation technology. Dai [11] presents that in the Chinese animation industry, the animation companies should play the dominant role in integrating resources, and extend the industrial chain both vertically and horizontally.

2.2. Business Model in the Cultural and Creative Industry

Scholars discuss different models of the cultural and creative industry, most of them focusing on the business model. Horng [12] presents a Culture Creative-Based Value Chain, based on where three different business models in Taiwan are compared. Dai et al. [13] introduce the business model, profit model and value chain in Shanghai. Yi [14] focuses on the cultural industry in Shenzhen and summarizes several cross-development models of the industry. Benghozi and Lyubareva [15] consider innovation as a kind of competitive advantage for the cultural industry and introduce three kinds of online business models. Vassiliki [16] point out that new business models in creative industries can be used in certain areas, which is an opportunity for European Union (E.U.) counties. Lerro and Schiuma [17] introduce the impact of European business models on the value creation mechanisms.

Meanwhile, Zhao [18] analyzes the animation industry in Europe, and presents three models: the French government-led model, the British government coordination patterns, and the German model based on local coordination. Chen [19] introduces the stages of Japanese animation development, the relationship between Japanese animation and the comics publishing industry, and the growth mechanism of the animation industry. Zhang et al. [20] focus on the Japanese animation industry and present two developing models, including cartoon creation-oriented and commercial operation-oriented. Cui et al. [21] compare the Chinese animation industry with the Korean animation industry and try to find countermeasures to enhance the competitiveness of the Chinese animation industry.

2.3. Operation Model in the Cultural and Creative Industry

Some other scholars mainly investigate the operation model of the cultural and creative industry. Dalecka and Szudra [22], for instance, analyze the operation of the cultural and creative industry and how it plays an important role in the development of cities. The article presents that the basic factors of the industry are creativity, skills, and talent. Magdalena [23] analyzes family business operation and discusses their value system. Chen [24] presents a decision-making model to evaluate the performance of the cultural industry. Strazdas and Cerneviciute [25] point out that some small firms are faced with complex markets, so creativity is essential in the operation process.

Scholars also focus on the industrial chain structure of the cultural and creative industry. Cai [26], for example, analyzes the diversified industrial chain structure and the profit-oriented product development model. Wang [27] uses Disney and DreamWorks as examples to analyze the animation industrial chain of the U.S.A., and presents a customer-value, creation-based mechanism. Wang et al. [28] list some problems of cultural and creative industries in China and put forward the management mode by analyzing the value chain. Both Wang et al. [29] and Madudova and Emilia [30] analyze the factors that affect the value chain model in the creative industry.

Therefore, few researchers put their emphasis on the profit model of the animation industry. The existing relevant literature is more descriptive research than in-depth theoretical analysis. The models in the existing literature are incomplete. Thus, an in-depth research, which is based on case studies, is needed to analyze the Chinese animation industry.

2.4. Profit Model in the Animation Industry

Based on the survey, Yu and Song [31] analyze the profit model of Chinese animation companies. Their research divides the profit model into six categories: original animation-driven, brand licensing, channel-driven, derivatives-driven, new media-driven, and the integration of OEM (Original Equipment Manufacturer) original design. Yuan [32] clusters the animated film industry chain into three types, and explores the profit model of animated film companies. His research finds three profit models, including profit from box office, profit from TV, video products and other new media distribution, and profit from stage opera based on animation and toys. Li [33] compares the profit models of the animation industry in the United States, Japan, and South Korea, and summarizes several profit-making models of the current network animation in China. Fu and Tang [4] suggest using online teaching and animation methods to develop animation education. Choi [34] analyzes the Korean animation industry and points out that the industry is the most profitable business model in modern society, which also promotes the development of related industries. Gu [6] compares the development experiences of Korea and China, and analyzes the problems of the Chinese animation industry. Ye and Zheng [35] present that the Chinese animation industry should optimize the industry chain, model, and rules and regulations. These researchers get some interesting findings, but most of them are only descriptive summaries without in-depth analysis of the mechanism behind the profit models of the companies.

The product in the animation industry is a kind of cultural product for consumption. The fundamental profit comes from the consumer. Therefore, it is concluded that fundamental profit is decided by the quantity of consumers and their consumption intention. Based on this, the following chart is produced (Figure 1). The profit model innovation chart in the animation industry is divided into four types of scenarios, Fan mode, Popular mode, Placement mode, and Failure mode, respectively.

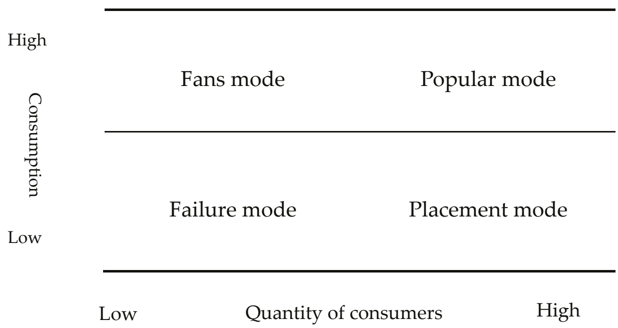

Figure 1. Profit model innovation in animation industry in Chinese Cultural and Creative Industry.

2.4.1. Fan Mode

The first part of the cycle is the Fan mode, which has a high consumption intention but a low quantity of consumers. This situation has loyal consumers who would like to buy the animation products even at a high price. The best strategy in this scenario is to cultivate a repeated direct purchase habit of the consumer for a variety of forms of animation and derivative products to mine customer experience value and train and expand the fan community.

2.4.2. Placement Mode

The Placement mode cycle deals with low consumption intention and high quantity of consumers. Although there are many consumers, they do not like to purchase the animation product directly and substantially. This scenario requires enhancing the consumer's attention and letting them realize the value of the animation product. To specify, the situation needs the support from advertisements to increase the ratings and hits of animation products.

2.4.3. Popular Mode

The Popular mode is the scenario where there is the optimum situation of a high quantity of consumers and high consumption intention. This method is the optimal condition, since it can make a profit from a small number of loyal consumers and a large quantity of non-loyal consumers, simultaneously.

2.4.4. Failure Mode

The Failure mode is the situation where the quantity of consumers is low, and the consumption intention is low. This is the worst situation. This situation occurs when the animation products are not delivering profits making it best to liquidate. Therefore, this situation is not discussed in this paper.

The following profit model innovation chart (Figure 1) for the animation industry can help an animation project to increase and monitor its market share and growth. All animation projects, whether big or small, should have a specific type of profit model on which to base their products, in order to track the market and what consumers want. Some animation projects in China will be employed to illustrate how to innovate in the profit model.

3. Methodology

Given the relatively new and unexplored nature of the phenomenon, this study adopted an exploratory research strategy [36,37]. Qualitative research is particularly useful for exploring implicit assumptions and examining new relationships, abstract concepts, and operational definitions [38,39].

The objective was to conduct an analysis of the profit model in the Chinese animation industry that would help to build theory and develop constructs that would facilitate future hypothesis testing [36].

The initial research questions provided guidance for this study, and helped to identify meaningful and relevant activities [37]. This paper adopted the following criteria for selecting the cases. First, the selected cases should have profit model innovation. Second, local firms should play a dominant role in the industry. Third, the selected cases should be financially sustainable and scalable. That is, the business in the case should have the potential for large-scale commercialization.

According to the above criteria and theoretical sampling [36], three companies were selected from the animation industry. All the companies were similar in terms of products, so exploration of similar challenges regarding technology, sourcing, production, distribution and marketing was possible. The cases varied in terms of organizational structure and positioning in the industrial chain, so comparison of the effect of different models adopted by different companies was accomplished. The interactive strategy was adopted for the overall research design. That is, the cases were selected, dumped, re-selected, and confirmed as research progressed, rather than determined at the very beginning.

4. Results and Discussion

4.1. Fan Mode

4.1.1. An Overview of Fan Mode

The Fan mode was defined as the profit model with high consumption intention but low quantity of consumers, the purpose of which was to cultivate repeated direct purchase by the consumer for a variety of forms of animation and derivative products. Japanese Season broadcast television animation demonstrated that the Fan mode was engaged in a wide variety of profitable ways:

Animation Sales

Box office earnings first, then sales of animation broadcasting rights for television and internet platform, and finally sales of audio-visual products are the typical animation sales process. There are some examples where firms directly sell audio-visual products without the first two processes mentioned above, but it is not common.

Brand Licensing and Collaboration

Get the copyright fees from authorizing other manufacturers to use the image works and design concept, and even from collaborating with them to design, produce, and sell products. These products always include, for example, stationery, toys, food, and authorized bank cards.

Content-Based Peripheral Product Sales

Sell other forms of film and television works, novels, comic books, radio plays, and stage plays adapted from the initial contents of animation; sell phased or partial results of animation, for example, Materials Collection, Original Art, OST (Original Sound Track), etcetera.; recreation based upon original content, for example, music collection, the side story novels, and comics etcetera.

Image and Design-Based Peripheral Product Sales

Sell dolls or models of representative animation characters; sell decorative or practical items of the animation; sell products that combine FMCG (Fast Moving Consumer Goods) with characters or designs in the animation.

To summarize, the Fan mode mainly focused on the development and sale of peripheral products based on the content or design, which was a key to determining whether the operation of an animation project was successful. Next, is a discussion of a typical Fan mode feature, Kuiba, an animation project lunched by Vasoon Animation Co., Ltd. in 2011.

4.1.2. A Case of Fan Mode: Kuiba

Kuiba, launched in 2011 and produced through combining two-dimensional hand-drawn and three-dimensional rendering technology, was a series of passionate, realistic works that were focusing on animated films, which told the growth story of the protagonist "Man Gi" who fought in a fantasy world. Kuiba, at the time of its launch, was positioned to target an audience of people over the age of 14, with a "realistic beauty" style. Domestic animation in 2011 featured only works for younger children, such as Pleasant Goat and Big Big Wolf, which were successful. Kuiba was popular with supporters of the animation industry and both Chinese and Japanese animation fans.

Kuiba was the first time Vasoon Animation engaged in original animation filming (Table 1). Its Research and Development began in 2006 and production in 2008. The beginning of the project planning stage had "Mountain Lingshan" shown in the marketing film out of the network in 2009, which originally planned to produce 156-episodes of TV animation and five animated films. According to the relevant report after Kuiba launched, the budget of television animation reached 80,000 yuan per minute and the television pre-sale maximum price reached several million. Simultaneously, the preferential policies in China provided subsidies for the length of time, which caused Vasoon Animation to receive approximately 1000–2000 yuan per minute. Thus, Vasoon gave up the plan of "making first the T.V. show, and, later, the movie", rather, Kuiba was made as an animated film immediately.

Vasoon Animation, founded in 1992, was one of the earliest domestic private animation companies. It had participated in the production of scripts, sub-images, and medium-term processing of many animated works, as well as several original award-winning television animations, so it had mature TV animation production skills and production management experience. However, after deciding to make animated film, the play based television animation had to be rewritten, and technical differences between television and film also increased the difficulty of the production, which made the cost per minute increase dramatically. The total production cost for 83 min for the first episode of Kuiba, released in the 2011 Summer Edition, was about 35 million yuan. Due to the fear of the company being overtaken by venture capitalists, the production of funds came from self-financing, which did not include the cost of publicity and distribution. Although it won the praise of the target audiences of 14-year-olds, secondary school, and college students, and formed a positive reputation in the animation fan base, the box office was not very good initially. Producers spontaneously requested the stars to advertise with microblogs, which was ineffective, but the movie finally gained 3.09 million yuan, which was far away from the cost. Pleasant Goat and Big Big Wolf 3, launched during the Spring festival of the same year, captured 139.23 million yuan, and became the highest grossing animated movie. Although widely considered to be average, the Chinese animation, Seer, launched at the same time, and having a similar amount of investment as Kuiba, gained 43,510 million yuan. By contrast, it seemed that the box office earning of Kuiba was bleak.

Wu Hanqing, the producer and CEO of Vasoon Animation, said in many media interviews that the main reason for the loss of box office in the first episode of the Kuiba series was due to the lack of experience in the promotion of movie distribution. Vasoon only invited their dubbing voice actors to engage in the activities once in the early advertising, and that impact was quite limited. Moreover, the co-distribution company, Toonmax Media Co., Ltd., took a similar strategy with Pleasant Goat and Big Big Wolf that targeted young children, a process that did not fit for the older target market for Kuiba. Moreover, less row, less time, and a low attendance rate formed a vicious circle. Consequently, Kuiba fell into an awkward situation with good reviews but bad box office earnings. Based on the good reputation on the internet and the formation of the fan community, Vasoon Animation felt that it might be better to produce Kuiba continually and share the cost in the early phase. Additionally, improvements to deficiencies in film distribution, operation, and production were needed to recover the cost.

Table 1. The descriptive analysis on Animation Film-Kuiba.

Animation Name	**Kuiba**
Production Company	Vasoon Animation Co., Ltd.
Project Content	5 animation films
	(Three have been completed; the fourth was delayed indefinitely)
Production Date	2011 (part 1) 2013 (part 2) 2014 (part 3)
Technical Types	Combination of 2DCG (Two Dimensions Computer Graphics) and 3DCG (Three Dimensions Computer Graphics)
Prime Costs	Production cost; 35 million yuan (part 1), 20 million yuan (parts 2 and 3), over 100 million yuan in total
Broadcast Channels	Theaters
Audience	Animation audiences between 14 and 40
Community	
Production Method	Autonomous production
Issuing Company	Toonmax Media Co., Ltd. (part 1) Tianjin Bona Media Co., Ltd. (part 2) Wanda Media Co., Ltd. (part 3)

Therefore, after the launch of Kuiba, Vasoon Animation set out to continue the production of the second animated film Kuiba 2, while also mining outside the box office income, including the network and overseas distribution, exploring content based supporting roles stories and serializing it on the Comic Show. Furthermore, Vasoon re-edited Kuiba 2 and added a new title and trailer into the eleven-minute, ten-episode version of the television animation, and broadcast on Kaku Children's channel. Vasoon also simultaneously published graphic setting and original painting-based original novels, Book of Kuiba, and designed and explored image and vision-based peripheral products. However, Vasoon Animation substantially expanded its acquisition of other products in the cultural and creative industries in the form of IP (Internet Protocol) rights. The company sold peripheral products that were customized by the manufacturer through Taobao. Additionally, Vasoon employed two comic creators to adapt the animation. However, due to a lack of understanding by Vasoon Animation of comic cartoons, cooperation with the author on the basic concepts created conflict, ending the collaboration. The comic author then wrote a long diary in blogs online to criticize the company's lack of professionalism in comic creation, utilitarian work, choice to ignore the quality of the content, and their disrespect toward the labor. These papers were widely reprinted on microblogs and forums, which caused heated discussions among fans of online animation and had a negative impact on the reviews and brand image after Kuiba launched. This was in early May 2013, not long before the release of the animated film Kuiba 2 on Children's Day. Finally, Kuiba 2 earned 3 million yuan on the first day, the first week box office breakthrough was 20 million yuan, and the final box office earning was 25.27 million yuan.

Drawing on the lessons of Kuiba, Kuiba 2 cooperated with Tianjin Bona Media Co., Ltd., taking appropriate marketing that was more in line with the norms of film publicity, and launched planned network marketing. Since Vasoon Animation could not afford large outreach costs, Vasoon tried making the best use of Weibo, a social media channel that built on social media presence to enhance the character of the animation and the interaction between the founders and fans. Vasoon also made efforts to adjust the Kuiba 2 content to cater to young children. Based on the Research and Development and technology of Kuiba, the cost of Kuiba 2 was reduced to 20 million yuan per part, which made the box office earnings of Kuiba 2 grow dramatically when compared with Kuiba. The total box office earnings of Chinese animation films nearly doubled in 2013, as compared with two years prior, reaching 628 million yuan. The number of Chinese animated films also increased from 15 to 24, which meant that the box office earning of Kuiba 2 only approached the average level. Although there was an obvious increase, it was still a money-losing film.

To contrast, although Kuiba 2 was more mature in business operation and achieved the market-average box office earning, review among target audiences shows differentiation. The scandal about the comic destroyed the corporate image among the animation fans community, and the concession to the younger market affected the older audience as well. Having a wide range of online publicity attracting much more animation fans focus caused some audiences who had watched many works or who had some professional basis, to point out that Kuiba 2 plagiarized Japanese animation shots and had some technical problems of production. The intellectual property in other areas of the industrial chain extension capabilities and strategic integration capabilities of the weaknesses began to emerge at the same time.

4.1.3. Lessons from Kuiba

Kuiba's series of animation projects operation experience made it easy to notice that the starting point of creative planning of Kuiba was high and it interacted well with the target audience's fan base. Although the master team denied the imitation of the Japanese animation style, there was an obvious overlap between target audiences and the Japanese animation fan community. Given that the box office earning was limited, the audience was small enough to make money by brand licensing. Vasoon Animation also combined with the domestic market and animation fan group spending habits for toys, garage kits, and commodities, as well as re-creation novels, comics, and original net anime. Unfortunately, Kuiba, as a case of Fan mode, was not a success in the Chinese market. These experiences and lessons are meaningful to animation project operation regarding Fan mode in a domestic market. This is summarized as follows:

Insufficient Commercial Planning and Unreasonable Cost Allocation

Vasoon Animation increased the production cost at the beginning and hoped to cover that with "projected" box office earnings of Chinese animation film. It was impossible to solve the problem that television animation could not cover the high production cost that way, and this reflected the lack of awareness of the movie industry and the commercialization of the animation company that had operated for many years in a traditional manner with television. Due to a hurried transformation from television animation to animated film, the company blindly pursued the first-class technical level and image quality, but neglected the important aspect of publicity in the norm of the film industry. Based on this, the company was concerned that they might lose control of intellectual property if they chose venture capital, but in not doing so, they also lost the opportunity to promote and operate Kuiba with better capital. The self-made production cost of 35 million yuan put financial pressure on the company and it became a heavy burden on the follow-up operation, allowing the enterprise to fall into the dilemma of short-sighted behavior due to financial pressure.

Poor Strategic Integration and the Blind Expansion of Internal Chain

After the loss of box office earning by Kuiba, Vasoon Animation considered using the good reviews to develop other forms of derivative products in the cultural and creative industry. Adaptation of the works for comics, books, and development of peripheral products was adapted, for example. However, Vasoon Animation turned to unfamiliar parts, like comic production, development of peripheral products, and sales, rather than the common way, like cooperating with other companies or licensing, which ignored the condition and capacity of the company and violated the commercial discipline. It increased the burden on business operation and affected the enterprises' investment in the development of animation works as the core of the content.

4.2. Placement Mode

4.2.1. An Overview of Placement Mode

The Placement mode is defined as the profit model with low consumption intention but high quantity of consumers, the purpose of which is to capture the value of consumers' attentions by placing advertisements in the animation product. The mode is quite popular in the film, television, and other industries, and plays an important supporting role in the profit model. However, it is not common in the field of animation because the audience base is quite limited.

When compared to the Fan mode, the Placement mode seems to be rather simple, only profiting from advertisement placement. However, the cost of the placement mode is much lower, the operation is easier, and the collaboration space is much broader, thus allowing it a stronger practical feasibility. Next, a typical Placement mode of Miss Puff, an animation project lunched by Youku.com and Beijing Hutoon Co., Ltd. in 2011 will be discussed.

4.2.2. A Case of Placement Mode: Miss Puff

Miss Puff was an original net anime about an urban white-collar female with the theme of urban life and emotion, with the aim of pursuing quality of life and spending power (Table 2). Each episode within an animated cartoon told an independent story of Miss Puff in just over 10 min. It was well received by viewers on Youku since it was launched in 2011, and produced a total of 63 episodes in five seasons, a 28-episode miniseries, and a microfilm. The cumulative number of broadcasts was more than 300 million.

The division of Youku.com and Beijing Hutoon Co., Ltd. was clear in the process of cooperation. Hutoon took charge of content production, while Youku took charge of promotion and broadcast, and they shared the production cost. They also developed derivative products together and shared copyright, and divided earnings by a certain percentage. Regarding technology, Hutoon had a director, Pi San, who was a leading figure in the Chinese animation industry. Pi San innovatively made Miss Puff a combination of FLASH and live photography, which not only created a unique artistic style, many live shots also largely reduced the difficulty and cost of using animated technology. More importantly, this creation made Miss Puff less animated and more likely to break the general public's notion of animating younger people, allowing for Youku to promote the network animation as a homemade drama.

Although Miss Puff succeeded in ratings, from the perspective of the animation project, the audience did not pay to watch the video on the network. The traditional source of online video revenue was only video patch ads for Miss Puff to develop brand value and turn the attention of the audience into revenue for the animation project. When considering the content of the form of Miss Puff features, the main role was very small, and the prominent visual image was only the main character, Miss Puff. Each episode told the story in the independent form, which made it difficult to shape the character and relationship. This made Miss Puff in accordance with the traditional ideas according to the work itself, but to develop derivative products or content was more limited; only the small pylons, picture books and other forms of print were suitable for the style of the work. Thanks to the high click-through rate of Youku's platform and its clear and accurate target audience positioning, Miss Puff realized the groundbreaking profit through the placement of advertisements. The company also realized commercial cooperation through Youku because the work illustrated female urban life, and the characteristics of the real part of the screen through the Youku platform helped to obtain business cooperation, food, commodities, devices, and cars, which helped them to gain broader profit space. Since the animation was produced continually, and there was gradual formation of brand influence, Miss Puff also started to operate the official product online shop, sell its own brand of cosmetics, fashion accessories and daily necessities, and tried the packaging and management of fashion brands.

Table 2. The descriptive analysis of Animation Film-Miss Puff.

Animation Name	**Miss Puff**
Production Company	Beijing Hutoon Co., Ltd.
Project Content	5-season original net anime with 63 episodes A 28-episode miniseries A microfilm (the original net anime was produced persistently until March 2015.)
Production Date	2011 (season 1 and 2) 2012 (season 3 and 4) 2013 (miniseries, microfilm) 2014 (season 5)
Technical Types	Flash and location shooting
Prime Costs	About 5–10 thousand yuan per minute
Broadcast Channels	Internet
Audience	White-collar females from 21–27 and college students who are going to enter society
Community	
Production Method	Autonomous production
Issuing Company	Youku.com

4.2.3. Successful Experience of Miss Puff

Miss Puff was produced by both Youku.com and Beijing Hutoon Co., Ltd. and was exclusively broadcast in Youku, so the companies only benefitted from pre-movie advertising and advertisement placement at the very beginning. The companies began to expand the animation brand based on fashionable brand, in the long run. The successful case provides Placement mode with the classical paradigm as to how the content producer cooperated with the internet platform. It also was not hard to see that the animation project could profit through the implantation mode and the relationship with the development of Internet media was also inseparable. The company did not succeed by accident, and there were some critical factors included.

High-Quality Content and Precise Market Positioning

Pi San, the director of Miss Puff, graduated from the art department with the major of oil painting from Shanxi University, had rich experience in independent animation production and cooperation with television, film, and music, as well as strong aesthetic art competence and sensitivity to business. The content of the film came from city life, which included true feelings and easily aroused the resonance of the audience. When considering that the target audience was white-collar females and college students that were prepared to enter society, the companies accurately segmented the market and found consumers who had high purchase capacity and commercial cooperation intention, which created a solid foundation for success.

Achieve Low-Cost and Efficient Dissemination through the Network Media

The dissemination of online media itself had the characteristics of low copy cost, fast transmission, and strong interaction. The convenience and availability met the habit of target audiences at any time. The highly interactive nature of online media enabled Miss Puff to quickly gather feedback and opinions from audiences through click through rates, reviews, and social media channels, and to reflect on follow-up productions. It was also important for Miss Puff to maintain sound comment and incremental communications.

Sound Forms of Cooperation and Reasonable Division of Labor

Thorough cooperation of Youku.com and Beijing Hutoon Co., Ltd. was one of the necessary factors for Miss Puff to be successful. The common interests of a clear division of labor, complementary advantages, and close cooperation made the team focus on the creativity and production of animation and ensured the quality of work. Furthermore, Youku provided excellent online and offline marketing resources and a professional business cooperation platform to achieve the optimal allocation of resources, which helped Miss Puff to succeed in the long term.

4.3. Popular Mode

4.3.1. An Overview of Popular Mode

The Popular mode is defined as the profit model with high consumption intention and high quantity of consumers, the purpose of which is to cultivate a direct, repeated purchase habit of the consumer for a variety of forms of animation and derivative products, and to capture the value of consumers' attentions by placing advertisements in the animation product.

Although combining the revenue model of Fan mode and the Placement mode, the Popular mode also engaged in a wide variety of profitable ways, including animation sales, brand licensing and collaboration revenues, content-based peripheral products sales, and image and design-based peripheral product sales, and sales of placed advertisements, there were still differences between the Popular mode, the Fan mode, and the Placement mode.

Similar to the Fan mode, the two key points of Popular mode are the formation and cultivation of audiences and consumers, as well as a mechanism for perfecting the brand authorization and derivative product development and sales in the industrial chain.

The difference between the Popular mode and the Fan mode is that the former has much stronger profiting capability of animation sales and brand licensing and collaboration revenues, while the latter has stronger profit capability of peripheral products sales. Moreover, the difference between the Popular mode and the Placement mode was that the former did not only depend on the profit from advertisement placed in the animation, since the advertisement sale was one of the supporting profitable ways.

The difference between the Popular mode and the Fan mode in terms of cultivation of audiences and consumers was that the former emphasized the accumulation of quantity, thus the cultivation of audiences and consumers relied more on strong channel resources as compared with Fan mode, which depended on symbolized content that was based on creativity and artistic creation to interact with fans. Presently, Popular mode, as a typical mode in China, mainly cultivates audiences by television, and has difficulty in operation due to the long cash conversion cycle and high entry threshold of the channel. However, with the development of the internet, smart mobile devices and new media, it is realizable to cultivate audiences and consumers by the low entry threshold of channel-like video websites, so there is a future possibility of more successful cases.

Popular mode was also different from Fan mode in terms of brand licensing and development of derivative products and sales, due to the limited rights protection capacity and pirated market environment, rather than lacking a cooperation mechanism. The recent increase in the awareness of copyrights and laws, as well as capital infusion by large culture media companies (e.g., Fantawild Animation Inc., Hong Kong, China), toy corporations (Guangdong Alpha animation, Guangdong, China), video websites (Youku and Tudou), and absorption and adaption of qualitative creativity and content, has made it hopeful to see the development of Popular mode with the increasing channel resources and capacity of strategic integration and expansion of the industrial chain. To summarize, it is a huge challenge for the creative planning, production, and operation of an animation project to achieve both high consumption intention and high quantity of consumers. Next, illustration of a typical Popular mode of Pleasant Goat and Big Big Wolf, an animation project lunched by Creative Power Entertaining Co., Ltd. from 2005 will follow.

4.3.2. A Case of Popular Mode: Pleasant Goat and Big Big Wolf

Pleasant Goat and Big Big Wolf, launched by Creative Power Entertaining Co., Ltd., was a television animation, which was voluminous, funny, and intellective. The basic information is as follows (Table 3).

Table 3. The descriptive analysis on Animation Film-Pleasant Goat and Big Big Wolf.

Animation Name	Pleasant Goat and Big Big Wolf
Production Company	Creative Power Entertaining Co., Ltd.
Project Content	Television animation with 14 seasons and 530 episodes (finished) 7 animation films (one per year until March 2015)
Production Date	2005 (television animation) 2009 (animation film, one per year)
Technical Types	Flash (television animation) Flash and CG (animation film)
Prime Costs	Production cost of television animation is about10 thousand yuan per minute Production cost of animation film is under 10 million yuan per part and publishing fee is under 20 million yuan per part
Broadcast Channels	Television and theaters
Audience	All ages, mainly young children and their parents
Community	
Production Method	Autonomous production
Issuing Company	Local children's channel, film distribution corporations

The company formulated the marketing strategy of "broadcasting to the market first through television", then targeting local children's channels and developing audiences with the exposure rate. When considering that the unmanageable cost of producing animated films and the long-term exposure needed to foster the audience, Pleasant Goat and Big Big Wolf opted to minimize production costs by using FLASH technology (about 10,000 yuan per minute), to attract audiences with simple and vivid images and an interesting plot. Workers of Creative Power Entertaining Co., Ltd. told the media, to achieve the high visibility of the work, Pleasant Goat and Big Big Wolf did not benefit in the first two years to increase exposure.

Since television animation premiered on Hangzhou TV Children's Channel it experienced stable ratings and unprecedented popularity with the audience, so the TV and television broadcasters gradually expanded 75 TV stations, which had broadcast Pleasant Goat and Big Big Wolf repeatedly by 2013, including 14 seasons and 530 episodes. Between 2005 and 2009, Pleasant Goat and Big Big Wolf had built its own Chinese animation brand gradually and cultivated large amounts of audiences and consumers through television.

During the production of the television edition, Creative Power Entertaining Co., Ltd. had begun to consider the production of movie plans. However, domestic animation film faced a high production cost and low box office earnings before 2008, so the company waited for a right time. Domestic animation film in 2008 started to enter a stage of rapid increase in output and growing demand, and thus the company believed that the film of Pleasant Goat and Big Big Wolf could cover the cost based on market research, and even make profits. Following negotiations with Shanghai Media Group, which had animated marketing and distribution experience, Creative Power Entertaining decided to produce the animation film of Pleasant Goat and Big Big Wolf, taking the "whole family concept" as its marketing strategy to bring the movie box office growth effect by "hand in hand".

The television animation of Pleasant Goat and Big Big Wolf finished in 2009 and was successful in its first animated film. Following that, Creative Power Entertaining started to transform from television animation to animated film. Pleasant Goat and Big Big Wolf had launched one film per year during the Spring festival since 2009, earning sound profit.

The important thing to note is, after the peak of 167.55 million at the box office of the fourth film in 2012, there was a declining trend since 2013 and the box office earning in 2015 was even lower than that of 2009. There were two reasons behind it: one was the change in the market environment. Increasing quantities of domestic animation films and distribution of new brands like Boonie Bears, for example; another was internal change at Creative Power Entertaining in terms of asset structures and leaving of creators.

Following the end of television animation in 2009, Huang Weiming, one of the creators, left Creative Power Entertaining due to disagreements with the company's overall direction of development. Between 2009 and 2011, Pleasant Goat and Big Big Wolf became popular all over the country. Although the value of works and brands was recognized in the market, Creative Power Entertaining lacked the bargaining power in the market due to the strong position of television and film distribution channels. That meant the company could not cover the cost although the ratings were high. The box office earning was tens of millions of yuan, while the revenue was only several million yuan. Furthermore, the profit from content-based derivative product sales was discounted due to the undisciplined market of derivative products and lacking copyright protection. Creative Power Entertaining, in 2011, maintained the copyright of the animation and story, as well as the right of content creation, but sold trademarks of image and derivative products and licensing, in the form of capital operation, to Disney and Imagi International Holdings Limited (IMAGI) and made a tripartite agreement of brand management. An investor named Su Yongle and another master named Lu Yongqiang then sold shared cash, Guangdong Alpha animation and Culture Co., Ltd., in 2013, took full control of both IMAGI and Creative Power Entertaining, capturing the majority of copyright and operation rights. However, during the capital operation of different owners, the acquirer's lack of innovation and construction of brand image and content, added to the departure of creators one after another, and made the animation film gradually fall into the embarrassment of overdraft brand value. Box office earnings also reduced in the context of intense competition in the animation film market. Whether Pleasant Goat and Big Big Wolf could change the unfavorable trend and recreate the success depended on, ultimately, whether the present team could achieve innovation and break the audience for the series of animation films aesthetic fatigue.

4.3.3. Lessons from Pleasant Goat and Big Big Wolf

It was easy to notice that the most commonly successful path of animation project, Popular mode, was still from a young television animation to an animated movie with children driving parents into theaters. CCTV (China Central Television) started broadcasting the new Chinese animation brand Boonie Bears (Fantawild Animation Inc., Hong Kong, China) in 2012 and its animation films in 2014 and 2015 hit a staggering 247.9 million yuan and 29.291-million yuan, respectively. The box office series of Boonie Bear domestic animation brands, was also a case of Popular mode other than Pleasant Goat and Big Big Wolf. Their enlightenments include:

Preheating the Market with Promotion

Although Creative Power Entertaining used the lowest cost by producing television animation with FLASH, it took the company over four years to cover the cost. Boonie Bears was an animation brand that was popular with audiences as soon as possible, but also showed a loss while broadcasting on television for two years before being released in 2014. Therefore, although saturating the market with high exposure through television channels was feasible, it put forward very high requirements on the capital input and working ability of enterprises in the pre-operation of animation projects.

Strategic Integration and Expansion Capacity of Industrial Chain

Although Pleasant Goat and Big Big Wolf had made success in television animation, film, and branding, it was difficult for Creative Power Entertaining to capture the value through content and derivative products. It eventually acquired it by capitalization, showing strong domestic channels and weak copyright protection, with the original motivation similar to the lack of strategic integration capabilities.

5. Conclusions

This paper divides feasible profit models of animation projects into Fan mode, Popular mode, and Placement mode, and discusses the domestic cases of them and their operation, after discussing the operation and profit model of animation projects.

There are few successful cases of Fan mode among domestic animation projects. These animation projects (e.g., Kuiba) reflect that in the case of lacking in-depth cooperation on the industrial chain, Fan mode should be considered cautiously for companies that are weak in the whole business plan and internal management due to the high production cost and investment risk. Regarding domestic development of animation projects using Fan mode, animation companies should explore how to find a balance between satisfying the fans' cultural taste and controlling the production cost. How the Fan mode should be formed within the Chinese market and industrial environment with reasonable cooperation in the industrial chain path also needs more practical attempts and discussions.

Placement mode is a typical model that was formed by the rise of the online media industry in China's animation industry. Similar to the movie media industry in the United States of America, or the animation and television media in Japanese animation, there is a close relationship between online media and the implanted model. The cooperation model of Miss Puff, which was launched by Youku.com and Beijing Hutoon Co., Ltd., also provides Placement mode with a classical cooperation paradigm of content producer and channel platform. Placement mode is very suitable for transforming independent animation to commercial ones, but it is limited by the content and creation based on the unique profit model. Thus, it cannot meet the needs, in most cases, if a project depends on this mode totally, and, as for most projects, they can partly draw on the experience of cooperation with other platforms or introduce advertisement placement as a supplement of profit model.

Popular mode is the most mainstream development path for Chinese animation projects. Taking Pleasant Goat and Big Big Wolf as the example, this project cultivates the market through long-time television broadcast at first, and then extends the box office receipts through animation films and other links to toys, peripheral products, entertainment industry income, etcetera. Placement mode requires a lot of upfront capital investment, strategic integration and expansion of the industrial chain for the main actors in animation projects, when considering that its profitability is greatly affected by the market environment, such as copyright protection and piracy. The biggest problem is how to protect the interests of enterprises and market environment. However, it should be noted that with the capital market's concern for the animation industry, other links of cultural and creative industries, such as cultural media groups, online video media, entertainment industry, and toy industry began to integrate capital, channel resources, strategic integration, and industrial chain expansion capabilities into the animation industry. This improvement of the market environment makes it possible for the Placement mode to extend the industrial chain vertically, and to be widely applied to cultural media companies, large cultural and creative companies, or media based on successful experiences abroad.

There are both distinctions and relations among Fan mode, Placement mode, and Popular mode, and it is possible for these three modes to transform under the market and media environment. A work, based on Fan mode, introduces the profit model of placement advertisement with the increase in the fan community and impacts, and then transforms into Popular mode. Additionally, work based on the Placement mode might promote the consumption intention of consumers by content-based innovation and improvement, and then turn to Popular mode; when separating fan community from audiences of Popular mode, it can also include Fan mode. Therefore, much more possibilities of translation and combination among profit models for the animation industry remain to be explored for the future practice of the animation industry. Moreover, the case study method was employed to explore the profit model innovation. Therefore, quantitative research can be adapted in the future.

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Article

Regional-Level Carbon Emissions Modelling and Scenario Analysis: A STIRPAT Case Study in Henan Province, China

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Abstract: Global warming has brought increased attention to the relationship between carbon emissions and economic development. Research on the driving factors of carbon emissions from energy consumption can provide a scientific basis for regional energy savings, as well as emissions reduction and sustainable development. Henan Province is a major agricultural province in China, and it is one of most populous provinces. Industrial development and population growth are the causes of carbon emissions. The STIRPAT model was conducted for analyzing carbon emissions and the driving factors for future carbon emission in Henan Province. The results show that: carbon emissions and energy consumption in Henan Province presented a rising trend from 1995 to 2014; Energy consumption due to population growth is the main contributor to carbon emissions in Henan Province. As every 1% increase in the population, GDP per-capita, energy intensity, and the level of urbanization development will contribute to the growth of emissions by 1.099, 0.193, 0.043, and 0.542%, respectively. The optimization of the industrial structure can reduce carbon emissions in Henan Province, as suggested by the results, when the tertiary sector increased by more than 1%, the total energy consumption of carbon emissions reduced by 1.297%. The future pattern of carbon emissions in Henan Province is predicted to increase initially and then follows by a decreasing trend, according to scenario analysis; and maintaining a low population growth rate, and a high growth rate of GDP per-capita and technical level is the best mode for social and economic development.

Keywords: carbon emissions; energy consumption; STIRPAT model; driving factors; scenario predictions

1. Introduction

Global warming has become an irrefutable issue that needs to be recognized and urgently addressed by all mankind [1–5], to keep the increase in the average global temperature well below 2 °C above pre-industrial levels and to pursue efforts to limit the temperature increase to 1.5 °C above pre-industrial levels [6,7]. Carbon dioxide emissions due to human activities contribute about 80% to the greenhouse effect [8]. With rapid economic and population growth, human activities increasingly rely on energy consumption [9–12]. In particular, excessive fossil fuel consumption produces massive emissions of carbon dioxide and the subsequent greenhouse effect [13–15]. In this context, a consensus has been reached among the international community to develop a low-carbon economy and technologies, and actively acknowledge and address climate change [16,17]. Fundamentally, reducing greenhouse gas emissions is an economic issue [18,19]; to attain sustainable and harmonious development of ecology, economy, and human society, it is necessary to correctly understand the relationship between economic development, energy consumption, and carbon emissions [20–24].

Researching the driving factors of carbon emissions will provide a scientific reference for attaining low-carbon development and taking appropriate measures on supply-side reform [25–28]. Greenhouse gas emissions produced by human activities are primarily driven by factors such as population, affluence, and technological advances [29–32]. Currently, many different methods have been used to examine the impact factors of CO_2 emissions. Among them, the logarithmic mean Divisia index (LMDI) and stochastic impact by regression on population, affluence, and technology (STIRPAT) models are the two most well-known methods for examining such factors [33]. The LMDI model can only provide limited useful information for shaping CO_2 emissions reduction strategies [34–36]. The STIRPAT model, an extension of IPAT, can examine many more impact factors than the LMDI model, and it became the mainstream method for uncovering the driving factors of energy consumption or carbon emissions over the world [37–41].

Some researchers have studied the factors influencing China's carbon emissions [24,42–45]. Their results reveal that economic development contributes significantly to China's carbon emissions in the short term, while population growth is the most significant contributor in the long term. Additionally, researchers have found that China’s carbon emissions were influenced most significantly by population and industrial structure, compared with energy prices, and foreign trade intensity [46]. Related research at the Chinese provincial level has shown that the factors influencing carbon emissions vary somewhat from province to province; population, investment in fixed assets, GDP per-capita, heavy industry (secondary sector), the working-age population, and the urbanization rate are the most significant influences on carbon emissions within the Chinese provinces [35,47–52]. Evidently, spatial heterogeneity and regional differences both influence carbon emissions [53,54]. In summary, China at the national scale and provinces at the reginal scale are both inevitably facing a serious dilemma: if carbon emissions were reduced, economic development and GDP would slow down consequently [13,55].

China covers a vast territory, and socio-economic development varies from region to region [56]. If a same model is applied to different study areas, it is necessary to fully consider their social conditions and economic development characteristics. Henan Province, as a major agricultural province, has the largest population and the increasing GDP. In recent years, grain production has enabled rapid social and economic development with convenient transportation. Henan has become an attractive hut for economic activities and subsequently has been faced with continuous population growth, while striving to maintain its status as a large agricultural province. In this context, its primary concern is to optimize its industrial structure, and thus to improve economic and environmental benefits.

This study quantitatively evaluates carbon emissions from energy consumption in Henan Province, fully accounting for its status as a large agricultural province and its transformation in industrial structure. By introducing the industrial structure to the STIRPAT model, this study predicts future trends in carbon emissions. Based on the simulation results and predication model, carbon emissions in Henan Province are estimated under different development patterns, represented using a combination of factors such as population, economic level, technological advances, and industrial structure. Based on a comparison of development scenarios, this study proposes an optimal low-carbon development pattern suited to the province, thus providing a scientific basis for building a less developed area into a low-carbon society. Henan is in a period of rapid development due to its large population and extensive energy consumption. This paper can be a reference to other areas—such as Africa, Southeast Asia, Eastern Europe and South America—which also are facing the same dilemma.

2. Data Sources and Methodology

2.1. Study Area

Henan Province is located in mid-east mainland China, and includes the middle and lower reaches of the Yellow River. Most of its area is situated in plains (Figure 1). In 2015, its annual GDP was 3701 billion yuan, a year-to-year increase of 8.3%. The ratio of value added to the primary, secondary, and tertiary sectors was 11.4:49.1:39.5 in 2015. By the end of 2015, the total population of Henan Province was 107.22 million people, about three times of Canada. Total energy consumption was 23.2 billion tons, and energy consumption per 10,000 yuan of GDP was 0.63 tons, an annual decrease of 4.76%. In recent years, Henan Province has embraced rapid socio-economic development and a continued increase in urbanization, accompanied by an expansion in energy consumption. Meanwhile, carbon emissions have continued to increase for various reasons, including enormous population, imbalanced economic development, unreasonable industrial structure, low technological level, and a coal-dominated energy consumption structure.

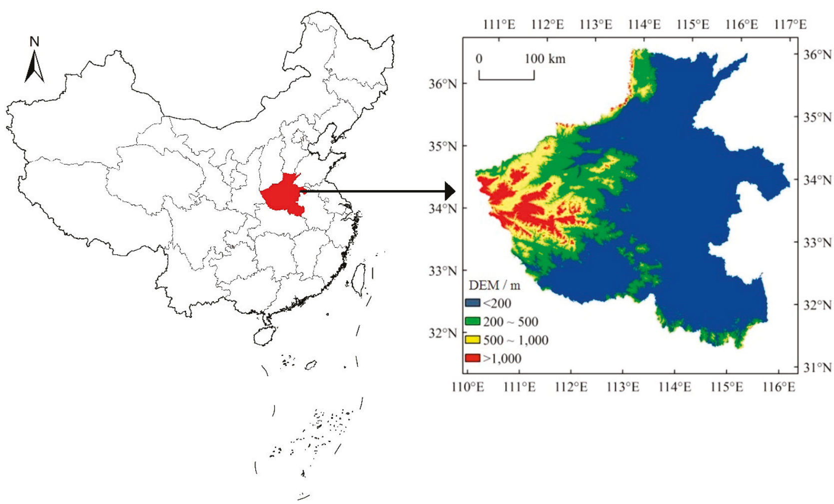

Figure 1. Study area.

2.2. Methodology

2.2.1. Carbon Emissions Estimation from Energy Consumption

Carbon emissions in Henan Province were calculated using data and methodology recommended by the IPCC (2006) [57]. The three major energy sources in Henan Province are coal, fossil oil, and natural gas, accounting for 76%, 13% and 5% of total energy consumption in 2015, respectively. Therefore, this study selected three energy sources to calculate carbon emissions from energy consumption. The calculation equations are [57–59]

$$C = \sum_{i=1}^{3} C_i = \sum_{i=1}^{3} S_i N_i = \sum_{i=1}^{3} S_i V_i N \quad (1)$$

where C indicates total carbon emissions from energy consumption, C_i represents carbon emissions from each i type of energy, S_i is the carbon emission coefficient for each i type of energy, N_i is the consumption of each i type of energy, N_i is the proportion of consumption for each i type of energy in the total energy consumption, and N is the total energy consumption. In this paper, the primary energy carbon emission coefficients used are those recommended by the Energy Research Institute of Chinese National Development and Reform Commission. The coefficients for coal, fossil oil, natural gas, and non-fossil energy are 0.5394, 0.8359, 0.5956, and 0, respectively (ton C/ton TJ).

2.2.2. STIRPAT Model

Ehrlich and Holdren established the IPAT model, and applied this model to the evaluation of environmental stress [60,61]. This model is formulated as

$$I = PAT \tag{2}$$

where I indicates environmental stress. In a traditional environmental stress model, population, economic development, and technological advances are considered the major driving factors in environmental stress, which are respectively expressed as P, A, and T. In the evaluation process, the employed coefficient is singular and fixed; its fixed substitution value can only be used to calculate the emissions of solid carbon. Therefore, this model has low precision and many limitations. Subsequently, Dietz and Rosa [62] and York et al. [33,63] proposed the STIRPAT model by extending the IPAT equation. The STIRPAT model expresses the IPAT model in stochastic rather than fixed form, specifically

$$I = \mathrm{a}P^bA^cT^d \tag{3}$$

where I indicates the environmental impact, which is denoted using the carbon emissions from energy consumption in the present research; P represents the regional population; A represents the regional GDP per-capita (affluence); T indicates the regional technological level; a is the model coefficient; b, c, and d are three exponents that need to be estimated; and e indicates the error term [51]. Applying the natural logarithm to both sides of Equation (3) results in

$$\ln\ I = \ln\ a + b\ \ln\ P + c\ \ln\ A + d\ \ln\ T + \ln\ e \tag{4}$$

As previously mentioned, Henan Province is a large agricultural province in China. While maintaining the fundamental position of its agriculture, adjusting and optimizing the industrial structure is important for the coordinated development of the social economy. Therefore, this paper introduces a few industrial structure indices to improve the model

$$\ln I = \ln a + \beta_1 \ln P + \beta_2 \ln A + \beta_3 \ln T + \beta_4 \ln U + \beta_5 \ln S + \ln e \tag{5}$$

where I indicates carbon emissions (unit: 10,000 tons) in Henan from energy consumption; P is population (unit: 10,000); A represents affluence, which is denoted by GDP per-capita (unit: yuan per capita); T is the energy consumption intensity per unit GDP (unit: ton of standard coal per 10,000 yuan); U is the percentage of urbanization; S is the proportion of tertiary sector; β_1, β_2, β_3, β_4, and β_5 are elasticity coefficients, respectively indicating the changes in β_1%, β_2%, β_3%, β_4%, and β_5% every time P, A, T, U, and S are changed by 1%.

2.2.3. Environmental Kuznets Curve (EKC)

To further study the relationship between economic development and environmental protection, this study introduces the Environmental Kuznets Curve (EKC) [64]. Specifically, the intent is to determine whether the relationship between economic growth and carbon emissions can be represented using the EKC. The EKC is shaped as an inverted U: with economic growth, carbon emissions go up at first and then go down. To study the foresaid relationship between Henan carbon emissions from energy consumption and its economic development, Equation (3) is adjusted as

$$\ln I = \ln a + \beta_1 \ln P + \beta_{21} \ln A + \beta_{22} \ln(\ln A)^2 + \beta_3 \ln T + \beta_4 \ln U + \beta_5 \ln S + \ln \varepsilon \quad (6)$$

where β_{21} is the coefficient of the GDP per-capita logarithm and β_{22} is the coefficient of the quadratic term of the GDP per-capita logarithm.

Equation (6) can be simplified as

$$\ln I = \beta_{21} \ln A + \beta_{22} (\ln A)^2 \quad (7)$$

This formula conforms to the quadratic function relationship. When β_{22} is negative, the opening is oriented downwards, thus obtaining the elasticity coefficient (EE_{IA}) of the GDP per-capita with respect to the carbon emissions from energy consumption

$$EE_{IA} = \beta_{21} + 2\beta_{22} \ln A \quad (8)$$

For negative β_{22} values, the relationship between GDP per-capita and carbon emissions can be represented with an inverted U-shape curve.

2.2.4. Ridge Regression

The danger of multicollinearity is primarily its generation of large standard errors among related independent variables; these errors are characterized by large variances in the regression model parameters, making the regression model unstable. These standard errors can be significantly reduced using a curtain method. Thus, the negative consequences of such errors can be effectively eliminated, accordingly, even when multicollinearity remains in the regression model. Ridge regression, which can obtain acceptably biased estimates with smaller mean square errors in independent variables through bias–variance tradeoffs, is one of the most effective solutions for dealing with multicollinearity [65].

2.3. Data Sources

In order to dynamically measure and analyze Henan Province carbon emissions from energy consumption, this study selected related socio-economic data for Henan Province from 1995 to 2014, including energy consumption, population, urban population, GDP, and output from tertiary industries, which are respectively available from the *China Energy Statistical Yearbook* (1996–2015) and *Statistical Yearbook of Henan Province* (1996–2015).

Coal is the main fuel for Henan, accounting for a larger amount of carbon dioxide emissions. The carbon emissions of coal continued to rise, reaching the maximum in 2011, 283.74 Mt, and then began to decrease. The proportions of other energy types—oil and gas—according to Table 1, have gradually increased in recent years, even though they are not in a large proportion in total energy consumption.

From the perspective of population, Henan has a growing population, which broke through 100 million people in 2010. The growth rate of urban population was fast. From 1995 to 2014, the urban population increased by 27 million annually. The increase in population, especially in urban areas, lead to increasing energy consumption and carbon dioxide emissions.

From an economic perspective, the development of the economy associates with carbon dioxide emissions to some extent. The total amount of GDP in Henan province increased rapidly during 1995–2014. The change from 300.27 billion yuan in 1995 to 3493.82 billion yuan in 2014. The contribution of the third industry increased significantly, which increased from 81.95 billion yuan in 1995 to 1296.17 billion yuan in 2014.

Table 1. Descriptive statistics of the data.

Years	Energy Consumption			Population		Economy	
	Coal (Million Tons)	Oil (Million Tons)	Gas (Million Tons)	Total Population (Million)	Urban Population (Million)	GDP (Billion Yuan)	Output of Tertiary Industries (Billion Yuan)
1995	79.60	4.02	0.07	91.00	15.64	300.27	81.95
1996	82.05	3.98	0.06	91.72	16.87	363.47	100.46
1997	79.75	4.48	0.07	92.43	18.11	404.11	115.07
1998	80.63	4.87	0.07	93.15	19.37	430.82	127.25
1999	82.99	5.61	0.08	93.87	20.64	451.79	138.21
2000	87.24	6.10	0.08	94.88	22.01	505.30	156.23
2001	93.25	5.98	0.09	95.55	23.34	553.30	174.67
2002	103.33	6.01	0.10	96.13	24.80	603.55	192.93
2003	114.19	6.37	0.12	96.67	26.30	686.77	225.70
2004	149.38	7.05	0.15	97.17	28.09	855.38	265.23
2005	184.68	6.69	0.17	97.68	28.75	1058.74	325.83
2006	210.03	6.97	0.22	98.20	30.50	1236.28	383.80
2007	231.71	7.14	0.24	98.69	32.14	1501.28	469.16
2008	238.68	7.04	0.27	99.18	33.97	1801.85	534.57
2009	244.45	7.86	0.30	99.67	35.77	1948.05	604.58
2010	260.50	8.35	0.34	104.37	36.21	2309.24	707.71
2011	283.74	8.75	0.39	104.89	38.09	2693.10	865.35
2012	252.40	10.10	0.53	105.43	39.91	2959.93	1000.85
2013	250.58	19.52	0.57	106.01	41.23	3219.13	1147.57
2014	242.50	19.78	0.55	106.62	42.65	3493.82	1296.17

3. Results and Discussion

3.1. Carbon Emissions and Related Driving Factors

The energy consumption structure of Henan Province from 1995 to 2014 is showed in Figure 2. Total energy, fossil oil, and natural gas consumption have continued to increase annually, while coal consumption has shown a decreasing trend. This type of consumption accounted for less than 77% in 2013 and 2014, despite it being at least 80% in other years. However, when compared to other energy sources, coal consumption accounts for a far larger proportion of the total energy being consumed; moreover, these percentages are far higher than the Chinese average, which happens to be 64%.

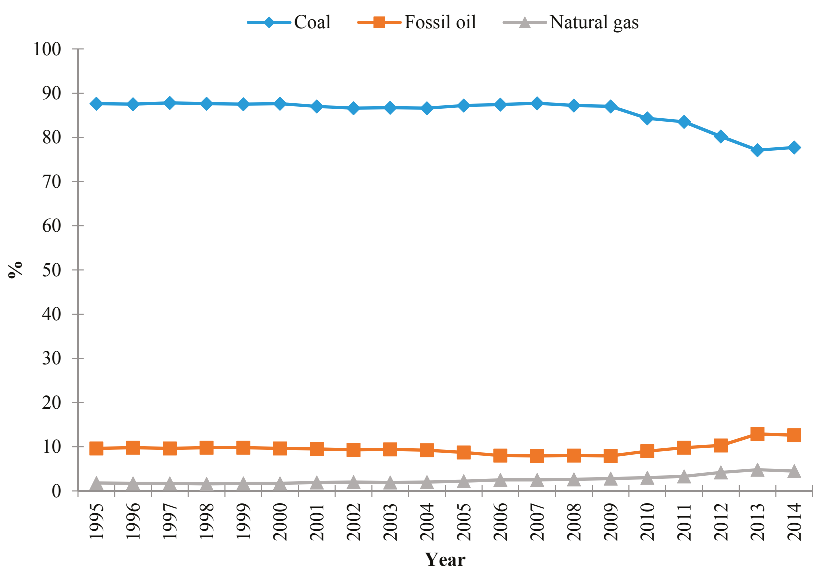

Figure 2. Energy structures in Henan Province from 1995 to 2014.

Figure 3 shows the changes in Henan Province energy consumption and its influencing factors. Overall, the trend in carbon emissions from energy consumption can be divided into two stages:

slow growth from 1995 to 2003, and rapid growth from 2004 to 2014. From 1995 to 2003, there was a slow increasing trend in carbon emissions from energy consumption due to population size, GDP per-capita, urbanization rate, and proportion of tertiary sector. During this same time, a decreasing trend in energy consumption intensity was observed. From 2004 to 2014, there was a large fluctuation in the driving factors in carbon emissions from energy consumption. Aside from the continued decline in energy consumption intensity during this time, there was a relatively rapid increase in carbon emissions, population size, GDP per-capita, urbanization rate, and proportion of tertiary sector. In 2004, the Strategy for Central China's Rising was proposed and implemented, which boosted the socio-economic development of Henan Province. Specifically, the GDP per-capita grown from 8802 yuan (2004) to 37,027 yuan (2014), with corresponding growth of carbon emissions from energy consumption. In 2014, Henan Province's carbon emissions from energy consumption reached 182.7 million tons, an increase of 60% over 2004. In addition, the urbanization rate increased from 28.91% (2004) to 45.19% (2014), and the proportion of tertiary sector increased from 31% (2004) to 37% (2014). While population growth has been very slow, the population base remains large. In 2014, the permanent resident population was as large as 94.4 million. The enormous population has been an important driving factor in the increase of carbon emissions. We also found that the trends of energy carbon emission and influencing factors of Henan Province are very similar with China, however, quite different from the world at large (Figure 3). Because Henna Province is a typical example of central and western China with coal-based energy structure and agricultural population.

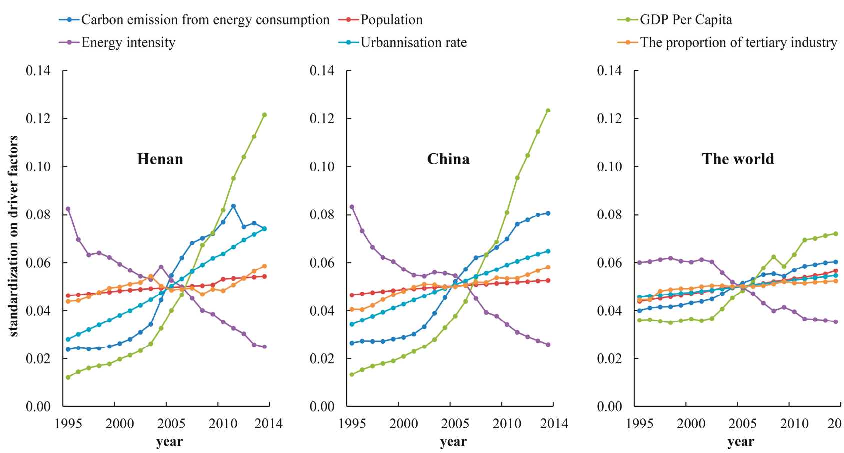

Figure 3. Comparison of energy carbon emission and influencing factors among Henan Province, China and the world from 1995 to 2014.

3.2. STIRPAT-Based Modeling

By substituting carbon emission data from Henan Province into the STIRPAT model, this study developed a model for carbon emissions from energy consumption; additionally, multiple linear regression (MLR) analyses were conducted accordingly (as described in Table 2). According to the analysis results, the variance inflation factor (VIF) values for all variables are greater than 10. For example, the VIF values for GDP per-capita and urbanization rate are as high as 681 and 786, respectively; this indicates that the results obtained using the least squares estimation method contain severe multicollinearity, and the fitting coefficients obtained from this method are also unreliable. To eliminate the influence of multicollinearity, the present research instead uses ridge regression analysis, which is a statistical method that is specially used for analysis of collinearity data. This method cedes the unbiased found in the least square method, but seeks a more practical and suitable regression equation [66,67]. The results of the ridge regression estimation for Equation (9) are described in Table 3. The results are highly reliable (R^2 = 0.983), all indices pass the test of 5% significance, and the F statistics pass the 1% significance test. Clearly, Equation (9) can explain the relationship between carbon emissions and related variables, which is expressed as

$$I = \exp(-0.888 + 1.099 \ln P + 0.193 \ln A - 0.036 (\ln A)^2 + 0.043 \ln T + 0.542 \ln U - 1.297 \ln S) \quad (9)$$

Table 2. Analysis results of multiple linear regression.

Items	Coefficients	Std. Error	Beta	*T*	Sig. *T*	Tolerance	VIF
Constant	2.182	3.558		0.613	0.550		
$\ln P$	0.053	1.291	0.005	0.410	0.968	0.025	40.122
$\ln A$	0.829	0.347	1.267	2.390	0.33	0.001	681.283
$(\ln A)^2$	−0.047	0.085	−0.463	−0.553	0.590	0.001	1701.400
$\ln T$	1.030	0.219	0.688	4.696	0.000	0.019	52.087
$\ln S$	−0.290	0.517	−0.042	−0.560	0.585	0.074	13.592
$\ln U$	−0.123	0.933	−0.075	−0.132	0.897	0.001	786.108

Table 3. Analysis results of the ridge regression.

Items	Coefficients	Std. Error	Beta	*T*	Sig. *T*
Constant	−0.888	1.542	0.000	−0.548	0.093
$\ln P$	1.099	0.467	0.113	2.423	0.031
$\ln A$	0.193	0.141	0.291	13.472	0.000
$(\ln A)^2$	−0.036	0.003	−0.347	−12.467	0.000
$\ln T$	0.043	0.076	0.173	0.343	0.074
$\ln S$	−1.297	0.321	−0.185	−3.993	0.000
$\ln U$	0.542	0.056	0.324	9.541	0.000

3.3. Analysis of STIRPAT Model Results

As described in Table 3, Henan Province carbon emissions from energy consumption are positively influenced by population size, GDP per-capita, energy consumption intensity, and urbanization rate, but inversely influenced by the proportion of tertiary sector. Clearly, an excessive pursuit of rapid economic development and magnitude combined with a disregard for the quality of economic development will bring a substantial increase in carbon emissions from energy consumption. To suppress carbon emissions, it is necessary to adjust and optimize the industrial structure. Population growth is the major factor driving the increase in carbon emissions; for every 1% increase in population, its carbon emissions from energy consumption will increase 1.099%. Henan Province has a large population base, and its population size has increased from 91 billion in 1995 to 106.6 billion in 2014. The huge population has led to an enormous scale of production and life consumption, thus producing a direct and continued increase in energy consumption and carbon emissions.

The rise in the urbanization rate is the second major factor driving the increase in carbon emissions; for every 1% increase in urbanization rate, its carbon emissions from energy consumption will increase 0.542%. The increase in urban population will directly lead to a demand for food, transportation, infrastructure, and housing consumption, thus causing a substantial increase in carbon emissions from energy consumption. Every time GDP per-capita increases 1%, its carbon emissions from energy consumption will increase 0.193%. The increase in per-capita income directly increases energy consumption and, consequently, increases carbon emission. The increase in per-capita purchasing power indirectly leads to an increase in energy consumption and, consequently, higher environmental stress. Every time energy consumption intensity increases 1%, its carbon emissions from energy consumption will increase 0.043%. Energy consumption intensity is positively correlated with carbon emissions from energy consumption. This shows that energy consumption is confronted with various problems, including inefficient energy utilization, unreasonable energy utilization structure, and substantial energy waste. Optimizing industrial structure is negatively correlated with carbon emission; for every 1% increase in the proportion of tertiary sector, its carbon emissions from energy consumption will decrease 1.297%. Clearly, an increase in the proportion of the tertiary sector with low energy consumption aids in achieving energy conservation and emissions reduction in Henan Province.

As described in Table 3, the $(\ln A)^2$ coefficient is negative. In the study period, Henan Province carbon emissions from energy consumption first increased with a continued increase in GDP per-capita and economic development; after the GDP per-capita increased to a certain level, carbon emissions from energy consumption began to decrease. Therefore, the relationship between them is represented with an inverted U-shape curve. The predicted elasticity coefficients for carbon emissions from energy consumption for a GDP per-capita increase from 100 yuan to 100,000 yuan is provided in Table 4. On one hand, according to the absolute values of the coefficients (absolute elastic), we may conclude that the elasticity coefficient of energy consumption (EE_{IA}) in Henan Province increases as the GDP per-capita increases. This is mainly because the increase of GDP per-capita introduces higher levels of consumption per capita. Thus, energy consumption and carbon emissions also increase accordingly. On the other hand, there was less variation in elastic coefficients of carbon emissions, which implies that the rapid increase in prosperity, along with the advance of science and technology, have contributed significantly to reducing carbon emissions.

Table 4. Changes in elasticity coefficients for GDP per-capita energy consumption at different economic development levels.

A	100	1000	2000	4000	6000	8000	10,000	20,000	40,000	60,000	80,000	90,000	100,000
EE_{IA}	−0.136	−0.300	−0.350	−0.399	−0.428	−0.449	−0.465	−0.514	−0.564	−0.593	−0.613	−0.622	−0.629
ΔEE_{IA}		0.164	0.049	0.049	0.029	0.021	0.016	0.049	0.049	0.029	0.021	0.008	0.008

3.4. Scenario Analysis

Scenario models have been widely used for quantitative evaluation [20,68,69]. The future economic scenarios, which are simulated according to (historic and current) carbon emissions and economic developments, are expected to provide useful information for the sustainable development of ecological economy.

The simulation results obtained from the STIRPAT model have allowed this study to predict future carbon emissions in Henan Province from 1995–2014. Given the various influencing factors previously mentioned, Equation (8) was used. Then, the simulated values are compared with historical values, as shown in Figure 4; the regression analysis for the simulation results have an R^2 value of 0.986, indicating that the simulation results are of high accuracy.

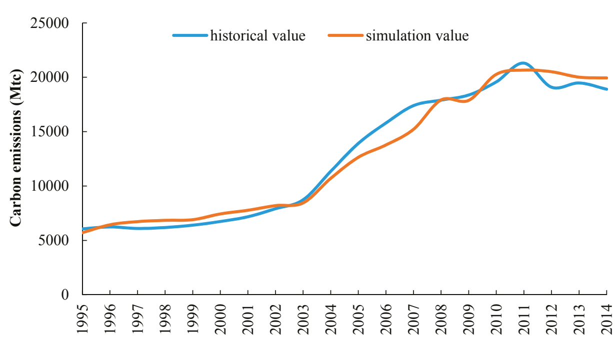

Figure 4. Comparison of simulation and observed values for carbon emissions from energy consumption.

In order to determine the urbanization rate, various sources were considered. According to *The Planning of Henan Province on New-Type Urbanization (2014 to 2020)* released in 2014, the urbanization rate for the permanent resident population will reach 56% by 2020. According to the *Blue Book of Macro-Economy* released by Zhang and Liu [70], China's urbanization rate will reach 67.81% by 2030. According to *The Report on China's Modernization: A Study of the World's Modernization*, China's urbanization rate will exceed 80% by 2040 [71]. According to United Nations predictions, the urbanization rate in developed countries will reach 86% by 2050. Based on these combined predictions, the Henan Province urbanization rate is estimated to reach 56%, 67%, 80% and 86% in 2020, 2030, 2040, and 2050, respectively. Accordingly, this study verified the urbanization rate for 1995 to 2014, and calculated the growth rate of Henan Province's urbanization for past years.

According to the related indices, including population size, GDP per-capita, proportion of tertiary sector, and energy consumption intensity for Henan Province from 1995 to 2014, respective growth rates were calculated. The maximum growth rates for population, GDP per-capita, and proportion of tertiary sector were set as the high growth rates, and their minimum growth rate was set as the low growth rates; high growth rates were 4.72%, 23.91% and 5.43%, respectively, while low growth rates were 0.49%, 4.06% and 0.67%, respectively. In addition, this study selected the maximum growth rate of energy consumption intensity as the low growth rate (−2.32%), and the minimum growth rate as the high growth rate (−15.08%). Energy consumption intensity represents the technological level in Henan Province, and the proportion of tertiary sector represents the socio-economic development level. Details on each scenario are provided in Table 5.

Table 5. Development scenarios for Henan Province.

Scenario	Population	GDP Per-Capita	Technological Level	Socio-Economic Development Level
1	H	H	L	L
2	H	H	L	H
3	H	L	H	L
4	H	L	H	H
5	H	L	L	L
6	H	L	L	H
7	H	H	H	L
8	H	H	H	H
9	L	L	H	L
10	L	L	H	H
11	L	H	L	L
12	L	H	L	H
13	L	H	H	L
14	L	H	H	H
15	L	L	L	L
16	L	L	L	H

Notes: H = high growth and L = low growth.

As shown in Figure 5, the future trends in Henan Province carbon emissions can be summarized with two patterns: (1) a continuous increase; and (2) an initial increase followed by a decrease. The first pattern covers Scenarios 1, 2, 5, 6, 11, 12, 15, and 16, and the second pattern covers Scenarios 3, 4, 7, 8, 9, 10, 13, and 14. The first pattern is in opposition to China's pursuit of harmonious development of economy and ecology, and the second pattern conforms to the relationship represented by an EKC. In the eight scenarios covered by the second pattern, peak carbon emissions all occur in 2039; specifically, they are 4.20×10^8, 4.41×10^8, 5.28×10^8, 5.55×10^8, 1.70×10^8, 1.79×10^8, 2.14×10^8, and 2.25×10^8 tons, respectively, in the eight scenarios. In 2050, the carbon emissions are 2.84×10^8, 3.03×10^8, 3.61×10^8, 3.85×10^8, 8.64×10^8, 9.21×10^8, 1.10×10^8, and 1.17×10^8 tons, respectively, in the eight scenarios. The carbon emissions from energy consumption will remain relatively low under the development patterns represented by Scenario 9, 10, 13, and 14. Under the development patterns represented by Scenario 9 and 10, carbon emissions from energy consumption will be the lowest. However, this development pattern demands that Henan Province maintain a certain growth rate in GDP per-capita and socio-economic level. Clearly, this development pattern is in opposition to trends for harmonious and sustainable development of economy, society, and the environment because it optimizes the environment at the cost of improving resident living standards and industrial structure. Under the development pattern represented by Scenario 13, carbon emissions are also low; however, this development pattern demands that Henan Province maintain a low socio-economic growth rate, and an outdated industrial structure under this development pattern is counter to trends in China's economic development. Under the development pattern represented by Scenario 14, carbon emissions are relatively low; this development pattern demands that Henan Province maintain a low growth rate in population, and a high growth rate in GDP per-capita, technological advances, and socio-economic level. Therefore, this development pattern conforms to sound and rapid socio-economic development in Henan Province. To accomplish energy conservation and emission reduction in Henan Province, the optimal development pattern is to maintain a low growth rate in population, but a high growth rate in GDP per-capita, technological advances, and socio-economic level.

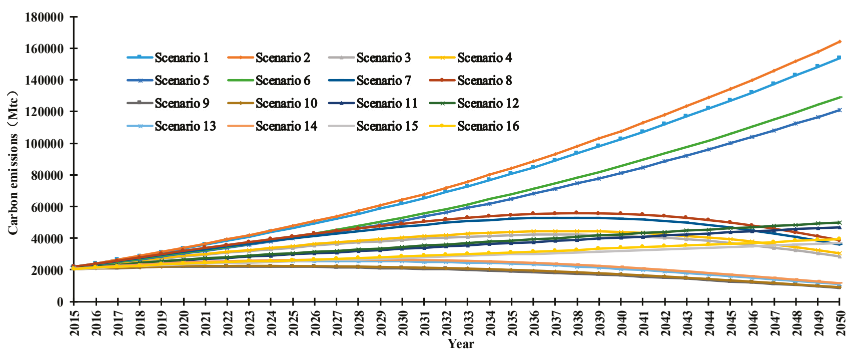

Figure 5. Evolving trends in carbon emissions from energy consumption in Henan Province under different developmental scenarios in the future.

4. Conclusions and Policy Implications

Based on primary energy consumption, this study calculated Henan Province carbon emissions from energy consumption during 1995–2014. During the study period, total energy consumption and carbon emissions continued to increase, and only energy consumption intensity decreased, while population size, GDP per-capita, urbanization rate, and proportion of tertiary sector all showed an increasing trend and clearly fluctuated. Population growth, GDP per capita, energy intensity, and the level of urbanization development are the main contributors to carbon emissions in Henan Province; the tertiary sector is the major contributor to reducing carbon emissions. While there is a continued increase in GDP per-capita (from 100 yuan to 100,000 yuan), the absolute values of the coefficients (absolute elastic) for carbon emissions from energy consumption shows a decreasing trend, but the value of the elasticity coefficient shows an increasing trend. In addition, the EKC has a standard inverted U-shape curve. Based on the 16 multi-scenarios analyses, we predicted that Henan Province's environmental quality initially deteriorated and then improved, along with the increase in GDP per-capita.

To achieve sound and rapid socio-economic development in Henan Province, the optimal development scheme is to maintain a low growth rate in population, but a high growth rate in GDP per-capita, technological advances, and socio-economic level. As China opens its two-child policy, effectively controlling carbon emissions should be a long-term mission. Henan Province development should emphasize the following points: (1) control population size and growth rate moderately; and (2) further improve energy utilization efficiency and promote the optimization and improvement in industrial structure, while ensuring continued improvement in resident living standards. In contrast, lack of effective control over population growth, inefficient energy utilization, and outdated industrial structure would result in a substantial increase in carbon emissions in Henan Province.

The "13th Five-Year" plan in China clearly stated necessary responses to global climate change. It places equal emphasis on mitigation and adaptation of carbon emissions, emission reduction commitments, the ability to adapt to climate change, the depth of participation in global climate governance, and the contributions to addressing global climate change. Henan province is a province with a large population. It is also a big economic and agricultural entity in the nation. In order to curb carbon emissions in Henan, focus should be paid on the effective control of industrial growth, and usage of electric power, building materials (iron/steel), chemicals, and other sources of carbon emissions. In the meantime, promotion of low carbon industry, energy, construction, transportation, are other key strategies. Henan should carry on different possible low carbon pilot projects and implement the demonstration projects of near zero carbon emission. We should actively promote the trading market of carbon emission, carbon emissions reporting system, and the verification, certification, and quota management of key emission units. Henan should improve the system of statistical accounting, evaluation and accountability, and improve the standard system of carbon emission. Other regions in the world with similar population and economic issues could learn the experience of emission control in Henan, and actively participate in the negotiation of global climate change, and promote the establishment of a fair, reasonable, and win–win global climate governance system.

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sustainability

Article

Conceptual Model Development of Sustainability Practices: The Case of Port Operations for Collaboration and Governance

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Abstract: Sustainability practices in port operations are critical issue to achieve port sustainability involving economic, social and environmental issues. To assist ports to successfully implant sustainability practices into their operations, this paper conceptualized the structure of sustainability practices in international port operations, by clustering the relevant issues, empirically. Using 203 samples collected from port stakeholders in the major ports in Northeast Asia, multi-measurement items were analyzed on exploratory factor analysis in SPSS 21. Results generated a structure that consists of five sub-dimensions conceptualizing sustainability practices in the context of port operations. As operative practices to accommodate current and future demands in a port, the five-factor model clustering the relevant issues incorporate environmental technologies, process and quality improvement, monitoring and upgrading, communication and cooperation, and active participation. Providing useful insights for strategic agenda to assist ports to incorporate sustainability practices in their operations, the five-factor model offer both a descriptive and diagnostic management tool for future improvement in port operations.

Keywords: sustainability practice; international port operations; conceptual model development; Northeast Asia

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1. Introduction

As port functions change to act as an economic catalyst and take on a central position in industries engaged in international maritime transport, issues of economic stability and corporate responsibility shed new light on port operations [1–3]. Moreover, with increasing environmental consciousness, ports need to improve their operational sustainability within the bounds of the environmental regulations, by accommodating stakeholder expectations [3,4]. To accommodate the current and future needs of ports and their stakeholders, ports need to find a balance between valuable land, labour and technology, as well as to perform as a multifunctional business centre which can produce added-value and growth in their host cities [5–7], in that:

- First, port success is relevant to national competitiveness and economic growth [8]. Ports are considered as a significant component of the local economy and economic cooperation with its surrounding areas which integrates the overall production and distribution systems [5].
- Second, ports function as an economic catalyst on revenue and employment [6,9]. As stated by [9] (p. 491), "*The ratio of direct return from port operations to the indirect return from port related activities is 1:5 and the ratio of direct employment to indirect employment is around 1:9, respectively*".
- Third, with increasing environmental consciousness, environmental issues have become a central point of the strategic and operative management policies in various fields in the shipping and

port industries, which aim to achieve effective protection of the environment alongside economic growth [10]. A large number of stakeholders engaged play a significant role in the governance of the port cluster, having a huge impact on port operations. The achievement of sustainable port operations and development is a difficult challenge and a complex problem to be solved, in which ports have a complex organizational and technical structure and a number of stakeholders engaged in port operations [4]. Accordingly, collaboration among the stakeholders engaged and governance for environmental performance are crucial for sustainable port operations.

- Moreover, new opportunities to achieve competitive advantage and/or to sustain a competitive position are critical issues for sustainable port development and operations in sophisticated port competition [2]. As a result, organizations and industries related to port operations have progressively begun to translate sustainability issues from a side-lined management concern into a core issue directly related to collaboration and governance for enhancing efficiency and competitiveness [1,3,10].

The needs for sustainability practises that aim to achieve sustainable port development and operations has become widespread across the world's ports without limitations to a particular country or region (e.g., Los Angeles/Long Beach, Rotterdam, Antwerp, Seattle, Hong Kong, Singapore, etc ...). Although academic and practitioner interest has focused on sustainability issues in port operation, the focus was on environmental impact minimization and environmental index development. Less attention has been devoted to conceptualise the structure of actual sustainability practises in the context of port operations. Therefore, to assist ports to conceptualise sustainability practises in port operations, and successfully incorporate the certain practises in their operations, this paper aims to investigate sustainability practises for achieving sustainability in port operations, by clustering the relevant issues empirically. After introducing research background, Section 2 reviewed the relevant literature. Section 3 present research design and data collection processes. Using 203 samples collected from port stakeholders in the major ports in Northeast Asia (NEA), multi-measurement items were analyzed on exploratory factor analysis (EFA) in SPSS 21. The data analysis and results are presented in Section 4 before discussing their implications, both conceptual and substantive issues, with suggestions for future research. Results provide useful insights for strategic agenda to assist ports to incorporate sustainability practises in their operations, and the five-factor model offers both a descriptive and diagnostic management tool for future improvement.

2. Literature Review

2.1. Port Sustainability

Ports are considered as critical nodes of global trade and supply chains, which have a complex organizational structure. The ports contribute to global or major regional trade and the local economy, and play an important role as an economic catalyst to revenue and employment [6,7] and as a central position serving industries related to international trade [11]. Therefore, it appears that the concept of sustainability in port operations shapes not only the character of success in the real dynamic competition between ports, but also the role and responsibility as a central position in industries associated with international trade [5,6]. In the same vein, the concept of sustainability in international port operations should incorporate the following four main perspectives: Economic perspective including returns on investment, efficiency of the use of the port area, and provision of facilities for companies to maximize their performance [12,13]; Competition perspective ensuring capability that improve their operational performance and their businesses remain competitive in sophisticated port competition [14]; Social scope such as the direct contribution to employment in port companies and activities connecting to the port (indirect employment, the interaction and relationship between port and city, the contribution to knowledge development and education, and the liveability of the area surrounding the port) [13,15]; and Environmental performance and management including noise pollution, air quality, dredging operations, dredging disposal, dust [12,13].

As mentioned by Tan [16] (p. 226), the traditionalist argues that "environmental protection activities and regulations would reduce economic success and the companies in industries with higher environmental impacts will face disadvantages if we burden them with higher environmental compliance costs". However, these restricted views are more associated with minimum level compliance [16,17]. The relationship between sustainability performance and economic performance from different economic perspectives, and the longer-term dynamics implicates the efficiency frontier development in order to help enhance competitiveness and promote their innovative capacity [16]. This means that when the environmental management issues are in line with increased competitiveness and economic performance, successful management of sustainability performance can be achieved in the long-term perspective.

Sustainable development does not mean 'no development'. Sustainable development in port operations means 'business strategies and activities' in order to accommodate the current and future needs of the port and its stakeholders, protecting and sustaining human and natural resources [1]. Therefore, to successfully achieve sustainability in port operations, ports need to a balance between valuable land, labour and technology, as well as to perform as a multifunctional business centre which can produce added-value and the growth in its host city [5,6], as sustainability issues including economic stability, low environmental impacts and social responsibility shed a new light on the port operations literature [14]. In addition, new opportunities to achieve competitive advantage and/or to sustain a competitive position will also be a critical issue for sustainable port operations in the real competitive business environment.

2.2. Sustainability Practises in Port Operations

2.2.1. Drivers of Sustainability Practise in Port Operations

Sustainable development and operations have become a central point of the strategic and operative management in port operations, playing a very important role in achieving outstanding port activities including an improvement in container terminal efficient/cost-efficient operation, throughput, and profitability [18]. Kim and Chiang [2] provided five potential types of motives leading a port entity to invest in sustainability practises. Figure 1 depicts the potential types of motivation in port operations, which includes regulatory compliance, societal pressures and direct economic benefits, development and planning in a port, operational issues, and new opportunities to gain competitive advantage from the sustainability practices in port operations.

Specifically, authors have argued that sustainability strategy and practises can enhance the sustainability of competitive advantage [19,20], simultaneously reducing the negative effects of their performance on the natural environment [10]. This in turn generates the opportunities to improve their competitiveness in a highly competitive environment [18,21,22], as the following elements cited by Francisco [17] (p. 825): "*quality; savings (cost and energy efficiency); security (risk reduction); market (capturing new customers); image (reputation); ethics and social responsibility (low environmental impact); intention to continue and survive in the future; and new business opportunities (management and application of technologies aimed at preventing, mitigating and restoring, in order to resolve environmental problems)*". Through corresponding improvements in sustainability, the port can achieve more economic stability and continuous improvements in subsequent performance within the bounds of the environmental regulations [23,24].

Figure 2 presents a sustainability framework to promote business competitiveness and innovative capacity [16]. This framework provides a benchmark to evaluate and improve sustainable performance. These common perspectives are that sustainability strategies and/or practises can not only reduce negative impacts of a firm's activities on the natural environment, but also simultaneously contribute to better firm performance.

Figure 1. Types of motivation in port operations.

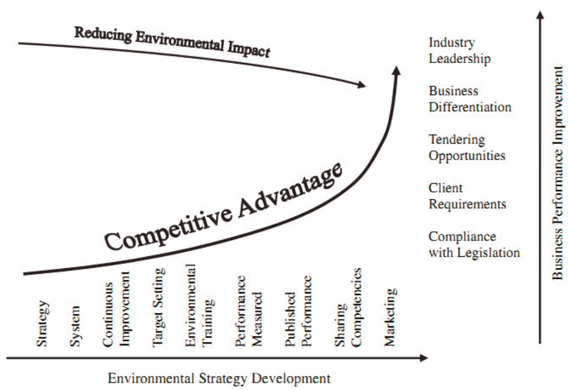

Figure 2. Mutuality between sustainability and profitability (Tan et al., 2011: 227).

Besides, Lun [10] and Yang et al. [24] identified a linkage between sustainability issues and the opportunities to achieve competitive advantage, and argued that sustainability practises such as green management practise have a win-win relationship in terms of performance incorporating economic and environmental aspects. As mentioned by Lun [10] (p. 565), this is because sustainability practise such as "*green management practises can not only help to conform to environmental regulations, but also assists firms to scrutinize their internal operations, engage employees in environmental issues and to monitor for environmental improvement*". Through continual environmental and organizational improvement of all of these actions, ports can achieve the opportunities to improve their internal operations and greater efficiencies [17].

2.2.2. Sustainability Practises in Port Operations

Sustainability strategies achieving long-term viability in the face of economic uncertainty, low environmental and social impacts are critical for sustainable development of maritime operations [2,3]. Accordingly, integrating the consideration of sustainability into all activities in and around a port is part of an aim to be a sustainable and efficient port. Annual sustainability reports published on port websites suggest guidelines and strategic advice towards port sustainability to address issues related to sustainable port operations and development with economic, social and environmental considerations [25–27]. The suggested issues for "best practises" include: operational efficiency, safety and security in a port, cooperation and communication, monitoring and upgrading port facilities, and environmental management systems. Objectives of these practises embrace: resource, environmental, community and human resource management, continuous growth, and port operators and supply chain management [12,13].

During recent years, to address issues related to sustainable port development and operations, as well as to assist decision-making processes oriented towards sustainable development in port industry, a number of international organizations (OECD, IMO, and ESPO) and international ports have devised and proposed guideline and strategic advice towards port sustainability practises. For instance, international association of ports and harbour (IAPH) introduced best practice cases of European ports [28]. To investigate the details for sustainability practises adopted in container port operations, Kim and Chiang [2] reviewed "annual sustainability reports" published by commercial ports and international organizations such as ESPO, OECD and IAPH (see Table 1). The suggested practises in port operations includes reducing financial and environmental risks in ports; upgrading port facilities and equipment to cut operation costs; sustainable building construction in a port/hinterland; enhancing long-term viability of operations; safety and security in a port; resource efficiency; eco-friendly and socially responsible image; improving relationships with key stakeholders; port infrastructure utilization; optimizing the routing of vehicles; vehicle utilization (modal shift); employee productivity improvement; recruitment and retention of employees; social and working environment; expansion of the coastal region facilities; and providing incentives for green practises. In addition, based on thematic analysis, prior study [2] clustered the relevant practises into four sub-dimensions incorporating environmental technologies, continual monitoring and upgrading, internal process improvement, and cooperation and communication.

Table 1. Sustainability practices: descriptions and details.

Practices	Description	Details
Reducing financial and environmental risks in ports	- Banks are concerned about their own legal liabilities, so they are taking a closer look at borrowing companies' eco-efficiency records - More investors are becoming interested in investing in environmentally responsible ports	- CO_2 emission assessment - Green gas emission assessment - Water quality assessment - Air pollution assessment - FDI (foreign direct investment)
Upgrading port facilities and equipment to cut operation costs	- Facilities and equipment improvement - External cost down including pollution, climate change, and other biological damages driving from transport	- AMP (Alternative maritime Power) - Tandem spreader - DPF (Diesel particulate filter trap) - e-RTGC (Electric rubber tired gantry crane) - Cold ironing (from inland) - LED street lamp - Solar power cranes
Sustainable building construction in a port/hinterland	- Reducing environmental impacts from construction method - Long-term viability of port facility	- Green building standard (LEED) - Use of noise reduction equipment
Enhancing long-term viability of operations	- Using renewable and alternative energy sources for less environmental impacts	- Solar energy, wind energy, and tidal energy - Use of CNG (compressed Natural Gas - Use of bio-Diesel, hydrogen fuel - LED (Light Emitting Diode) street lamp - Solar power cranes - Dredging for securing water depth

Table 1. *Cont.*

Practices	Description	Details
Safety and security in a port	- Reduction of accidents (oil spillage) and noise/light pollution - External cost down including pollution, congestion and accidents	- Reduction of accidents from using electronic transport - Public lighting - Auto Monitoring System (AMS)
Resource efficiency	- Cutting waste and using natural resources more efficiently can save costs and boost profits	- Resource recycling in a port - Sustainable purchasing
Eco-friendly and socially responsible image	- Improving 'Green" image, and transparency of port operation	- Sustainability report - Incentives to shipping companies and stevedores with eco-friendly equipment
Improving relationships with key stakeholders	- Collaboration for minimizing environmental impacts - Environmental groups and businesses are working together more to find solutions	- CSR (Cooperate social responsibility) - EMS (Environmental Management System) - Co-operation between stakeholders
Port infrastructure utilization	- Improving port infrastructure utilization to minimize congestion in a port - External cost down (congestion, accidents)	- Optimum use of space - Efficient gate processing system - Extended gate operating hours
Optimizing the routing of vehicles	- Energy/cost efficiency from optimizing the routing of vehicles - External cost down (congestion, accidents and other biological damages driving from transport)	- Reduction in road transport - Idling time reduction of ship/truck - AGV (Automatic Vehicle System)
Vehicle utilization (Modal shift)	- Repair and maintains a harbor-side road and introduction of new transportation modes - External cost down including pollution, congestion and accidents	- Shift in modal split - Parking space operations - Clean truck program - Electric trucks
Employee productivity	- Employee training/education - The best and brightest young people are more willing to work for environmentally responsible ports	- A combination of learning and working activities - Training/education
Recruitment and retention of employees	- Job creation - Improving employee's satisfaction	- Employee satisfaction - Public infrastructure and architecture for double use
The hinterland social and working environment	- Creation of a pleasant life environment	- Air quality and climate - Visual impact reduction - Open space and park development
Expansion of the coastal region facilities	- Prevention of ocean pollution caused by land activities	- Expansion and improve the sewage disposal plants, sewage landfills, waste water disposal plants
Providing incentives for green practices	- Encouraging eco-friendly practices in port activity area	- Green ship certification System - Incentives on the new cleaning technology - Green flag incentive program

Source: Kim and Chiang (2014: 22).

Hakam and Solvang [27] analyzed interdependency between sustainability and flexibility, and argued that flexibility in port operation can enhance sustainability endeavours. The suggested measures in port operations include improving the port's multimodal interface, tracking and coordinating of freight movements through IT, reducing the vessel's turnaround time, increasing labour flexibility through motivation and cross-training, and providing incentives to supply chain actors to cooperate in order to achieve higher flexibility for the overall network.

Prior work on sustainability in port operations [28] identified that improved stakeholders engagement and communication are an important aspect for achieving long-term sustainability in ports.

They argued that stakeholders assist ports to respond quickly to their expectations and a changing environment, as well as continuing to improve the operational performance of their business and distribution network over a long period of time sustainability with higher operational efficiency and service differentiation [29].

In addition, Dinwoodie et al [4] argued that ports can mitigate potential environmental risks and manage sustainable development of maritime operations through an accessible generic business process framework, highlighting the importance of educational dimensions, commercial missions and stakeholder engagement for sustainable development of maritime operations in ports.

Comtois and Slack [30] emphasized the importance of employee participation, in that the employees are important and proactive actors in the environmental management initiative in a port, and many papers illustrate that sustainability can result from employee participation in environmental management [30,31]. Based on prior studies, we adopted twenty three relevant practises to conceptualize sustainability practise in port operations. After eliminating overlapping and interrelated elements, this study carefully selected elements to conceptualize. Table 2 presents the final twenty three measurement items.

Table 2. Elements of sustainability practice in port operations.

Code *	Elements	References
SP 1	New equipment and technology introduction	[2,4,20,32]
SP 2	Renewable and alternative energy sources	[2,30,31,33]
SP 3	Sustainable building construction	[33,34]
SP 4	Optimizing the routing of vehicles	[1–3,14,16]
SP 5	Vehicle utilization (Modal shift)	[2,4,24]
SP 6	Reducing financial and environmental risks	[2,4,31,34]
SP 7	Improvement of safety and security in a port	[4,17,35]
SP 8	Upgrading port facilities and equipment	[1–4]
SP 9	Environmental index development	[33,34]
SP 10	Eco-friendly and socially responsible image	[20,33,34]
SP 11	Port infrastructure utilization	[1–4,14]
SP 12	Efficiency of the use of the port area	[2,7,33,34]
SP 13	Service differentiation	[2,3,35]
SP 14	Service quality improvement	[2,17,35]
SP 15	Joint planning and supply chain integration	[1,14,16,31]
SP 16	Operational transparency	[31,33]
SP 17	Exchange of information and knowledge	[1–4,16]
SP 18	Close relationships with key stakeholders	[2–4,14,16]
SP 19	Recruitment and retention of employees	[14,29,36]
SP 20	Good working environment	[1–5,14,17]
SP 21	Waste reduction	[2,30,31,33]
SP 22	Training and education	[2,4,29]
SP 23	Providing incentives for green practices	[2,3,14,17]

Source: Tabulated by Author * SP: Sustainability practice.

3. Method

3.1. Overview of Research Design

The achievement of sustainable port operations and development is a difficult challenge and a complex problem to be solved, in which ports have a complex organizational and technical structure and a number of stakeholders engaged in port operations [4,11]. Therefore, this study aims to empirically explore the structure of sustainability practise in the context of commercial port operations. To collect data, we adopted questionnaire survey.

A survey instrument was developed in several stages based on insights gained from the available literature and a preliminary field work, employing a five-point Likert scale widely used to scale responses in survey research. The survey begins with seeking the importance of the relevant issues of sustainability practise with respect to commercial port operations. The measurement items judged to conceptualise sustainability practise in port operations were listed and included (see Table 2).

The respondents were asked to indicate on a five-point Likert scale how important each of these items were for conceptualising sustainability practise in port operations (from 1—not very important to 5—very important). To enhance the external validity of the findings, the questionnaire was distributed to internal and external stakeholders engaged in port operations based on Winkelmans and Notteboom [36]; internal stakeholders (port operator) and three groups of external stakeholders including economic/contractual external (e.g., terminal operators), public policy (e.g., government bodies) and community/academic groups. Experts in various high positions in their organization were randomly selected to avoid deficiencies of knowledge. Finally, questionnaires were distributed to the major ports in NEA: Shanghai, Hong Kong and Busan, after translating the questionnaire into three different language versions (Chinese including Mandarin and Cantonese, Korean). Using 203 samples collected from port stakeholders in the major ports in NEA, the measurement items were analyzed on exploratory factor analysis in SPSS 21 (recent version of Statistical Package for the Social Sciences) in order to explore sub-dimensions of sustainability practise and eliminate potentially superfluous items. Based on data analysis, the findings provide useful insights for future port improvement and strategic agenda to assist ports.

3.2. Data Collection

Prior to collecting the data in 2015, we undertook a pilot survey by email. Thirty respondents included a group of researchers and experts were selected as practitioners working in a port. Based on the pre-tests, the final questionnaire was upgraded and revised. A total of 2000 questionnaires were distributed to port stakeholders of the major container ports in NEA: Shanghai, Hong-Kong and Busan, with 104 returned as non-deliverable. Two weeks after the initial mailing a cover letter highlighted the various means to respond, and reminder emails were sent to all potential respondents. The last wave of mailing was sent two weeks later.

A total response of 203 gave an effective response rate of 10.7% (203/1896). Table 3 presents the general characteristics of the sample collected with responses representing all stakeholders. Organization type was individually classified into seven categories. The results represented a diversity of organizational sizes in a port (see Table 3). Regarding the age of the organizations represented almost half had existed for over two decades. Over 80% of the respondents had worked for their organization for over 10 years. Most of the respondents (82.8%) were in senior and middle groups entitled vice president or above, board member, director, manager of department, section chief, operational supervisor, although more junior levels representing operational staff were also represented.

Table 3. Sample Demographics.

Variable	Frequency	Percentage (%)
Organization Type		
Port Authority	36	17.8
Terminal Operator	48	23.6
Shipping line	23	11.3
Inland Shipper	27	13.3
Forwarder/Cargo Owner	26	12.8
National/Local Government	26	12.8
Local Community/Researcher	17	8.4
Firm's Age		
Less than 5 years	9	4.4
5–10	46	22.7
10–15	29	14.3
15–20	22	10.8
Over 20 years	97	47.8

Table 3. *Cont.*

Variable	Frequency	Percentage (%)
Number of Employees		
Less than 50	46	22.6
50–100	28	13.8
100–150	13	6.4
150–200	17	8.4
200–250	16	7.9
250–300	33	16.3
More than 300	50	24.6
Working Experience		
Less than 5 Years	16	7.8
5–10	18	8.9
10–15	55	27.1
15–20	69	33.9
Over 20	45	22.3
Job Position		
Senior	106	52.3
Middle	62	30.5
Junior	35	17.2

3.3. Non-Response Bias and Common Method Bias

In order to assess non-response bias, this paper applied widely used extrapolation methods whereby late respondents are hypothesized to behave similarly to non-respondents [37,38]. We compared the central tendency between the responses of the first and fourth quartiles of respondents. The results revealed no significant difference on *t*-tests for all the answers of each section adopted (see Table 4). Thereafter, to minimize common method bias, were measured through one method and questionnaires collected at regular intervals. In addition, to statistically assess common method bias at the level of measurement item, we employed Harman's single factor test which is to identify the presence of common method effect in SPSS [37]. All the 23 variables were entered into an EFA, using principal component analysis with varimax rotation to determine the number of factors that are necessary to account for the variance in the variables, assuming that a single factor emerge from the factor analysis when a substantial amount of common method variance is present. The results revealed that no a single factor emerged from the factor analysis in EFA (see Table 5). Based on these results, non-response bias and common method bias is not expected to inhibit our analysis.

Table 4. Comparison of early and late respondents.

Factor *	Mean		Std. Deviation		*t*-Value	Sig.
	Early (n = 50)	Late (n = 50)	Early	Late		
ET	3.6960	3.7200	0.60507	0.52060	−0.213	0.832
MU	3.3050	3.1900	0.58312	0.49115	1.067	0.289
PQI	3.7920	3.6160	0.64265	0.64376	1.368	0.174
AT	3.1900	3.3450	0.67302	0.69783	−1.130	0.261
CC	3.3120	3.1680	0.93211	0.68852	0.897	0.382

Factor * ET: environmental technology; MU: monitoring and upgrading; PQI: process and quality improvement; AT: active participation; and CC: cooperation and communication.

Table 5. Results of Exploratory Factor Analysis.

Items *	Factor Analysis					
	ET	PQI	MU	CC	AP	Cronbach's α
SP 1	0.821					
SP 2	0.816					
SP 4	0.814					0.854
SP 5	0.721					
SP 3	0.695					
SP 6		0.772				
SP 7		0.754				0.852
SP 8		0.754				
SP 9		0.730				
SP 15			0.780			
SP 11			0.774			0.823
SP 13			0.739			
SP 14			0.691			
SP 22				0.798		
SP 19				0.778		0.785
SP 21				0.754		
SP 23				0.682		
SP 16					0.807	
SP 17					0.782	0.818
SP 18					0.757	
Eigen-value	6.581	2.400	1.991	1.392	1.058	
% of Variance	32.907	12.000	9.957	6.962	5.292	Total: 67.118

Kaiser–Meyer–Olkin Measure of Sampling Adequacy: 0.866. * SP: sustainability practice; ET: environmental technology; MU: monitoring and upgrading; PQI: process and quality improvement; AT: active participation; and CC: cooperation and communication.

4. Data Analysis and Results

Results of Factor Analysis

This research has been designed to conceptualise the structure of sustainability practise, empirically clustering the relevant issues. This section presents the results of EFA in SPSS 21 to determine how clearly and to what extent an observed variable is linked to the underlying factors, and to eliminate potentially superfluous items. In order to extract the minimum number of factors which account for the co-variation amongst observed variables, principle components analysis with varimax rotation was adopted in which it assumes independence between factors and maximises the sum of the variances of the squared loadings. Twenty three measurement items for conceptualizing sustainability practise in a port were assessed. The criteria used for selecting measurement items were eigen-value (>1.0) and factor loading (>0.50) [38]. Table 5 presents the result of EFA empirically grouped the scale of items of sustainability practise in a port into the five dimensions. To enhance the reliability and validity of measurement items, although all 23 items presented factor loadings >0.5, we eliminated three items due to low communality <0.5. The eliminated items include SP 10 (eco-friendly and socially responsible image), SP 12 (efficiency of the use of the port area) and SP 20 (good working environment). Finally, the factor loading values of the 19 purified items were between 0.682 and 0.821 and their communality was all above 0.5, exceeding acceptable standards. The results indicate that the variables are well represented by the extracted factors, and hence that the factor analysis is reliable. In addition, to measure the appropriateness of the factor analysis, we employed Kaiser–Meyer–Olkin's measure indicating that values blow 0.5 imply that the factor analysis may not be appropriate. Kaiser–Meyer–Olkin's measure of sampling adequacy was 0.866, which indicates the extent to which the observed variables are 86.6% linked to their underlying facts. Based on the five factors underlying the 19 significant items, total variance explained is approximately 67.11% indicating that the extracted five sub-dimensions explain 67.11% of the inherent variation in their items. Lastly, to identify the construct's internal consistency of the factors extracted, we measured

Cronbach's α for all five extracted factors. The internal consistency of the five factors was acceptable (>0.70). Table 4 summarized the results of EFA.

Based on the results of EFA, the structure conceptualising sustainability practises in port operations was developed (see Figure 3), using labels of '*environmental technologies*', '*monitoring and upgrading*', '*process and quality improvement*', '*active participation*', '*cooperation and communication*' and. Further details of sub-dimensions are as follows:

***Environmental technologies*:** New equipment and technology introduction (SP 1), renewable and alternative energy sources (SP 2), optimizing the routing of vehicles (SP 4), modal shift (SP 5), and sustainable building construction (SP 3).

***Monitoring and upgrading*:** Reducing financial and environmental risks (SP 6), safety and security in a port (SP 7), upgrading port facilities and equipment (SP 8), and environmental index development (SP 9).

***Process and quality improvement*:** Joint planning and supply chain integration (SP 15), port infrastructure utilization (SP 11), service differentiation (SP 13), and service quality improvement (SP 14).

***Active participation*:** Training and education (SP 22), recruitment and retention of employees (SP 19), waste reduction (SP 21), and providing incentives for green practises (SP 23).

***Communication and cooperation*:** Operational transparency (SP 16), exchange of information and knowledge (SP 17), and relationships with key stakeholders (SP 18).

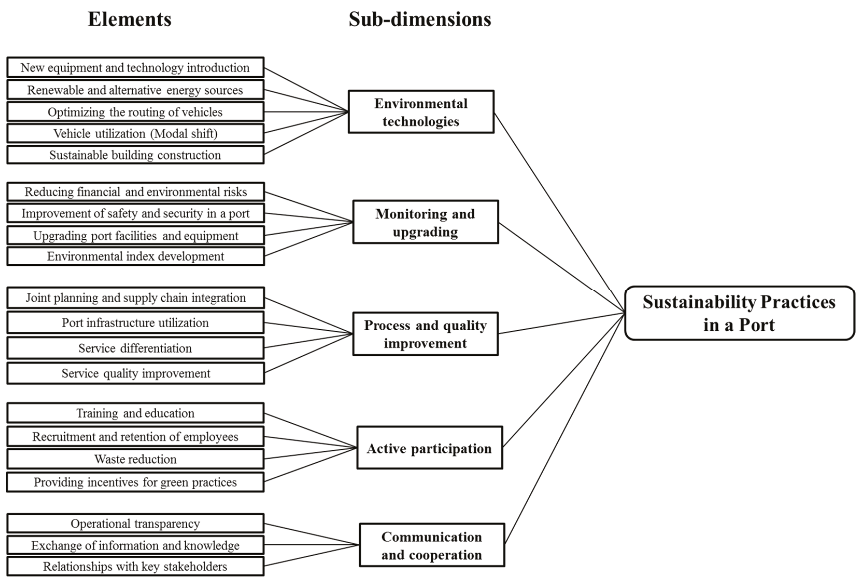

Figure 3. The Structure of Sustainability Practices in Port Operations.

5. Discussion and Conclusions

Based on data analysis. This study provides useful insights for operators and managers who are interested in implementing sustainability practice to successfully respond to changing business environments. Although international ports including America, Europe, Australia and Africa have reacted aggressively on the issues cope with sustainability practice (e.g., IAPH world port sustainability program that will be launched in Antwerp March 2018, world association for waterborne transport infrastructure and international association of ports and harbour), the respond to sustainability issues of Asian ports are late and reluctant to take aggressive attitude due to highly competitive business environment. Therefore, to overcome a lack of understanding of sustainability practice in NEA as against Western countries, this study investigated and analyzed the importance and applicability of the attributes of sustainability practice adopted in international port operations (i.e., environmental technology, continual monitoring and upgrading, process and quality improvement from internal strengths, active participation, and communication and cooperation).

Each finding was supported by literature and verified in the unique competition structure in NEA. The findings have significant theoretical implications which place the case of NEA in a global context, as well as investigating the relevant issues required to understand the specific and general features of sustainability practices in port operations in NEA. The five factors identified include environmental technology, continual monitoring and upgrading, process and quality improvement from internal strengths, active participation, and communication and cooperation, as following; First, environmental technologies incorporate equipment, methods and procedures, and delivery mechanisms that improve energy, cost, and resource efficiency. In the shipping and ports industry, green port practices can be considered as new process innovation, in that innovation means significant changes that embody a new idea that is not consistent with the current concept of port business and aimed at shaping changes in the external environment. These innovative processes are "a catalyst for organizational change". Moreover, enhanced resource productivity makes companies more competitive and sustainable, reducing the negative effect on the natural environment. This attribute embraces many practices: upgrading port facilities and equipment to cut operation costs, sustainable building construction in a port and hinterland, enhancing long-term viability of operation through using renewable and alternative energy sources, and expansion of the coastal region facilities.

Second, Sustainability practice in a port means a continual process of improvement by all parties engaged in port activities. Ports need to effectively respond to stakeholder concerns and to communicate the result achieved because ports must constantly find innovative solutions to respond to pressures from competitors, customers, and regulators. Therefore, the role of a port also includes continual monitoring and improvement for existing and new facilities, measuring and reporting on continuous improvement in port operations. From an operational perspective, potential benefits influencing competitiveness are service quality improvement and service differentiation through continuous monitoring and improvement. On the other hand, in terms of social-environmental perspectives, continual monitoring and improvement practices can improve ports' reliability alongside risk reduction, be eco-friendly and create a socially responsible image.

Third, ports can improve their operational efficiency from various practices including automation system, efficiency of the use of the port area, optimizing the routing of vehicles (modal shift), and provision of facilities for companies to maximize their performance. Moreover, from integration processes such as IT or system, process and procedures can achieve simplification of procedures. Examples include, electronic data interchange (EDI), IT integration, joint planning, supply chain integration, and integrated ICT, joint ventures, which can reduce turnaround times of ships with cost efficiency. Benefits related to ports' operational efficiency include efficient use of resources and energy, cost saving from optimizing the routing of vehicles (modal shift) and waste reduction. Therefore, ports can also enhance their sustainability by improving operational efficiency.

Fourth, stakeholder pressures on sustainability practices from internal stakeholders (e.g., employees, tenants and manager) may differ from external stakeholder pressures, in which employee participation is defined as "enthusiasm for work" and "satisfaction with work". Comtois and Slack [25] emphasized the importance of employee participation, in that the employees are important and proactive actors in the environmental management initiative in a port, and many papers illustrate that sustainability can result from employee participation in environmental management. All sorts of internal stakeholders including employees, tenants, and managers will require training and education in order to be competent in their work and improve environmental awareness for long-term sustainability in ports.

Lastly, Sarkisa et al. [26] found that the increased stakeholder pressures significantly affect the adoption of sustainability practices. As argued by Cheon and Deakin [14], port authorities and other stakeholders including industries, governments, and commodity groups should effectively coordinate and cooperate with them in order to respond to the increased pressures of all sorts of stakeholders including competitors, customers, and regulators [4]. Visibility to achieve sustainability depends on the sustainability of its stakeholder's relationship which can be achieved through active engagement of all stakeholders of the port infrastructure, which allow responding quickly to stakeholder expectations and a changing environment, as well as continuing the operational performance of the business and distribution network over a long period of time sustainable and with higher operational efficiency and service differentiation [2]. The satisfaction of stakeholders, operational transparency, exchange of information and knowledge, active employee participation, and incentives are categorized under this attribute.

On the other hand, in terms of practical issues, this study has identified the five critical elements of sustainability practice in port operations in NEA. The findings can be utilized to establish their sustainability strategies and a strategic agenda to assist ports to manage and monitor sustainability practice. Prior studies dealing with port sustainability have focused on environmental indicators, such as air pollution, noise and water quality [32,33]. However, it is claimed that an environmental performance index (EPI) is insufficient and/or laborious to approach sustainability issues. As pointed out by prior studies (e.g., [4,14,33]), sustainability indicators that are focused on environmental indices are not sufficient to successfully reflect a sustainability performance because sustainability practices in port operations incorporate multiple tasks that cannot simply be measured by the specific indicators [2]. Darbra et al. [14] and Bell and Morse [33] claimed that there were difficulties in collecting an exact environmental figure and/or index from ports because of the scarcity and/or the lack of data, as well as the policy and confidentiality concerns of ports. Therefore, this study suggests an alternative model to monitor and manage sustainability practices by the level of implementation. This approach will make it available to monitor and measure the level of implementation, proposing an alternative solution to manage the sustainability practices in port operations.

Limitations and Suggestions for Future Research

Some limitations of this work present interesting directions for future research. First, because of financial and access constraints, the population for this study was limited only to Shanghai, Hong-Kong, and Busan port. As the theory can be strengthened by utilizing multiple examples, to improve the ability to generalize findings, further studies will be needed to extend the research area, covering the competing global mega container ports. Moreover, to generalize findings beyond container port operations in NEA would require comparative studies between at least two different industries or global regions.

In addition, this study is based on cross-sectional data. The findings only provide an analysis of a current situation, as opposed to a longitudinal approach. However, a longitudinal approach requires historical data to evaluate and extrapolate the impacts of some practices [34]. A longitudinal approach would be required to analyze the impacts of sustainability practices over time, utilizing panel data through continuous monitoring for systematic development to provide more useful and effective tools to monitor performance.

Lastly, the adoption and implementation of sustainability practice is relevant to attitudes towards responding to the external business environment, such as entrepreneurship and CSR (corporate social responsibility). Therefore, this study recommends that academic attention should be given to the theoretical relationships between attributes such as entrepreneurship and CSR that stimulate the adoption of sustainability practice also required to provide practical implications for port industries.

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Article

Does Hazy Weather Influence Earnings Management of Heavy-Polluting Enterprises? A Chinese Empirical Study from the Perspective of Negative Social Concerns

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Abstract: During the 2014 APEC Conference, there was a long presence of blue sky (APEC Blue) after a long-time occurrence of hazy weather in Beijing, China, which prompted the public's attention to heavy-polluting enterprises to reach a new peak. Will the public's negative concern about the incident will affect the operation of heavy-polluting enterprises? In this paper, we analyzed the influence of the haze-related exogenous events before and after the "APEC Blue" on earnings management of heavy-polluting enterprises from a new perspective of negative social attention. We carry out research from three perspectives for further research, which involve the growth in the demand for accounting information disclosure, the increase of consumers' low-carbon consciousness and differences in the amount of attention on enterprises with different properties and scales. Results indicate that heavy-polluting enterprises have stronger preference for downward earnings management, especially in those enterprises that are large in scale, non-state owned, or have a direct relationship with consumers.

Keywords: hazy weather; heavy-polluting enterprises; earnings management; difference-in-difference model

1. Introduction

Haze, as a threat to human health, has been a hot topic that greatly raises public concern after the serious fine particulate matter ($PM_{2.5}$) event at the end of October 2011 in China. Especially, the blue sky during the APEC conference in Beijing revived people's confidence in haze management. Meanwhile, heavy-polluting enterprises were exposed to the public. Much of the negative social concern forced heavy-polluting enterprises to lower their accounting book data and take downward earnings management to reduce corporate exposure.

Rohde [1] studied the causes of haze in Beijing and pointed out that most haze pollutions are attributed to heavy industrial districts nearby with a small proportion attributed to local factories. It is worth mentioning that accounting information is one of the important means through which the public can evaluate whether a heavy-polluting enterprise is "the heartless rich" and failed to commit to the social and environmental responsibilities. Therefore, accounting information disclosure of heavy-polluting enterprises is extremely important. It is not only the basis for making accurate judgment whether they have illegal operations, but also one of the critical references for policy implementation. Therefore, accounting information has attracted extensive attention from scholars, society and government. The public is concerned about whether heavy-polluting enterprises are "the heartless rich" and whether they have fulfilled social responsibilities in environmental protection practically, while scholars pay more and more attention to the authenticity of the disclosed information. Using the breakpoint regression model, Guo et al. [2] tested whether heavy-polluting enterprises adopted obvious earnings management measures before and after the launch of the control policy for them in 2010 under the influence of air pollution during 2008–2012, and found that heavy-polluting enterprises have adopted downward earnings management when Air Pollution Indexes (APIs) were 100, 200 and 300. Liu et al. [3] discussed the influence of haze-induced political cost on earnings management of heavy-polluting enterprises through the exogenous $PM_{2.5}$ event, and found that the experimental groups adopted downward earnings management measures after the event to avoid social and government attention.

As discussed above, most of the previous studies based on the serious $PM_{2.5}$ event focus on the influence of haze on the heavy-polluting enterprises. The previous studies explore the relationship between haze and the quality of accounting information disclosure of heavy-pollution enterprises from the perspective of political costs. In comparison, our study chooses a different approach to study this problem; that is, from the perspective of public pressure. Because the $PM_{2.5}$ event broke out suddenly and people had little knowledge of haze, public attention on haze has only put small pressure on heavy-polluting enterprises. Hence, $PM_{2.5}$ is inapplicable as the exogenous event of this study. By contrast, the occurrence of "APEC Blue" in 2014 raised the public awareness and drew people's attention to hazy weather. The present study discussed the influence of haze on the quality of accounting information disclosure of listed heavy-polluting enterprises under negative social attention based on earnings management changes before and after the "APEC Blue". After studying the impacts of the rich list on accounting information disclosure of enterprises, Ye et al. [4] pointed out that negative social attention would influence the quality of disclosed accounting information from enterprises to some extent. Recently, the public has been paying attention to some heavy-polluting enterprises after their environmental pollution behavior was disclosed by social media. The public will label a company as "the heartless rich" if they earn high profits but produce a large amount of pollution. The public will also resist the products produced by those enterprises. Therefore, these heavy-polluting enterprises keep a "reasonably" low profile and sacrifice the quality of disclosed information, especially the profit information, aiming to avoid being labeled by the public as "seeking happiness at the cost of causing pain to the public".

In addition, the present study discussed the earnings management of heavy-polluting enterprises from the new perspective of negative social attention. Therefore, our conclusions are of strong theoretical and practical significance, especially to the research on the motivation of earnings management of heavy-polluting enterprises. In the present study, heavy-polluting enterprises were divided into three categories according to different motivations of earnings management. Our results provide important implications for future research, especially by providing references for researchers to identify heavy-polluting enterprises that may significantly reduce the accounting information quality. Our study will therefore improve the accuracy and reliability of follow-up empirical studies based on the accounting information. Moreover, our research will contribute to the study on the authenticity of accounting information disclosure, which is helpful for related authorities to formulate air pollution control policies.

The rest of this paper is organized as follows. Section 2 outlines the theoretical analysis and research hypotheses. Section 3 describes the method of the empirical research, which involves sample selection, data collection, model development and definition of variables, while the empirical results and analysis are presented in Section 4. Section 5 summarizes and concludes with suggestions for future research.

2. Theoretical Analysis and Research Hypotheses

Social attention on haze has brought pressure to all sections of society, causing heavy-polluting enterprises to reduce the quality of accounting information disclosure. After the "APEC Blue" event, those heavy-polluting enterprises asked to halt production during the APEC meeting are highly concerned by local public. These enterprises are considered as the "culprit" of local hazy weather and are therefore strongly suppressed by the local public. Thus, reducing negative social attention becomes the primary motivation for earnings management of heavy-polluting enterprises. Heavy-polluting enterprises with high profits are "highlighted" which attract wide attention of the public and government. Such high profits of heavy-polluting enterprises, with the image of "culprit" for air pollution, are viewed as "ill-gotten gains" by the public. Due to the development of Internet, both capital market and the public's low-carbon consciousness result in the high demand for enterprise information disclosure. In the present study, the theoretical analysis of the relationship between social pressure caused by haze and accounting information disclosure of heavy-polluting enterprises from the perspective of earnings management involves the growth in the demand for accounting information disclosure, the increase of consumers' low-carbon consciousness [5,6] and differences in the amount of attention on enterprises of different properties and scales. The influence mechanism of haze-induced social pressure on accounting information disclosure quality of heavy-polluting enterprises is shown in Figure 1.

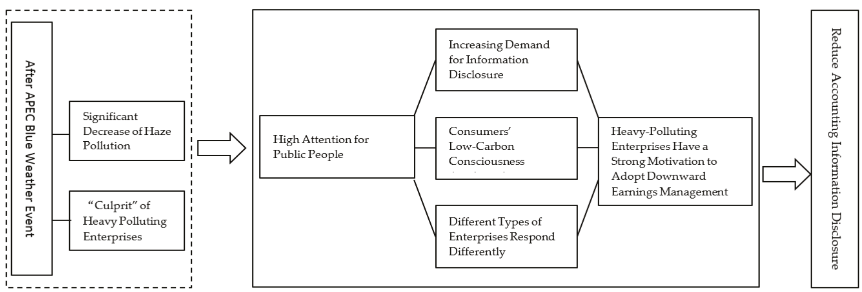

Figure 1. The influence mechanism of haze-induced social pressure on accounting information disclosure quality of heavy-polluting enterprises.

Firstly, since heavy polluting-enterprises are unwilling to face the increasing demand for accounting information disclosure caused by haze, they have a strong intention to control earnings after the "APEC Blue" to avoid increasing other costs caused by excessive social attention. When studying the social responsibility of information disclosure of enterprises, Dan [7] pointed out that China's heavy-polluting enterprises are passive in disclosing information and believe that relevant information disclosure to the public will increase the costs of enterprises. Liu et al. [3] reported that high-quality accounting information disclosure and high profit are easier to make heavy-polluting enterprises more transparent and consequently disclose problems of other enterprises. Subsequently, social media will make deep investigations and reports, further increasing social attention on enterprises. To decrease the negative social attention caused by haze and meet the increasing demand for information disclosure, enterprises have a strong motivation to adopt downward earnings management to reduce book profit. Downward earnings management can cope with the growth of information disclosure demand caused by haze and reduce negative social attention on their production management. In other words, enterprises successfully gain sympathy from the public through downward earnings management, which can not only relieve negative social attention and suppression, but also effectively avoid control from relevant governmental authorities. These enterprises can even obtain certain subsidies for environmental protection. Hence, based on the theory of enterprise information disclosure, a hypothesis (H1) is proposed as follows:

Hypothesis (H1). *Heavy-polluting enterprises have a strong motivation to reduce the quality of accounting information disclosure after the "APEC Blue" event and adopt downward earnings management to reduce social attention and meet the increasing information disclosure demand.*

Secondly, consumers' low-carbon consciousness is awakening. Social pressure on heavy-polluting enterprises will directly influence consumers' demand for their products. Heavy-polluting enterprises that are directly related with consumers (e.g., cloth and shoes manufacturers) have a strong motivation to adopt downward earnings management and create a corporate image of "low profits but quick turnover", aiming to avoid large-scale consumer boycott against their products because of their heavy pollution. As the intensification of hazy weather which causes serious threats to the public's living quality, people's "indignation" for haze reaches the peak. They begin to actively look out for environmental pollution behavior of local heavy-polluting enterprises and publicize it through network propaganda and large-scale protest. With the enhancing low-carbon consciousness of consumers, people concern more on green production techniques [8] and the fulfillment of enterprises' social responsibilities in environmental protection [9,10]. When heavy-polluting enterprises are labeled as the "heartless rich", they will face abundant negative attention from consumers, which will bring great pressure to their future production development. Moreover, such negative attention from consumers is likely to disclose more improper acts from the enterprises if there is any, and even results in real-time monitoring, hefty fine or forced shutdown from relevant department. To leave a good impression with consumers, heavy-polluting enterprises that are directly related with consumers have to create a corporate image of actively fulfilling environmental protection responsibilities and avoid consumers' attention caused by the sharp contrast and association between high profits and heavy pollution. Taken together, based on the theory of green consumption, the second hypothesis (H2) is proposed as follows:

Hypothesis (H2). *Heavy-polluting enterprises that are directly related to consumers have a strong motivation to reduce accounting information disclosure quality after the "APEC Blue" event and adopt downward earnings management to retain consumers' loyalty.*

Finally, heavy-polluting enterprises with different properties and scales will receive different levels of social attention and are thereby motivated to different degrees for earnings management. Large-sized enterprises are easier to attract public attention than small-sized ones. In other words, the public expects a higher social responsibility from large-sized enterprises, compared to small-sized ones. The western scale hypothesis postulates that large-sized enterprises have a stronger motivation to conceal huge profits and prefer downward earnings management to relieve attention from government departments with the increase of government cost. As a large-scale experiment of haze control in China, "APEC Blue" has achieved considerable effects. It enhances the confidence of environmental protection departments in haze control and provides the government with an explicit management direction. Therefore, large-sized enterprises would keep a reasonably "low profile" to avoid public attention after the "APEC Blue" event. They protect their production and operation from increasing political costs through the downward earnings management. In terms of enterprise properties, compared to non-state-owned enterprises, state-owned enterprises have certain advantages in government-enterprise relationship and financing. Besides, they possess rich resources and subsidies, enabling them to cope with the increasing cost caused by environmental regulation [11]. Most environmental regulations are to restrict non-state-owned enterprises, so they will face higher political costs and more social attention. Therefore, non-state-owned enterprises have a stronger motivation of earnings management than state-owned enterprises when coping with public pressure and government regulations caused by haze [12,13]. Hence, based on the theory of political cost and the theory of enterprise scale, the third and fourth hypotheses (H3 and H4) are proposed as follows:

Hypothesis (H3). *Large-sized heavy-polluting enterprises have a strong motivation to adopt downward earnings management to avoid unnecessary political cost and social attention after the "APEC Blue" event.*

Hypothesis (H4). *Non-state-owned heavy-polluting enterprises have a stronger motivation to decrease accounting information disclosure quality and adopt downward earnings management to avoid unnecessary political cost and social attention after the "APEC Blue" event.*

3. Research Method

3.1. Sample Selection and Data Source

Considering the data availability, the sample interval is set at 2012–2016. According to settings of difference-in-difference model, heavy-polluting enterprises are used as the experimental group and non-heavy-polluting enterprises are used as the control group based on the "APEC Blue" event. Heavy-polluting enterprises are divided according to *Announcement on Special Emission Limit of Atmospheric Pollutants* (hereinafter referred as *Announcement*), which covers the industries of thermal power, steel, petrifaction, cement, nonferrous metals and chemical engineering. Non-heavy-polluting enterprises are divided according to *Guideline for Industrial Classification of Listed Companies* of China Securities Regulatory Commission revised by Liu et al. in 2012. The remaining listed companies in the same category of heavy-polluting enterprises are considered as non-heavy-polluting enterprises. A total of 417 enterprises are selected, including 204 heavy-polluting enterprises and 213 non-heavy-polluting enterprises. A further selection is conducted to ensure the complete disclosed enterprises data: (1) enterprise samples with poor and missing financial data and ST enterprises are eliminated; and (2) enterprise samples with obvious business crossing over the heavy-polluting enterprises and non-heavy-polluting enterprises are eliminated. Finally, there are in total 1205 available observation data points, including those for 204 heavy-polluting enterprises and 205 non-heavy-polluting enterprises. All data are collected from the Wonder Database and the missing enterprise data is supplemented manually from disclosed information in the enterprises' annual reports.

3.2. Model Setting and Definition of Variables

3.2.1. Measurement Model of Earnings Management

The early studies of earnings management mostly employed the basic Jones model [14]. Later, scholars found that the modified Jones model can recognize accruable earnings management and estimate operating accruable profit better in panel data classified by industries. In the present study, earnings management quality indexes are estimated by the basic Jones model. In addition, the annual regression of industries is accomplished based on the cross-sectional modified Jones model. The annual non-operating accruable profit and operating profits of enterprises are established according to estimation parameters, and the earnings management index is measured by operating accruable profit [15]. Therefore, earnings management is measured by the basic Jones model and the modified Jones model, resulting in indexes EM1 and EM2.

The basic Jones model is:

$$\frac{NDA_{it}}{A_{it-1}} = \widehat{\alpha_1}\left(\frac{1}{A_{it-1}}\right) + \widehat{\alpha_2}\frac{\Delta REV_{it}}{A_{it-1}} + \widehat{\alpha_3}\left(\frac{PPE_{it}}{A_{it-1}}\right) \tag{1a}$$

where NDA_{it}/A_{it-1} is the non-operating accruable profits of the listed company i after the final total assets of $t-1$ period, A_{it-1} is the final total assets of company i of the $t-1$ period, ΔREV_{it} is the changes of sales revenue of company i in the current year and the last year after t period, and PPE_{it} is the original value of fixed assets at t period. Based on the annual regulations of different industries, the estimation parameters a_1, a_2 and a_3 are gained and brought into Equation (1b), producing the total profits of the year (TA_{it}). The model is:

$$\frac{TA_{it}}{A_{it-1}} = \alpha_1\left(\frac{1}{A_{it-1}}\right) + \frac{\alpha_2\Delta REV_{it}}{A_{it-1}} + \alpha_3\left(\frac{PPE_{it}}{A_{it-1}}\right) + \varepsilon_{it} \tag{1b}$$

Equations (1a) and (1b) are calculated and the results are put into Equation (1c) for regression, thus EM1 can be gained as:

$$\text{EM1} = \frac{TA_{it}}{A_{it-1}} - \frac{NDA_{it}}{A_{it-1}} \tag{1c}$$

The modified Jones model is:

$$\frac{NDA_{it}}{A_{it-1}} = \widehat{\alpha_1}\left(\frac{1}{A_{it-1}}\right) + \widehat{\alpha_2}\frac{(\Delta REV_{it} - \Delta REC_{it})}{A_{it-1}} + \widehat{\alpha_3}(\frac{PPE_{it}}{A_{it-1}}) \tag{2a}$$

where ΔREC_{it} is the receivables difference of company i between the end of t period and the end of last period. The other variables have the same meaning as the variables in the basic Jones model. In comparison, the receivables difference (ΔREC_{it}) is deducted from the sales revenue of company (ΔREV_{it}) in the modified Jones. Based on the annual regulations of different industries, the estimation parameters a_1, a_2 and a_3 are gained and brought into Equation (2b), producing the total profits of the year (TA_{it}). The model is:

$$\frac{TA_{it}}{A_{it-1}} = \alpha_1\left(\frac{1}{A_{it-1}}\right) + \frac{\alpha_2(\Delta REV_{it} - \Delta REC_{it})}{A_{it-1}} + \alpha_3\left(\frac{PPE_{it}}{A_{it-1}}\right) + \varepsilon_{it} \tag{2b}$$

Equations (2a) and (2b) are calculated and the results are put into (2c) for regression, thus EM2 can be gained as:

$$\text{EM2} = \frac{TA_{it}}{A_{it-1}} - \frac{NDA_{it}}{A_{it-1}} \tag{2c}$$

3.2.2. Empirical Model

A difference-in-difference (DID) model is built to verify the proposed hypotheses. Settings of the DID model are similar with those in Bertrant [16] and Hanlon et al. [17]. Bertrant pointed out that the DID model can effectively avoid mixing effects of other events on time sequences and recognize causal relationships of variables. It is widely used in empirical studies. The DID model can be expressed as:

$$\begin{aligned} EM_{1,2} = \beta_1 + \beta_2\text{Treated} + \beta_3\text{After} + \beta_4\text{Treated} * \text{After} + \beta_5\text{Age} + \beta_6\text{Size} \\ +\beta_7\text{Growth} + \beta_8\text{Lev} + \beta_9\text{avloss} + \mu \end{aligned} \tag{3}$$

In Model 2, $EM_{1,2}$ is a dependent variable covering EM1 and EM2, which is substituted into models during test and stands for the earnings management index. Treated, After and Treated $*$ After are independent variables. Treated is an indicator variable set according to hypothesis, with 1 for the experimental group and 0 for the control group. After is an indicator variable that distinguishes before and after the "APEC Blue" event, with 1 indicating before the event and 0 after the event. Treated $*$ After is the interaction term of two variables and its regression coefficient is the main observation data of the present study. It reflects whether the experimental group (heavy-polluting enterprises) after the event ("APEC Blue") has a stronger motivation to control accruable profits and adopt significantly downward earnings management than the control group (non-heavy-polluting enterprises) before the event. According to proposed hypotheses, Treated $*$ After is expected to be negative in the present study. Other variables are control variables, including scale of company (Size), age of listed company (Age), leverage ratio (Lev), growth opportunity (Growth) and avoiding loss (Avloss).

3.2.3. Definitions of Variables

(1) Explained Variables

Earnings management (EM): It is measured by the basic Jones model and the modified Jones model in order to ensure accuracy of research results. Jones model mainly considers total assets, fixed assets, receivables and sales revenue. Regression analysis on annual EM of different industries is performed, finally getting earnings management quality indexes (EM1 and EM2).

(2) Explanatory Variables

① *Treated*: Since the present study mainly focuses on heavy-polluting enterprises, we choose the heavy-polluting enterprises as the experimental group and therefore Treated is set as 1. Treated of non-heavy-polluting enterprises is defined as 0. Heavy-polluting enterprises and non-heavy-polluting enterprises are mainly divided manually according to the *Announcement* which was released in 2012. To meet H2, H3 and H4, samples in the present study are further divided into three subgroups according to consumers, enterprise properties and scale of company to verify the proposed hypotheses. According to the relationship between consumers and heavy-polluting enterprises, the heavy-polluting enterprises that are directly related with consumers are used as the experimental group (Treated = 1) and those indirectly related with consumers are defined as the control group (Treated = 0). In terms of enterprise properties, non-state-owned heavy-polluting enterprises are defined as the experimental group (Treated = 1) and the rest are the control group (Treated = 0). In terms of scale of enterprises, large-sized heavy-polluting enterprises are defined as the experimental group (Treated = 1) and small-sized enterprises are the control group (Treated = 0). Scale division is accomplished according to the median of different industries.

② $After$ the "APEC Blue" event occurred in November 2014: Enterprises have inadequate time to revise submitted accounting data. Therefore, 2012–2014 is defined as the time before the event (After = 0) and 2015–2016 is defined as the time after the event (After = 1).

③ $Treated * After$: The regression coefficient of Treated ∗ After is the main observation data of DID model and an important content in the research analysis. It indicates whether the experimental group (heavy-polluting enterprises) has a stronger motivation to control accruable profits after the "APEC Blue" event than the control group (non-heavy-polluting enterprises) before the event.

(3) Control Variables

Based on the results of Ye and Yao et al. [18], scale of company (Size), age of listed company (Age), leverage ratio (Lev), growth opportunity (Growth) and avoiding loss (Avloss) are chosen as the control variables of company characteristics. Considering the applicability of Torbin's Q on Chinese stock markets, growth of companies is defined by growth rate of sales revenue. Controlling growth opportunity of enterprises will influence earnings management of enterprises. Variables and their definitions are listed in Table 1.

Table 1. Selection and definitions of variables.

	Variables	Definitions
Explained variables	**DA1**	Earnings quality in the basic Jones model
	DA2	Earnings quality in the modified Jones model
Explanatory variables	Treated	1 for the experimental group and 0 for the control group
	After	1 for at the year and after the occurrence of "APEC Blue" (2014–2016), and 0 for before it (2012–2013).
	Treated ∗ After	Interaction term of the two variables above. It is the main observation variable.
Control variables	**Age**	Age of listed company
	Size	Scale of company = logarithms of total enterprise assets
	Growth	Growth = growth rate of sales revenues = (sales revenues of the current period − sales revenues of the last period)/sales revenues of the last period
	Avloss	Avoiding loss: if roe of the company is in the interval [0, l%], avloss = 1, or avloss = 0.
	Lev	Leverage ratio = long-term assets/total assets

4. Empirical Results and Analysis

4.1. Descriptive Statistics

The descriptive statistics of the whole sample are shown in Table 2. To avoid influences of extremum, all continuous values are processed by winsorize. In Table 2, EM is generally low and the mean of EM is −0.0116. Descriptive statistics of different variable groups before and after the "APEC Blue" are shown in Table 3. Based on the comparison of data before and after the "APEC Blue" in Table 3, heavy-polluting enterprises have a strong motivation to adopt downward earnings management after the event. According to EM of experimental group and control group before the event, EM is insignificant except mean EM in the modified Jones model is negatively significant on the 5% level. However, both mean and median of EM between the experimental group and control group have significant differences (−0.018) on the 1% level after the event, indicating that, compared to the control group, the experimental group implements downward earnings management more deeply after the event. In Table 3, two groups have significant differences in term of mean and median of Growth but the differences are small. Although there are certain differences in company characteristics between the two groups, it does not affect the results, as shown by the follow-up study. Here, we control the company characteristic variables.

Table 2. Descriptive statistics of the whole sample.

Variables	Observed Value	Mean	SD	Min	Max
Em1	1205	−0.0104	0.142	−0.256	0.231
Em2	1205	−0.0116	0.0813	−0.120	0.0934
After	1205	1	0	1	1
Treated	1205	0.400	0.490	0	1
Lnsize	1205	3.372	1.022	0.680	7.890
Age	1205	16.55	4.879	5	35
Lev	1205	4.434	4.808	0.490	74.60
Growth	1205	6.475	7.391	−54.59	119.9
Avloss	1205	0.0556	0.229	0	1

Table 3. Descriptive statistics of different variable groups before and after the "APEC Blue" event.

Before								
Variables	Experimental Group			Control Group			MeanDiff	MedianDiff
	Mean	SD	Median	Mean	SD	Median		(Chi2)
Em1	−0.0230	0.0790	−0.0300	−0.0230	0.0770	−0.0300	−0.00100	0.001
Em2	−0.0200	0.0893	−0.0300	−0.0330	0.0862	0.0866	−0.013 **	2.375
Lnsize	3.587	1.020	3.495	3.675	0.995	0.978	0.0890	1.277
Growth	5.964	7.280	5.510	7.081	7.502	5.510	1.118 **	3.646 *
Lev	0.0810	0.263	0	0.0420	0.253	0.228	−0.038 **	4.330 **
Avloss	0.0640	0.223	0	0.0560	0.216	0.231	−0.00700	0.174
After								
Variables	Experimental Group			Control Group			MeanDiff	MedianDiff
	Mean	SD	Median	Mean	SD	Median		(Chi2)
Em1	−0.00600	0.0821	−0.0100	−0.00800	0.0751	−0.0100	0.00200	0.166
Em2	−0.0300	0.0922	−0.0400	−0.0130	0.0862	−0.0200	−0.018 ***	9.059 ***
Lnsize	3.190	0.979	3.080	3.268	0.995	3.140	−0.0780	1.377
Growth	8.365	6.274	7.335	7.385	7.502	6.810	0.980 **	4.772 **
Lev	0.0630	0.251	0	0.0710	0.253	0	-0.00800	0.264
Avloss	0.0560	0.240	0	0.0450	0.216	0	0.0110	0.776

Note: ***, ** and * represent significance levels of 1%, 5% and 10%, respectively. MeanDiff represents difference of means and MedianDiff represents Chi-square value.

4.2. Correlation Coefficients

Correlation coefficients of variables are shown in Table 4. Obviously, correlation coefficients of variables are far smaller than 0.5 and the variance inflation factor (VIF) is significantly lower than 10, indicating that there is no obvious multicollinearity problem. To ensure the reliability of regression results and reduce effects of heteroscedasticity on the robustness of estimated results, White test is performed when using the Robust Command to correct SD and t statistics as well as to eliminate heteroscedasticity. Therefore, the model has no serious collinearity or heteroscedasticity and can be used for further regression test.

Table 4. Correlation coefficients.

(obs = 2045)								
	EM2	**Treated**	**After**	**Lnsize**	**Age**	**Lev**	**Growth**	**Avloss**
EM2	1							
After	0.0205	1						
Treated	0.0453	0	1					
Lnsize	−0.00420	−0.0235	0.184	1				
Age	0.0499	−0.0228	0.256	0.166	1			
Lev	0.00130	−0.0578	−0.0651	−0.263	−0.135	1		
Grow	0.00400	−0.119	−0.0952	0.0729	−0.0229	0.0878	1	
Avloss	−0.00120	0.00960	0.0265	0.00790	−0.0176	−0.0440	−0.184	1

4.3. Analysis of Regression Results

4.3.1. Whole Sample Regression Analysis

The regression analysis results of the whole sample are shown in Table 5. EM1 and EM2 are earnings management of heavy-polluting enterprises that are measured by manageable accruable profits by the basic and the modified Jones models. They are used to analyze changes of earnings management before and after "APEC Blue" event. In the present study, special attention is paid to Treated ∗ After, because it reflects the net effect of earnings management of heavy-polluting enterprises as a consequence of the "APEC Blue" event. According to H1, Treated ∗ After is expected to be negative. In Table 5, Columns (1) and (2) are earnings management quality (EM1), which is measured by the basic Jones model, while Columns (3) and (4) are earnings management quality (EM2), which is measured by the modified Jones model. Columns (2) and (4) are simplified models without control variables. By comparing Columns (1), (2), (3) and (4), the involvement of control variables will not significantly affect regression results of major variables. Therefore, certain difference in company characteristic variables will not affect the final results.

In Columns (1) and (3), Treated ∗ After is negative, which is consistent with the expectation and significant on the 10% level. Treated ∗ After in Columns (2) and (4) without control variables are negatively significant on the 10% level, indicating that heavy-polluting enterprises have a strong motivation to decrease accounting information disclosure quality after the "APEC Blue" event and adopt downward earnings management to reduce social attentions and meet increasing information disclosure demand. In other words, H1 is confirmed. After is the effect of other events after the "APEC Blue" on earnings management. It has a significantly positive correlation with earnings management on the 1% level, indicating that haze-related events might influence earnings management except for the "APEC Blue". This conforms to China's practical situation and reflects haze has caused great attentions after the "APEC Blue", which forces heavy-polluting enterprises to avoid such attention through earnings management. It is interesting that Treated depicts earnings management difference between heavy-polluting enterprises and non-heavy-polluting enterprises before the event. Regression results of Treated in Columns (1) and (2) are insignificant, but regression results of Treated in Columns (3) and (4) are negative and significant on the 1% level. This means that heavy-polluting enterprises have obvious downward earnings management compared to non-heavy-polluting enterprises before the event and such downward earnings management is further intensified after the "APEC Blue" event. This agrees with descriptive statistics of different group variables in Table 3. Heavy-polluting enterprises indeed adopt downward earnings management and disclose unsatisfying accounting information. The regression results of Treated ∗ After show that heavy-polluting enterprises implement significantly downward earnings management after the event, supporting H1.

The other control variables are significantly correlated with earnings management indexes of enterprises. Lnsize in Column (1) has a significantly positive correlation with EM on the 1% level, indicating that the larger the company is, the lower the earnings management will be. The internal control level is more perfect in the larger company, where earnings management is subject to certain restrictions. Age has a significantly positive correlation with EM on the 10% level, indicating that the "older" the company is, the weaker the motivation of earnings management will be. Size and Age are significant in Column (3). Leverage in Column (3) has a significantly positive correlation with EM2 on the 5% level, indicating that the higher leverage rate the company has, the lower the earnings management will be. Leverage reflects the company's solvency. The higher the leverage rate is, the stronger solvency the company has. With strong financial support, enterprise has greater confidence to deal with negative social concern caused by haze. Growth in Column (3) has a significantly positive correlation with EM2 on the 1% level, indicating that the greater the Growth is, the lower the earnings management will be. A high growth capacity of a company may signal its good business performance to investors, markets and the public, and its motivation of downward earnings management is weak. Avloss in Column (3) has a significantly positive correlation with EM2 on the 5% level, indicating that the stronger the motivation to avoid losses, the lower the earnings management will be. For the motivation of avoiding loss, enterprise prefer showing more decent book assets to downward earnings management to enhance employee motivation and win the trust of investors.

Table 5. Regression results of the whole sample.

Variables	(1)	(2)	(3)	(4)
	EM1	EM1	EM2	EM2
After	0.0253 *** (4.258)	0.0256 *** (4.228)	0.0185 *** (3.748)	0.0256 *** (4.228)
Treated	0.00278 (0.387)	0.0112 (1.554)	−0.00246 *** (−3.158)	−0.00325 *** (−4.287)
Treated * After	−0.0152 * (−1.723)	−0.0169 * (−1.875)	−0.00214 (−0.259)	−0.0174 * (−1.75)
Lnsize	0.0173 *** (6.615)		0.0166 *** (7.411)	
Age	0.000842 * (1.776)		0.000501 (1.180)	
Lev	0.000902 (1.569)		0.000658 ** (2.056)	
Growth	−0.000355 (−1.117)		0.00144 *** (5.742)	
Avloss	0.0111 (1.154)		0.0227 ** (2.573)	
Constant	−0.110 *** (−8.850)	−0.0370 *** (−7.758)	−0.108 *** (−10.483)	−0.0370 *** (−7.758)
Observations	2041	2041	2041	2041
R-squared	0.050	0.011	0.060	0.011

Note: Robust t-statistics in parentheses; *** $p < 0.01$, ** $p < 0.05$ and * $p < 0.1$.

4.3.2. Subsample Regression

The whole sample is further divided into three subgroups based on H2, H3 and H4. The division is made in terms of the relationship between consumers and heavy-polluting enterprises, enterprise properties and enterprise scale. Columns (1) and (2) in Table 6 show regression results of the subsample of heavy-polluting enterprises that are directly related with consumers. In Column (1), Treated ∗ After and EM1 are negative, but not significant. It is interesting that, in Column (2), Treated ∗ After is −16.62 and is significantly correlated with EM2 on the 5% significance level. Hence, it is speculated that errors might be caused by the difference between EM1 and EM2. Wang et al. [19] pointed out that the modified Jones model can recognize accruable earnings management and estimate operating accruable earnings management better in panel data of industries. Therefore, the present study concludes that H2 is true based on EM2. In Columns (1) and (2), some control variables are significantly correlated with earnings management. It is noteworthy that Age in Column (2) is negatively correlated with EM on the 1% significance level and is different from the regression results of the whole sample. In other words, "older" heavy-polluting enterprises that are directly related with consumers concern more on a good impression with consumers. After the haze event, "younger" enterprises have a stronger motivation to adopt downward earnings management to reduce consumers' attention.

Columns (3) and (4) in Table 6 are the regression results of the subsample of heavy-polluting enterprises divided in terms of size based on median of enterprises. Heavy-polluting enterprises larger than the median are large enterprises and defined as 1; otherwise, they are defined as 0. Attention is paid to whether Treated ∗ After in Column (4) is consistent with the expectation of the present study. It can be seen from Column (4) that Treated ∗ After is negative and significant on the 10% level. Therefore, H3 is true. Based on a further study, Treated is negative and significant on the 5% level, indicating that large-sized enterprises have implemented a significant downward earnings management before the "APEC Blue" event, which is further intensified after the event. This further proves that H3 is true. Large-sized enterprises are easier to attract social attention than small-sized ones. After the "APEC Blue" event, large-sized heavy-polluting enterprises are easier to attract attention from the government and the public, so they are more careful with information disclosure than small-sized ones, resulting in low quality of disclosed accounting information, even mixed with false information.

Columns (5) and (6) in Table 6 are the regression results of the subsample of heavy-polluting enterprises that are classified according to enterprise properties. Treated ∗ After in Column (6) is negative, which is consistent with the expectation of the present study. It is significant on the 1% level. Therefore, H4 is true. Treated is negative and significant on the 5% level, indicating that non-state-owned heavy-polluting enterprises have adopted obvious downward earnings management before the event. This further proves that H4 is true. In terms of practical significance, non-state-owned enterprises are inferior to state-owned enterprises with respect to resources accession. To cope with increasing social negative attention and government cost caused by haze events, they have a strong motivation to adopt downward earnings management to avoid excessive attention and unnecessary monitoring.

Table 6. Regression Results of Subsamples.

Variables	(1)	(2)	(3)	(4)	(5)	(6)
	CUST_EM1	**CUST_EM2**	**SIZE_EM1**	**SIZE_EM2**	**SOE_EM1**	**SOE_EM2**
After	0.0215 (1.612)	−16.11 (−1.192)	−0.00105 (−0.175)	0.0286 *** (4.334)	0.0159 *** (3.230)	−0.00462 (−1.007)
Treated	−0.00461 (−0.795)	8.162 (1.306)	−0.00593 (−0.852)	−0.0160 ** (−2.401)	−0.00897 (−1.379)	−0.0149 ** (−2.406)
Treated * After	−0.00884 (−0.470)	−16.62 ** (−2.263)	−0.00978 (−1.091)	−0.0167 * (−1.701)	0.00283 (0.345)	−0.0342 *** (−2.958)

Table 6. *Cont.*

Variables	(1)	(2)	(3)	(4)	(5)	(6)
	CUST_EM1	CUST_EM2	SIZE_EM1	SIZE_EM2	SOE_EM1	SOE_EM2
Lnsize	0.0166 *** (5.282)	0.710 (0.719)	0.00536 * (1.867)	0.0157 *** (4.853)	0.0131 *** (5.484)	0.00344 (1.476)
Age	0.000281 (0.498)	−0.985 *** (−5.319)	−0.000836 * (−1.712)	0.000272 (0.468)	−0.000612 (−1.390)	−0.000600 (−1.464)
Lev	0.000799 ** (2.026)	−0.456 ** (−2.237)	0.000378 (0.721)	0.000847 ** (2.079)	0.000716 ** (2.421)	0.000204 (0.605)
Growth	0.00728 ** (2.100)	−1.112 (−0.167)	0.0102 *** (3.794)	0.00750 ** (2.092)	0.00450 * (1.925)	0.0138 *** (5.634)
Avloss	0.00204 (0.194)	0.0189 *** (2.850)	−0.00108 (−0.128)	0.00229 (0.212)	−0.00297 (-0.405)	−0.00472 (−0.706)
Constant	−0.0890 *** (−6.417)	27.73 * (1.958)	−0.0304 ** (−2.271)	−0.104 *** (−7.106)	−0.0826 *** (−7.231)	−0.0320 *** (−2.984)
Observations	1116	1116	1132	1132	1414	1414
R-squared	0.063	0.006	0.030	0.059	0.043	0.042

Note: Robust t-statistics in parentheses; *** $p < 0.01$, ** $p < 0.05$ and * $p < 0.1$.

4.3.3. Robustness Test

To ensure the robustness of the results, the robustness of the whole samples is tested. Since the regression analysis is mainly based on EM2, it is used as the dependent variable of robustness test. Panel data and OLS are applied in the above empirical test. This paper adopts the method of replacing measurement method to test the robustness, which is substituting fixed effect panel regression for ordinary OLS. The panel model with fixed effect is used and control variables are added gradually. Regression results are shown in Table 7. It is noteworthy that there is a significant negative correlation between Growth and EM2 in Table 7, while a significant positive correlation is shown in Column (3) of Table 5, which needs further explanation. Enterprise with great growth has good prospects for development, whose corporate performance has shown steady growth in recent years. Meanwhile, some well-developed enterprises begin to receive public attention and bear more social responsibilities, thus having motivation to control earnings management for reducing public attention to avoid the social costs associated with additional social concern. From the point of view of data structure and regression model, this article uses the panel regression, the results of which are more convincing than ordinary OLS regression results. Therefore, from a practical point of view, heavy-polluting enterprises with better growth are more motivated to control earnings management. Apart from the Growth control variable, the regression results of main variables are similar to the previous hypotheses and regression results. Hence, empirical results in the present study have robustness.

Table 7. Robustness Test of Panel Regression.

Variables	(1)	(2)	(3)	(4)	(5)	(6)
	EM2	EM2	EM2	EM2	EM2	EM2
Treated	−0.00696 (−0.84)	−0.00666 (−0.80)	−0.00670 (−0.80)	−0.00666 (−0.80)	−0.00801 (−0.96)	−0.00783 (−0.94)
After	0.0110 ** (2.07)	0.0142 ** (2.46)	0.0143 ** (2.47)	0.00494 (0.58)	0.00277 (0.32)	0.00258 (0.30)
Treated * After	−0.0167 ** (−2.28)	−0.0178 ** (−2.47)	−0.0179 ** (−2.47)	−0.0184 ** (−2.54)	−0.0179 ** (-2.45)	−0.0180 ** (−2.47)

Table 7. *Cont.*

Variables	(1)	(2)	(3)	(4)	(5)	(6)
	EM2	EM2	EM2	EM2	EM2	EM2
Lnsize		−0.00791 (−1.04)	−0.00775 (−1.01)	−0.0114 (−1.42)	−0.00737 (−0.91)	−0.00716 (−0.88)
Lev			0.000246 (0.23)	0.000216 (0.20)	0.000121 (0.11)	0.000121 (0.11)
Age				0.00541 (1.42)	0.00455 (1.21)	0.00459 (1.21)
Growth					−0.00164 *** (−4.20)	−0.00164 *** (−4.20)
Avloss						0.00839 (0.78)
Constant	−0.0197 *** (−9.94)	0.00642 (0.26)	0.00473 (0.18)	−0.0703 (−1.17)	−0.0567 (−0.95)	−0.0584 (−0.97)
Observations	1636	1636	1636	1636	1636	1636
R-squared	0.01	0.01	0.01	0.01	0.02	0.02
Number of id	409	409	409	409	409	409

Note: Robust t-statistics in parentheses; *** $p < 0.01$, ** $p < 0.05$ and * $p < 0.1$.

5. Conclusions and Discussion

Based on the "APEC Blue" event in 2014, effects of social pressure caused by negative social attention on accounting information disclosure of heavy-polluting enterprises are discussed in this paper with the use of empirical data. We have investigated whether social pressure increase information disclosure quality of heavy-polluting enterprises. In terms of information disclosure intention of heavy-polluting enterprises, low-carbon consciousness of consumers and enterprise properties and size, heavy-polluting enterprises have a strong motivation to adopt downward earnings management. In the present study, net influences of haze effect on earnings management of enterprises are discussed based on interference of other events on time series eliminated by DID model, further verifying the proposed hypotheses. After the "APEC Blue" event, heavy-polluting enterprises have motivations to decrease book profits and the disclosed accounting information quality is decreased accordingly. According to the regression results of H2, H3 and H4, heavy-polluting enterprises that are directly related with consumers, non-state-owned enterprises and large-sized enterprises have stronger motivations to adopt downward earnings management. In addition, Guay [20] pointed out that negative social attention will influence the production process of enterprise information to some extent. More extensive scenarios are needed to test it. However, most existing studies describe effects of haze event on accounting information disclosure of enterprises from the perspective of political cost. In the present study, an empirical study is carried out from the perspective of negative social attention, which provides a new microscopic perspective to study haze. Considering downward earnings management of heavy-polluting enterprises in an attempt to reduce public attention and avoid environmental regulation, three suggestions are hereby proposed.

Firstly, non-state-owned heavy-polluting enterprises have a stronger feeling of "insecurity" upon negative social attention and strict environmental regulations caused by haze than state-owned enterprises. How to increase non-state-owned heavy-polluting enterprises' feeling of "security" is crucial to improve information disclosure quality. Relevant authorities should offer "punishment" and "award" simultaneously. In addition, the auditing department should perfect the auditing system of accounting information of enterprises, severely punish enterprises with financial fraud while offer certain subsides to heavy-polluting enterprises struggling with environmental pollution. Moreover, government should urge enterprises to enhance the "honesty" culture and encourage social media to pay attention to their social responsibilities in environmental protection and disclosure of financial information. Large-sized heavy-polluting enterprises need more strict supervision.

Secondly, consumers who are greatly associated with enterprises' benefits should play an important role in influencing enterprise behavior. According to the regression results, Treated * After of subsamples related with consumers is about −16 and significant on the 5% level, indicating that enterprises that are directly related with consumers have stronger motivations to adopt downward earnings management after the haze event. Therefore, it is extremely important to raise low-carbon consciousness of consumers. As the hot topic for three consecutive years, "haze" has wide concern in the public. Since haze control is not satisfactory in recent years, people have more concern for environmental issues and put forward higher and higher requirements on information disclosure quality of heavy-polluting enterprises due to the awakening low-carbon consciousness. However, people's low-carbon consciousness still focuses on energy conservation and power saving, paying little attention to the behavior of heavy-polluting enterprises. When low-carbon consciousness of consumers reaches a certain extent, the consumers will ask heavy-polluting enterprises to disclose high-quality information. They will take the initiative to supervise local heavy-polluting enterprises, which are conducive to avoid environmental pollution and pretended behaviors.

Thirdly, based on the empirical test data, we suggest that scholars pay more attention to heavy-polluting enterprises that are directly related with consumers, non-state-owned enterprises and large-sized enterprises. They should test the authenticity of disclosed accounting information and eliminate "false" information to reduce research error. According to the empirical regression in the present study, these types of enterprises have a stronger motivation to adopt earnings management when coping with social attention and government supervision, disclosing false accounting information to some extent. Scholars should judge the authenticity of data in future studies.

Finally, our study suggests several promising avenues for future research. Firstly, researchers could investigate other types of heavy-polluting enterprises (e.g., industry classification and brand awareness of enterprises). Secondly, researchers could explore whether heavy-polluting enterprises take action to conserve energy and reduce emission under public pressure, increasing operating costs and resulting in a deviation from earnings management results. Thirdly, whether the real economic structure has changed before and after the "APEC Blue" event needs to be further studied.

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sustainability

Article

Spatiotemporal Dynamics of Beijing's Urbanization Efficiency from 2005 to 2014

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Abstract: In the context of Beijing's accelerated economic growth, a high urbanization rate and associated urban problems pose challenges. We collected panel data for the period 2005–2014 to examine the relationship between Beijing's urbanization efficiency and economic growth rate as well as its spatial patterns of dynamic and static urbanization efficiency. Specifically, we developed a comprehensive index system for assessing Beijing's economic growth rate and urbanization efficiency at the district (county) level. Economic level was selected as an indicator of the economic growth rate. Economic urbanization and consumption levels were selected as indicators of urbanization efficiency. We applied a sequential Malmquist total factor productivity index to estimate the dynamic urbanization efficiency and economic growth rate at the district/country level from 2005 to 2014. We measured Beijing's static urbanization efficiency in 2014 using a data envelopment analysis model and assessed its spatiotemporal dynamics and urbanization efficiency pattern using a Getis–Ord General G_i index. The results indicated an overall average increase of 1.07% in the total factor urbanization efficiency (TFUE), with an average value of 0.91, while the total factor economic growth rate (TFEE) remained stable at an average value of 0.979. The low TFUE level evidently continues to significantly constrain TFEE. Both TFUE and TFEE levels in the Capital Function Core (CFC) area were significant, exhibiting high inputs and outputs, while these levels in the Urban Function Development (UFD), City Development Zone (CDZ), and Ecological Conservation Development (ECD) areas were below 1 for most periods, strongly indicating inefficient factor allocation. In view of this spatial pattern, TFUE's regional spatial distribution appears remarkable, showing a decreasing trend from north to south in Beijing, excluding CFC areas. During the period 2005–2014, the CFC area and northeastern Beijing gradually developed into high urbanization efficiency cluster regions. The dominant factors accounting for the difference in total factor productivity indices between TFUE and TFEE were technical change (TC) and scale efficiency change (SEC), and the main factors driving the regional spatial distribution pattern for urbanization efficiency were TC and technical efficiency change (TEC). Accordingly, local governments should promote TC, SEC, and TEC to improve urbanization levels, with optimal strategies entailing strengthening policy support and encouraging investments in technology in UFD, CDZ, and ECD areas. Within Beijing, Dongcheng, Xicheng, Shijingshan, Mentougou, and Yanqing demonstrated effectively balanced static urbanization efficiency levels in 2014, whereas these levels in the city's remaining 11 districts were not optimal, with extensive development. County governments should therefore promote efforts to reduce input redundancy and improve pure technical efficiency to maintain sustainable and steady development.

Keywords: urbanization efficiency; Malmquist index; total factor productivity; sustainability; Beijing

1. Introduction

Urbanization, which represents not just the level of economic development of a country but also a stage of social development, is considered the only route toward modernization [1–3]. Following its implementation of a reform and opening-up policy in 1978, China has pursued a strategy of rapid urbanization [2,4]. However, World Bank data indicate that China's current per capita GDP is close to that of the United States in the 1970s, while its current urbanization level is around 50% [5], lagging behind the level of the United States in the 1970s by 10%.

There is thus an apparent contradiction between China's high rate of urbanization and its relatively low level of urbanization [6]. In the process of rapid urbanization, Beijing's floating population increased 12.1 times, which is the main factor accounting for its urbanization rate. Beijing's urbanization rate is 86.2%, which is slightly lower than that of Shanghai. This pattern of urban sprawl causes a number of problems such as chaotic urban transportation, a deteriorating ecological environment, and the emergence of social problems [3,7] that lead to dysfunctional urban operations and irrational development. Moreover, a low level of urbanization efficiency restricts the level of social welfare and affects the impacts of development.

Charnes et al. [8] used a data envelopment analysis (DEA) model to evaluate the economic efficiency of 28 cities in China, thereby demonstrating that an urban system could be considered as a production system. Abdelfattah et al. [9] subsequently developed DEA model to assess the relative efficiency of 54 developing countries around the world. Morais and Camanho [10] also explored DEA as a means to assess and evaluate the performance of city managers in the promotion of urban quality of life of 206 European cities. The DEA model has grown into a powerful quantitative, analytical tool for evaluating performance, which has been successfully applied in Italian provincial capital cities [11], French provinces [12] and Spanish regions [13].

Because China is the largest developing country in the world, its urbanization efficiency has attracted considerable attention from scientists and policymakers in recent years [14–16]. Many scholars have subsequently applied a DEA model to examine urbanization efficiency represented by the total factor productivity (TFP) [17,18] or single factor productivity such as land [19]. They have attempted to achieve advances in areas such as index system establishment and model refinement [8,17], identify influence factors [20], and determine the evolution trend of urbanization efficiency [21]. Because of the availability of data at national or regional scales, empirical studies have mainly entailed a regional focus on, for example, the city clusters of the Yangtze River Delta [3]. Moreover, the relationships between cities and urban agglomeration in different provinces have received scant attention, even though an assessment of these relationships can provide scientific information to support decision makers in proposing effective strategies for promoting coordinated regional development.

The results of a survey conducted by the International Energy Agency in 2010 indicated that urban areas were responsible for 71% of global energy-related carbon dioxide (CO_2) emissions and that this percentage was likely to increase with the continuation of the trend of accelerated urbanization [22,23]. Because urbanization has a significant impact on CO_2 emissions [24–26], there is an urgent need to discuss the measurement and spatial patterns of urbanization efficiency in cities like Beijing. We therefore aimed to measure and identify the spatiotemporal pattern of Beijing's urbanization efficiency as a test case. To accomplish this aim, we applied a sequential Malmquist TFP index to measure dynamic urbanization efficiency and the economic growth rate at the district/country level in Beijing between 2005 and 2014, and analyzed the spatial patterns and evolution trend of urbanization efficiency. Moreover, we calculated the value of static urbanization efficiency in 2014. This result could provide a scientific basis for sustainable urbanization and assist decision makers in formulating, applying, and evaluating Beijing's urbanization policies.

2. Study Area

As China's capital, Beijing is the national political and cultural center and also constitutes a hub for international exchanges and innovations in science and technology. It is situated in the northern part of the North China Plain, at 39°38′ N–40°51′ N and 115°25′ E–117°30′ E, encompassing an area of 16,413.53 km^2. The city comprises a total of 16 urban and rural districts [27,28]. It has been divided into the following four major functional areas: the Capital Function Core (CFC) zone comprising the districts of Dongcheng and Xicheng; the Urban Function Development (UFD) zone comprising Haidian, Chaoyang, Shijingshan, and Fengtai districts; the City Development Zone (CDZ) comprising Changping, Shunyi, Tongzhou, Daxing, and Fangshan districts; and the Ecological Conservation Development (ECD) zone comprising Yanqing, Huairou, Miyun, Pinggu, and Mentougou districts. Figure 1 depicts these zones.

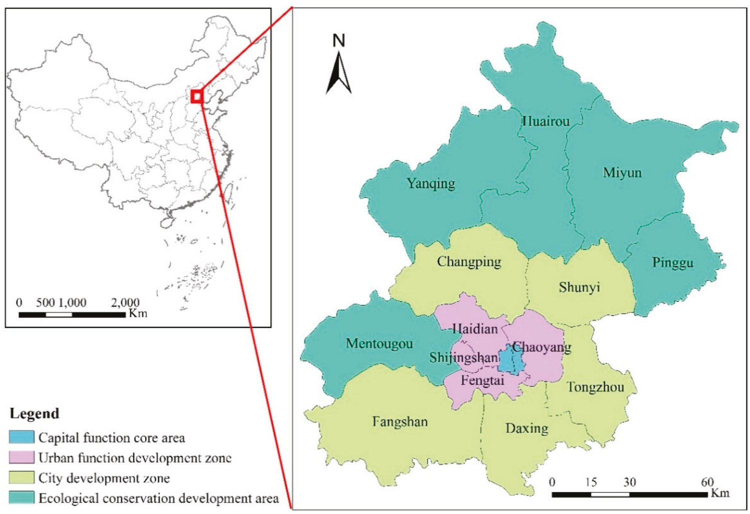


Figure 1. Location of Beijing and its administrative zones.

During the past 30 years, Beijing has experienced rapid urbanization at a rate that increased from 55.0% in 1978 to 86.3% in 2014. In 2014, its total population reached 21.52 million, and the city's GDP was 192.48 billion RMB, of which the shares of primary, secondary, and tertiary industries were 0.82%, 19.21% and 79.97%, respectively. Given Beijing's booming economy that continues to expand along with its growing population and rapid urbanization process, protection of its environment, efficient public service management, and rational resource allocation have become urgent issues. Accordingly, Beijing could serve as a representative case for a study of urbanization efficiency and the economic growth rate based on the application of a DEA-Malmquist model.

3. Data and Methodology

Figure 2 depicts the general framework of this study. We first developed a comprehensive index system for assessing Beijing's urbanization efficiency and the economic growth rate. Next, we applied the Malmquist TFP index to estimate the total factor urbanization efficiency (TFUE) and the total factor economic growth rate (TFEE). Based on the estimated values of TFUE at the district/country level, we used the Getis–Ord General G_i index to analyze the spatiotemporal pattern of dynamic TFUE during the period 2005–2014. We subsequently applied a DEA model to measure Beijing's static urbanization efficiency in 2014. As the final step, we identified the dominant factors in the TFP indices explaining differences between TFUE and TFEE and the driving factors of regional spatial distribution. We discussed their implications for developing a scientifically based and sustainable urbanization policy for Beijing.

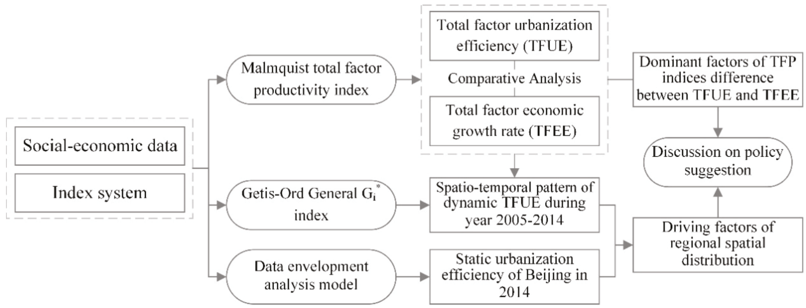


Figure 2. General framework of the study.

3.1. Data

We mainly used statistical data for this study. We obtained annual socioeconomic data pertaining to the index of urbanization efficiency and economic growth rate of each administrative area for the period 2005–2014 from the following data sources: the *Beijing Statistical Yearbook* for the years 2006–2015, the *Beijing Regional Statistical Yearbook* for the years 2006–2015, and the *Beijing Economic and Social Statistical Report* for the years 2005–2014 (see Table 1). These statistical reports are published by the Beijing Municipal Bureau of Statistics and the National Bureau of Statistics of China (CBS) survey office in Beijing. Additionally, we obtained some socioeconomic data on all 16 of Beijing's districts from the *Statistical Yearbook* published by the Bureau of Statistics.

Table 1. Descriptive statistics used in this study.

Factor	Mean	Standard Deviation (SD)	SD/Mean	Maximum	Minimum
Floor space of constructed buildings (10^4 km^2)	251.797	20.008	0.079	1426.800	18.400
Total investment in fixed assets (10^8 yuan)	306.920	22.206	0.072	1235.441	16.700
Foreign capital actually used (10^{10} USD)	382.749	53.210	0.139	3900.110	0.820
Employed persons (10^4 persons)	39.158	3.106	0.079	164.415	3.983
Financial expenditure (10^8 yuan)	131.733	8.770	0.067	593.370	17.055
Gross domestic product per capita (10^3 yuan/person)	55.130	3.545	0.064	234.430	13.796
Ratio of secondary industry and tertiary industry compared to gross domestic product (%)	95.271	0.379	0.004	102.387	82.155
Total retail sales of consumer goods (10^8 yuan)	357.667	36.594	0.102	2377.633	12.844

3.2. Index System

According to U. S. National Library of Medicine, Urbanization is the process whereby a society changes from a rural to an urban way of life. It refers also to the gradual increase in the proportion of people living in urban areas. However, the concept and standard definition of "urbanization" remains a subject of great dispute in China. Because the high urbanization of Beijing is due to rapidly increased floating population, it cannot be simply quantified as the level of urban development relative to the overall population.

Historical experience of modern urbanization development suggests that, at an early stage, the rural economy occupies a predominant position. Agricultural development provides the basic thrust for urban development and the urbanization process. Industrialization subsequently becomes the core factor influencing urbanization. Eventually, a transformation occurs in the development of the urban economy as it shifts from partial advantage to overall ascendance. During an advanced stage of urbanization, cities emerge as economic, technical, cultural, and commercial centers in a country. The propelling thrust for urbanization is now provided by the development of tertiary industry [29].

Based on a basic consideration of concept, identification and historical experience, urbanization creates enormous social, economic and environmental changes, which provide an opportunity for sustainability with the "potential to use resources more efficiently, to create more sustainable land use and to protect the biodiversity of natural ecosystems" [30]. Nevertheless, taking into account the difficulty of obtaining data, we choose the levels of economic urbanization and consumption as the index of the level of urbanization, which is commonly used in other studies [3,4,14].

The evaluation index system used to assess urbanization efficiency and the economic growth rate were derived from studies by Brülhart and Mathys [17]. We selected different forms of capital, i.e., material, human, land, financial, and foreign, as input factors to represent urban economic activities. Economic level was selected as the output factor for the economic growth rate. Levels of economic urbanization and consumption were selected as output factors for urbanization efficiency. Given the requirement of representative, authentic, and easily available index data, we selected the following input and output factors. For our input factors, we selected: the floor space of constructed buildings, X_1, as an index of land capital; total investment in fixed assets, X_2, as an index of material capital; foreign capital actually used, X_3, as an index of foreign financial; employed persons, X_4, as an index of human capital; and financial expenditure, X_5, as an index of financial capital. We selected the following output factors: Gross Domestic Product (GDP) per capita, X_6, as an index of the economic level; the ratio of secondary industry and tertiary industry compared to the GDP, X_7, as an index of the economic urbanization level; and total retail sales of consumer goods, X_8, as an index of the consumption level. The index system developed for the study is depicted in Table 2.

Table 2. Evaluation index system for assessing the economic growth rate and urbanization efficiency of Beijing.

Type of Index	Index Constitution	Description of Input/Output Factors
Input factors	Floor space of constructed buildings X_1	Land capital
	Total investment in fixed assets X_2	Material capital
	Foreign capital actually used X_3	Foreign financial
	Employed persons X_4	Human capital
	Financial expenditure X_5	Financial capital
Output factor for the economic growth rate	Gross domestic product per capita X_6	Economic level
Output factor for urbanization efficiency	Ratio of secondary industry and tertiary industry compared to gross domestic product X_7	Economic urbanization level
	Total retail sales of consumer goods X_8	Consumption level

3.3. Methodology

3.3.1. DEA Model

The DEA model developed by Charnes, Cooper, and Rhodes (CCR) [31] is a linear programming methodological tool that is used to measure the efficiency of multiple decision-making units when the production process presents a structure entailing multiple inputs and outputs. DEA has been applied within many industries to compare efficiency levels across firms. There are several types of DEA models, with the most basic one being the CCR version developed by Charnes et al. [31] in which efficiency is defined as a ratio of the weighted sum of outputs to the weighted sum of inputs. However, there are other DEA models that address varying returns to scale: constant returns to scale (CRS) and variable returns to scale (VRS). As the DEA-CCR model is a well-established model, we will not provide details about it here.

In our study, we used the DEA-CCR model to analyze the comprehensive efficiency, pure technical efficiency, and scale efficiency of Beijing's urbanization in 2014. Comprehensive efficiency refers to urbanization efficiency in relation to resource allocation, utilization, and scale concentration. Pure technical efficiency indicates the resource utilization efficiency of input factors. The scale efficiency indicates the efficiency of urban scale concentration.

3.3.2. Malmquist TFP Index

The Malmquist TFP index (MPI) is a formal time-series analytical technique used for comparing the performances of decision-making units over time [32]. MPI indicates whether there is an increase or decrease in efficiency with the progress or regress of frontier technology over time using a framework with multiple inputs and outputs. The DEA-Malmquist index has been used to evaluate growth in productivity within several fields. The MPI is calculated according to the following equation:

$$MPI_{t.\ t+1} = \left[\frac{d^t\left(x^{t+1}, y^{t+1}\right)}{d^t\left(x^t, y^t\right)} \times \frac{d^{t+1}\left(x^{t+1}, y^{t+1}\right)}{d^{t+1}\left(x^t, y^t\right)}\right]^{\frac{1}{2}} \tag{1}$$

where $\left(x^t, y^t\right)$ and $\left(x^{t+1}, y^{t+1}\right)$ are the allocation of production inputs and outputs during the time periods t and t + 1, and $d^t\left(x^t, y^t\right)$ is the distance function indicating the distance between $\left(x^t, y^t\right)$ and the production frontier during time period t. The value of $d^t\left(x^t, y^t\right)$ can be calculated using the following equation:

$$\left\{\begin{array}{l} d^t\left(x^t, y^t\right) = min\theta \\ \left(C^2R\right)_{s.\ t.}\left\{\begin{array}{l} \sum\limits_{j=1}^{n} x_j^t \lambda_j \leq \theta x_k^t \\ \sum\limits_{j=1}^{n} y_j^t \lambda_j \geq y_k^t \\ \lambda_j \geq 0,\ j = 1, 2, \ldots, n \end{array}\right. \end{array}\right. \tag{2}$$

where the distance function $d^t\left(x^t, y^t\right)$ is the efficiency function $F^t\left(x^t, y^t\right)$ of an input-oriented DEA model, that is, $d^t\left(x^t, y^t\right) = F^t\left(x^t, y^t\right)$. Therefore, MPI can be presented in the following form:

$$MPI_{t.\ t+1} = \left[\frac{F^t\left(x^{t+1}, y^{t+1}\right)}{F^t\left(x^t, y^t\right)} \times \frac{F^{t+1}\left(x^{t+1}, y^{t+1}\right)}{F^{t+1}\left(x^t, y^t\right)}\right]^{\frac{1}{2}} = \frac{F_t^{t+1}\left(x^{t+1}, y^{t+1}\right)}{F_t^{t+1}\left(x^t, y^t\right)} \tag{3}$$

where MPI is the index of efficiency change from time period t to time period t + 1. It can reflect a change of TFP. This equation can be decomposed into the following equation:

$$\begin{aligned} MPI_{t.\ t+1} &= \left[\frac{F^t\left(x^{t+1}, y^{t+1}\right)}{F^t\left(x^t, y^t\right)} \times \frac{F^{t+1}\left(x^{t+1}, y^{t+1}\right)}{F^{t+1}\left(x^t, y^t\right)}\right]^{\frac{1}{2}} \\ &= \left[\frac{F^t\left(x^{t+1}, y^{t+1}\right)}{F^{t+1}\left(x^{t+1}, y^{t+1}\right)} \times \frac{F^t\left(x^t, y^t\right)}{F^{t+1}\left(x^t, y^t\right)}\right]^{\frac{1}{2}} \times \frac{F^{t+1}\left(x^{t+1}, y^{t+1}\right)}{F^t\left(x^t, y^t\right)} \end{aligned} \tag{4}$$

Moreover, the above equation can be decomposed into equations for calculating the technical change (TC) and efficiency change (EC) as follows:

$$TC_{t.\ t+1} = \left[\frac{F^t\left(x^{t+1}, y^{t+1}\right)}{F^{t+1}\left(x^{t+1}, y^{t+1}\right)} \times \frac{F^t\left(x^t, y^t\right)}{F^{t+1}\left(x^t, y^t\right)}\right]^{\frac{1}{2}} \tag{5}$$

$$EC_{t.\ \ t+1} = \frac{F^{t+1}\left(x^{t+1}, y^{t+1}\right)}{F^{t}\left(x^{t}, y^{t}\right)} \quad (6)$$

If the TC index value is greater than 1, this indicates positive technical progress from the time period t to time period t + 1, whereas a value that is below 1 indicates negative, that is, lack of technical progress. If the EC index value is greater than 1, this indicates an improvement in efficiency from time period t to time period t + 1, whereas a value that is below 1 indicates a decrease in efficiency. If the MPI index value is greater than 1, this indicates positive MPI growth from time period t to time period t + 1, whereas a value below 1 indicates a decrease in MPI growth or performance relative to the previous year.

Based on the MPI index values, the contribution rates of technical progress, efficiency improvement, resource allocation, resource utilization, and scale concentration on urbanization efficiency and economic growth rate were analyzed, as discussed in the following section.

3.4. Getis–Ord General G_i^* Index

The General G_i^* statistic relating to overall spatial association is given as:

$$G_i^* = \frac{\sum_{j=1}^{n} w_{ij}(d) x_j}{\sum_{j=1}^{n} x_j}, \forall\, j \neq i \quad (7)$$

where x_j denotes attribute values for feature j; w_{ij} is a spatial weight matrix with ones for all links defined as being within distance d of a given feature i; n denotes the number of features in the dataset; and $\forall\, j \neq i$ indicates that features i and j cannot be the same [33].

If the value of the General G_i^* index is greater than 0, this indicates that the urbanization efficiency of features surrounding feature i is relatively higher, demonstrating high clustering. Conversely, a value that is below 0 indicates that the urbanization efficiency of features surrounding feature i is relatively lower, demonstrating low clustering.

4. Results and Discussion

4.1. Comparison of Beijing's Urbanization Efficiency and Economic Growth Rate for the Period 2005–2014

TFEE values fluctuated annually, mostly ranging between 0.852 and 1.111. During the decade 2005–2014, they evidenced little annual change, and the average TFEE value was 0.979 for this decade. This result indicates that the economic growth rate remained stable, approximating an effective balance.

TFUE values also fluctuated annually, evidencing a generally positive trend. The TFUE value increased from 0.903 during the period 2005–2006 to 0.906 during the period 2012–2013, with one exceptional period from 2013 to 2014 when the TFUE value was 0.898 (see Figure 3). There was an average overall increase of 1.07%, indicating a continual improvement in urbanization efficiency during the last decade. This result matches that of Zhao [34], which showed a tendency for Beijing's urbanization level to increase annually between 2005 and 2012. However, during this period, the TFUE values were below 1 with the exception of the period 2011–2012. This result indicates that even though the economy experienced rapid growth between 2005 and 2014, urbanization efficiency was still in a state of low efficiency that would also lead to a loss of efficiency.

The difference between the TFEE and TFUE values was above 0 except for the period 2011–2012, indicating that urbanization efficiency in relation to the economic growth rate was still low, causing a significant lag. Therefore, the imbalance between the economic growth rate and urbanization efficiency was marked. Zhao et al. [34] showed that rapid economic development was one of the most important factors affecting the evolution of urbanization in Beijing. Conversely, Zhao [6] indicated that, as in Western countries, rapid urbanization has greatly contributed to the promotion of economic growth and social wellbeing in Beijing. In our study, TFEE was relatively stable during the study period, and the increase in the TFUE did not depend on the economic growth rate.

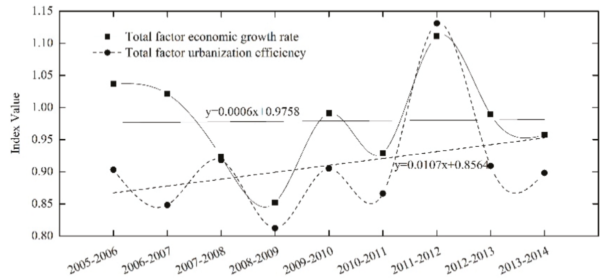
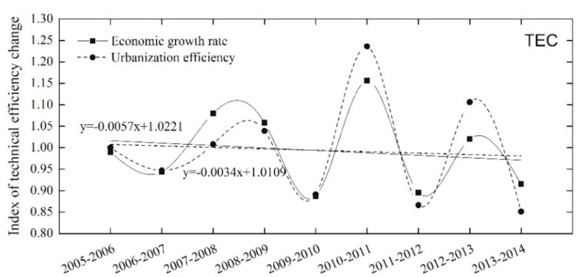


Figure 3. Dynamic trend of the total factor urbanization efficiency (TFUE) and total factor economic growth rate (TFEE).

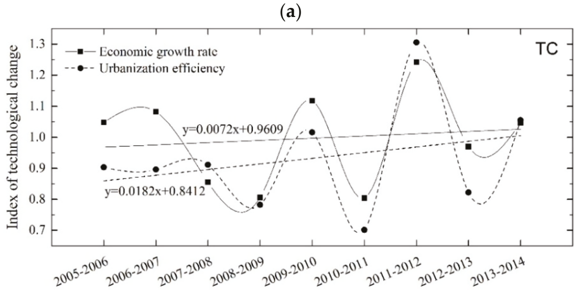
The same decreasing trend was found for the TEC of urbanization efficiency and the economic growth rate (see Figure 4a). The average values of TFUE and TFEE were also the same at 0.9938.

Figure 4c shows that the pure technical efficiency change (PTEC) of urbanization efficiency was comparable to that of the economic growth rate with the exception of the period 2007–2008. However, the PTEC of urbanization efficiency demonstrated a positive tendency, whereas the PTEC of the economic growth rate demonstrated a slightly decreasing trend.

There were only slight differences between the TEC and PTEC, with TC and SEC being the key factors influencing the difference in TFP indices between TFUE and TFEE (see Figure 4b,d). The TC of the economic growth rate was higher than that of the urbanization efficiency with the exception of the periods 2007–2008 and 2011–2012. This indicates that the TC of urbanization efficiency has not been well optimized. The SEC trends of the economic growth rate and urbanization efficiency showed periodic fluctuations in sine and cos waves with rapid decreases of 0.29% and 1.24%, respectively. This result implies decreasing returns to scale of urbanization efficiency in Beijing. Evidently, a pattern of extensive development is inappropriate for Beijing and cannot promote urbanization efficiency in the long term.

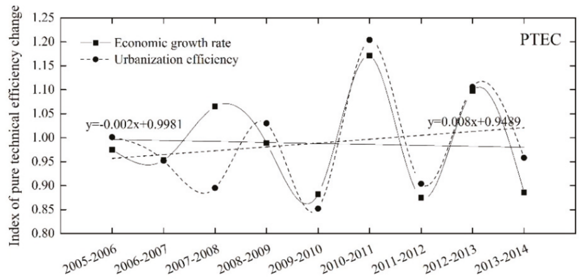


(**a**)

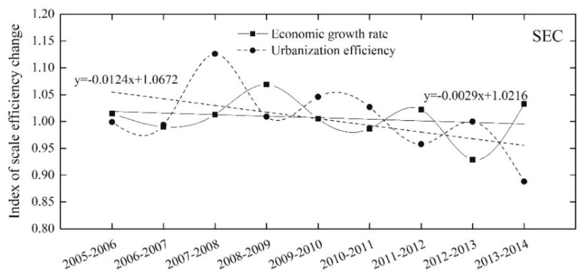


(**b**)

Figure 4. *Cont.*



(**c**)



(**d**)

Figure 4. TEC (**a**); TC (**b**); PTEC (**c**); and SEC (**d**) trends for urbanization efficiency and the economic growth rate.

The values of TFUE and TFEE in CFC were higher than 1 on the major functional area scale except for the period 2010–2011 (see Table 3). This finding indicates significant levels of urbanization efficiency and economic growth, with high inputs and outputs. The TFEE value was lower than that of the TFUE in the CFC during seven periods, indicating that rapid economic growth could no longer drive urbanization efficiency. The same trend that occurred for the CFC was found for the UFD for four periods from 2007 to 2010 and from 2011 to 2012. Further, the TFUE of the UFD, CDZ, and ECD areas was below 1 for most periods.

Table 3. TFUE and TFEE in Beijing during the period 2005–2014.

Period	Capital Function Core (CFC)		Urban Function Development (UFD)		City Development Zone (CDZ)		Ecological Conservation Development Area (ECD)	
	TFEE	TFUE	TFEE	TFUE	TFEE	TFUE	TFEE	TFUE
2005–2006	1.386	1.424	0.931	0.864	1.004	0.820	1.071	0.887
2006–2007	1.111	1.146	0.896	0.798	0.938	0.664	1.240	1.050
2007–2008	1.002	1.118	0.952	1.008	1.070	0.983	0.811	0.796
2008–2009	1.137	1.188	0.821	0.887	0.760	0.636	0.928	0.874
2009–2010	1.407	1.789	0.926	0.942	0.826	0.676	1.156	0.938
2010–2011	0.967	0.921	1.083	0.936	1.114	1.089	0.788	0.768
2011–2012	1.298	1.420	0.870	0.910	0.918	0.891	1.798	1.861
2012–2013	1.213	1.376	0.889	0.865	0.952	0.833	1.088	0.912
2013–2014	1.087	1.048	0.916	0.913	0.930	0.813	1.032	0.969

In 2005, the State Council approved the re-revised *Beijing Urban Master Plan (2004–2020)*, which was aimed at initiating a strategy for developing a "Center City–New Town–Town (including the key towns and general towns)" structure. In 2011, the municipal government of Beijing proposed a strategy for developing a "Center City–New Town–Small Town–the New Rural Communities" structure [34]. In view of conditions in the UFD, CDZ, and ECD areas, the optimal choice for local governments was to strengthen policy support for a novel development path, differing from that of traditional development, to encourage investments in technology for a fixed asset, and to introduce social capital for advancing urbanization in rural areas. This strategy is expected to promote local economic development, simultaneously enhancing the level of urbanization.

4.2. Spatial Pattern of Total Factor Urbanization Efficiency in Beijing

Beijing's urbanization efficiency has a remarkable regional spatial distribution, showing a decreasing trend from north to south apart from CFC areas. The average TFUE values were 1.235, 0.887, 0.804, and 0.924 in the CFC, UFD, CDZ, and ECD areas, respectively, and the TFUE values varied from 0.738 to 1.242 (see Table 4). Evidently, the TFUE in the CFC area was very high, whereas this value for other regions of Beijing was just 0.873. In the districts of Yanqing, Huairou, Miyun, and Pinggu in northern Beijing, the average TFUE value was 0.947, which was higher than the TFUE value (0.794) in Fangshan, Daxing, and Tongzhou districts of southern Beijing. The TFUE value for 12 districts was lower than 1, which strongly indicated inefficient factor allocation in these districts.

Table 4. Malmquist TFP index and decomposition of 16 districts in Beijing for the period 2005–2014.

District	Technical Efficiency Change (TEC)	Technical Change (TC)	Pure Technical Efficiency Change (PTEC)	Scale Efficiency Change (SEC)	Total Factor Productivity (TFP)
Dongcheng	1.069	1.162	1.000	1.069	1.242
Xicheng	1.099	1.118	1.000	1.099	1.228
Chaoyang	0.973	0.877	0.945	1.030	0.854
Fengtai	0.965	0.896	0.957	1.009	0.865
Shijingshan	1.000	0.885	1.000	1.000	0.885
Haidian	1.027	0.918	1.000	1.027	0.943
Fangshan	0.970	0.876	1.040	0.933	0.850
Tongzhou	0.923	0.860	0.949	0.973	0.794
Shunyi	0.952	0.882	0.978	0.974	0.840
Changping	0.929	0.858	0.946	0.982	0.797
Daxing	0.891	0.828	0.922	0.967	0.738
Mentougou	1.003	0.831	1.000	1.003	0.834
Huairou	1.014	0.895	1.000	1.014	0.908
Pinggu	0.995	0.870	0.992	1.003	0.866
Miyun	1.002	1.003	1.020	0.982	1.004
Yanqing	1.000	1.009	1.000	1.000	1.009
Mean	0.987	0.918	0.984	1.003	0.906

There was little difference in the TEC, PTEC, and SEC values for the Malmquist efficiency decomposition compared with the TC in different parts of Beijing during the period 2005 to 2014. The PTEC and SEC values in the 16 districts of Beijing ranged from 0.922 to 1.040 and from 0.933 to 1.099, respectively. These results suggest that pure technical efficiency and scale efficiency in the 16 districts approached the highest level. TEC values were also relatively similar apart from those for Daxing, Tongzhou, and Shunyi districts of southeastern Beijing. Therefore, TC was the driving factor of TFP that led to a remarkable regional spatial distribution (see Table 4 and Figure 5). In Dongcheng, Xicheng, Miyun, and Yanqing districts, the TC value was higher than 1, whereas with the exception of Haidian District, which had a TC value of 0.918, the TC of the other districts was lower than 0.9. In these latter districts, a lower level of technology was associated with a dramatic decline in urbanization efficiency. This distribution was strongly correlated with the regional spatial distribution of TFP.

Because urbanization efficiency was evidently imbalanced, neighborhood distances were used for measuring the Getis–Ord General G_i^* index, which indicates a concentration of high and low values for an entire study area. We selected the following three typical time periods: 2005–2006, 2009–2010, and 2013–2014. TEC, TC, and TFP, which were the mean driving factors for regional spatial distribution discussed above, were measured using the Getis–Ord General G_i^* index (see Figures 6–8).

High value TEC clusters were mainly located in central and northern Beijing (see Figure 6). The CFC area and Mentougou were found to be consistently high value cluster regions, whereas Daxing, Fangshan and Fengtai in southern Beijing, Changping in the central-northern part of Beijing, and Tongzhou in eastern Beijing were consistently low or sub-low value cluster regions during the period 2005–2014. Huairou, Miyun, and Yanqing in northern Beijing also evidenced high value clusters during the periods 2009–2010 and 2013–2014.

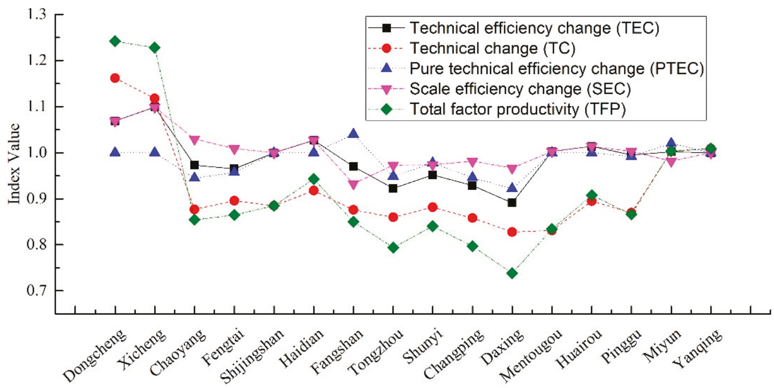


Figure 5. Malmquist efficiency index and decomposition of the 16 districts in Beijing for the period 2005–2014.

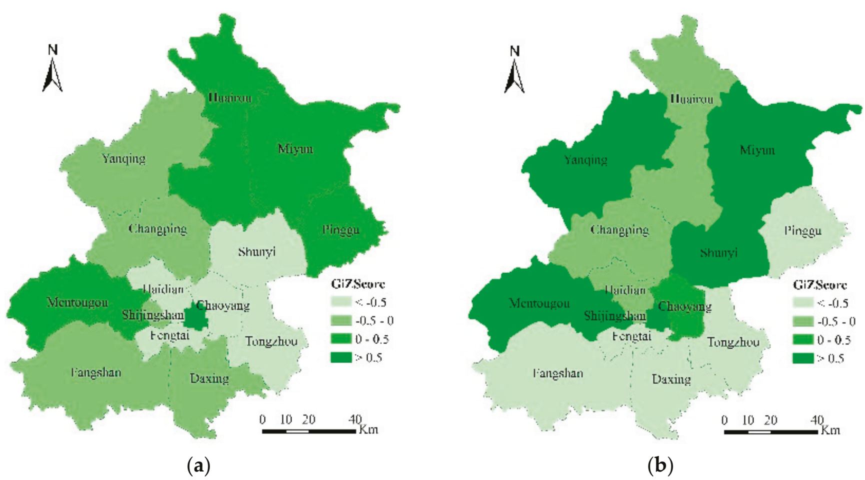
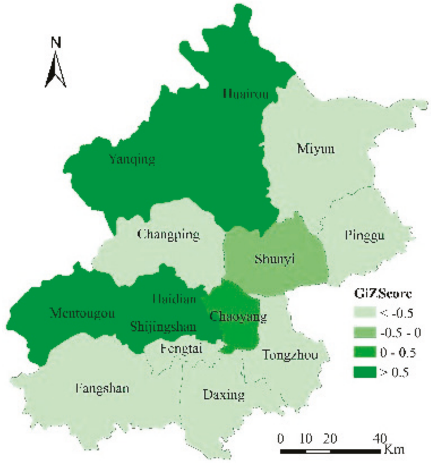


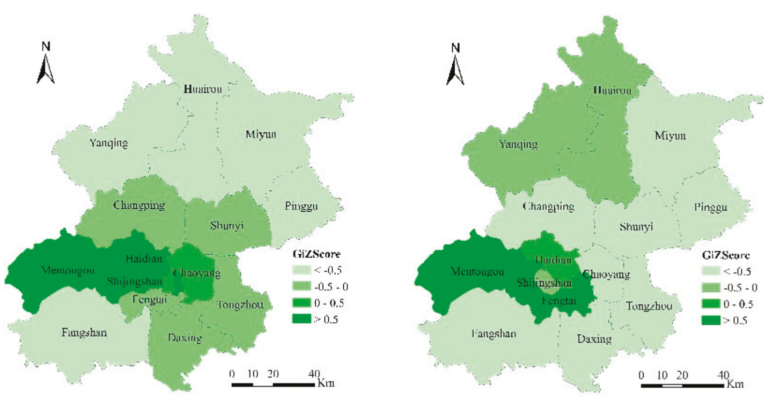
Figure 6. *Cont.*



(**c**)

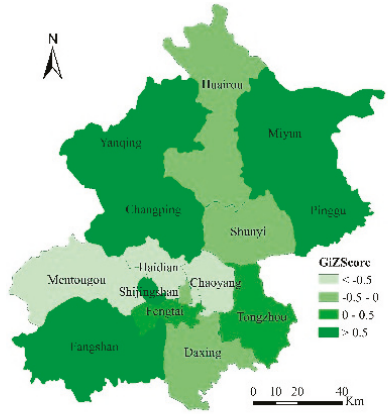
Figure 6. The spatial pattern of the G_i^* index of TEC during the period 2005–2014: (**a**) 2005–2006; (**b**) 2009–2010; and (**c**) 2013–2014.

Dongcheng, Xicheng, Shijingshan, Haidian, and Mentougou districts in central Beijing were high TC value cluster regions during the periods 2005–2006 and 2009–2010, whereas these districts transformed into low TC value cluster regions during the period 2013–2014. This shift could be related to investments made through several major projects, including the Zhongguancun Science Park in northern Beijing and the Olympic Games Park, which provided further impetus for improving TC [35]. Yang [27] and Zhang [36] found that the urbanized territory dramatically expanded along the 5th Ring Road, initially in a northerly direction during 1990s. After 2009, this expansion also spread to the south. However, the TC distribution in areas surrounding central Beijing, notably Fengtai, Fangshan, Tongzhou, and Changping, and those surrounding northern Beijing, namely Pinggu, Miyun, and Yanqing, showed the opposite pattern of distribution. Moreover, during the period 2005–2014, Daxing, Shunyi, and Huairou districts remained low or sub-low TC value cluster regions.



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

Figure 7. *Cont.*

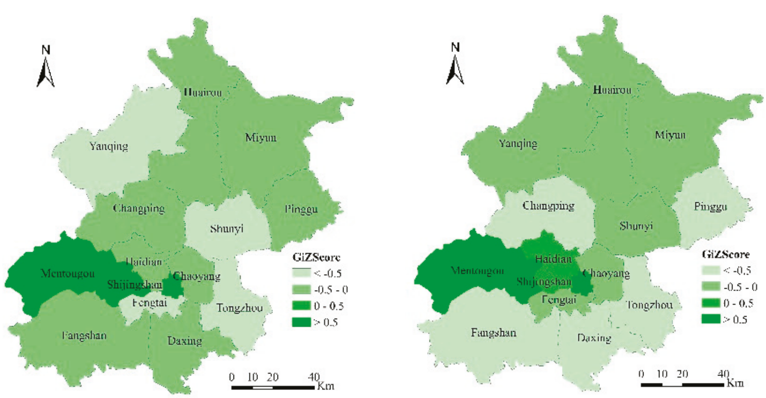


(**c**)

Figure 7. Spatial pattern of the G_i^* index of TC during the period 2005–2014: (**a**) 2005–2006; (**b**) 2009–2010; and (**c**) 2013–2014.

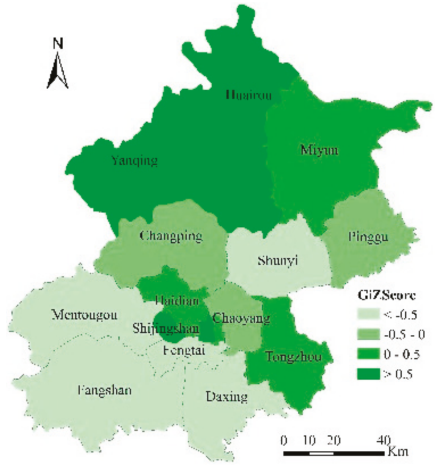
The TFP distribution demonstrating high index values gradually shifted from Mentougou and Shijingshan in western Beijing to Tongzhou, Yanqing, and Huairou in northeastern Beijing. Urban-rural development was, in general, poorly coordinated in Beijing [28,34], so the index values in the CFC area remained high, while low or sub-low TFP values were found in Daxing, Fangshan, and Fengtai in southern Beijing and in Changping, Shunyi, and Pinggu in central-northern Beijing during the period 2005–2014. Therefore, TFP distribution was strongly correlated with TC distribution and was also affected by TEC distribution.

We can conclude that the CFC area and northeastern Beijing are gradually evolving into high urbanization efficiency cluster regions. TC and TEC are the main factors driving the remarkable regional spatial distribution pattern for urbanization efficiency. Hence, the county government in southern Beijing should pay more attention to improving TC and TEC values to enhance urban competitiveness. However, the maintenance of high levels of development in the city is indicative of its ability to calibrate unbalanced regional development where it occurs [34].



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

Figure 8. *Cont.*



(**c**)

Figure 8. Spatial pattern of the G_i^* index of TFP during the period 2005–2014: (**a**) 2005–2006; (**b**) 2009–2010; and (**c**) 2013–2014.

4.3. Static Measurement of Beijing's Urbanization Efficiency in 2014

Based on our DEA-CCR model, we measured the comprehensive efficiency (TEC), PTEC, and SEC of Beijing's urbanization in 2014. The average values of TEC, PTEC, and SEC for this period were 0.625, 0.717, and 0.837, respectively.

Dongcheng, Xicheng, Shijingshan, Mentougou, and Yanqing demonstrated an effective balance of TEC and SEC, whereas these levels were not optimal in the remaining 11 districts (see Table 5). PTEC was effectively balanced in Huairou as well as in the five districts identified above. The number of districts demonstrating an effective balance relating to PTEC was higher than those with an effective balance of TEC and SEC.

Table 5. Static urbanization efficiency of 16 districts in Beijing in 2014.

District	Comprehensive Efficiency (TEC)	Pure Technical Efficiency (PTEC)	Scale Efficiency (SEC)	Returns to Scale
Dongcheng	1.000	1.000	1.000	-
Xicheng	1.000	1.000	1.000	-
Chaoyang	0.249	0.308	0.808	drs *
Fengtai	0.382	0.551	0.693	drs
Shijingshan	1.000	1.000	1.000	-
Haidian	0.300	0.391	0.767	drs
Fangshan	0.447	0.858	0.521	drs
Tongzhou	0.315	0.410	0.767	drs
Shunyi	0.342	0.439	0.778	drs
Changping	0.344	0.598	0.575	drs
Daxing	0.219	0.302	0.726	drs
Mentougou	1.000	1.000	1.000	-
Huairou	0.950	1.000	0.950	drs
Pinggu	0.756	0.764	0.990	irs **
Miyun	0.696	0.846	0.822	drs
Yanqing	1.000	1.000	1.000	-
Mean	0.625	0.717	0.837	-

* drs is short for decreasing returns to scale; ** irs is short for increasing returns to scale.

Of the remaining 11 districts, TEC values were below 0.5 in eight districts, with the lowest value (0.219) recorded for Daxing. This finding suggests inefficient factor allocation with 21.9% of optimal level. PTEC values were below 0.5 in five districts, with the lowest value (0.302) recorded for Daxing. There was no SEC value below 0.5, with the lowest value (0.521) being that of Fangshan. These results indicate that PTEC and SEC were not well optimized in most districts in 2014.

PTEC was lower than SEC in Chaoyang, Fengtai, Haidian, Tongzhou, Shunyi, Daxing, and Pinggu, indicating that the urbanization efficiency of these seven districts was driven by scale efficiency. These districts should therefore raise their PTEC levels. Conversely, PTEC values were higher than SEC values in Fangshan, Changping, Huairou, and Miyun, indicating that the urbanization efficiency of these four districts was driven by pure technical efficiency. These districts represented diseconomies of scale.

With the exception of Pinggu, all those districts with an ineffective balance of TEC and SEC evidenced decreasing returns to scale. This finding indicates that input resources exceeded the districts' capacities. Solely enhancing the scale of investment of elements could adversely affect an increase of urbanization scale efficiency and even halt it completely in the future. Moreover, apart from Pinggu, the other six districts with Chaoyang, Fengtai, Haidian, Tongzhou, Shunyi and Daxing, whose urbanization efficiency is driven by scale efficiency, demonstrated decreasing returns to scale. This extensive development is, however, still unreasonable and does not promote sustainable urbanization efficiency.

Accordingly, we recommend that county governments promote efforts to reduce input redundancy and improve pure technical efficiency to maintain sustainable and steady development.

It is worth noting that the methods and evaluation index system applied in our study area have been used in European regions [17]. In recent studies, Fang et al. [37] and Lobo et al. [38] also used a similar index to study China's 23 Urban Agglomerations and US cities, respectively. Therefore, the framework of this evaluation index is credible. We only need to modify the index based on our research target, and then it will be applied in other countries.

5. Conclusions

During the period from 2005 to 2014, TFUE demonstrated wavelike rises in a low efficient state, while TFEE remained stable, approximating an effective balance. The increase of TFUE was not dependent on the economic growth rate. Therefore, urbanization efficiency at present remains low and has caused a significant lag in the economic growth rate. TC and SEC were found to be the dominant factors influencing the difference in the TFP indices between TFUE and TFEE. Consequently, local governments should promote changes in technology and scale efficiency to enhance the level of urbanization.

A spatial comparison of urbanization efficiency and the economic growth rate revealed significant levels of both TFUE and TFEE in the CFC area with high inputs and outputs, while these levels in the UFD, CDZ, and ECD areas were below 1 during most of the study periods. This finding strongly indicates inefficient factor allocation. As rapid economic growth can no longer drive urbanization efficiency in the CFC area, the optimal choice for local governments is to strengthen policy support and encourage the investment of technology in the UFD, CDZ, and ECD areas.

Urbanization efficiency evidenced a remarkable regional spatial distribution, showing a decreasing trend from north to south in Beijing, with the exception of CFC areas. During the period 2005–2014, the CFC area and northeastern Beijing gradually developed into high urbanization efficiency cluster regions. The main factors driving the remarkable regional spatial distribution of TFUE were TC and TEC. Consequently, the county government in southern Beijing should pay more attention to improving TC and TEC to enhance urban competitiveness.

In 2014, Dongcheng, Xicheng, Shijingshan, Mentougou, and Yanqing demonstrated an effective balance in relation to static urbanization efficiency, whereas these levels were not optimal in the remaining 11 districts, indicating extensive development. Therefore, we recommend that county governments promote efforts to reduce input redundancy and improve pure technical efficiency to maintain sustainable and steady development.

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How Have Political Incentives for Local Officials Reduced Environmental Pollution in Resource-Depleted Cities?

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Abstract: Chinese resource-exhausted cities face more severe environmental pollution problems than other cities. In addressing these problems, the way local officials (usually senior party and government leaders) operate is very important, as their focus on political achievements may complicate how they manage environmental pollution in these cities. On the one hand, the traditional Gross Domestic Product-based quest for political achievement may lead top leaders to de-emphasize environmental pollution. On the other hand, changes made in 2003 to the way the performance of Chinese officials is evaluated have encouraged some local senior party and government leaders to pay more attention to environmental problems. Based on this, we analyze the relationship between political incentives and environmental pollution by applying the 2004–2014 panel data from 37 resource-exhausted cities. The findings reveal that firstly, among the factors which impact the environmental pollution of resource-exhausted cities, investment in fixed assets, foreign direct investment, industrial structure, per-capita education expenditure, and population density do not have a significant impact, thus indicating that local openness levels, the degree of industrial upgrading, and local investment in fixed assets are not the key variables in environmental pollution control. Secondly, the extent to which officials vie for political achievement affects environmental pollution in resource-exhausted cities. This depends upon whether the officials are municipal party secretaries or mayors; the former play a greater dynamic role in environmental pollution and have stronger robustness than the latter. The conclusion verifies both the existing authority structure of China and its effectiveness in the control of environmental pollution of resource-exhausted cities. That is to say, in contrast to the principles of the party committees, the mayors are in a subordinate position and often fail to fully and effectively exercise their functions. Accordingly, we point out that the selection of municipal party secretaries, rather than mayors, is particularly important in coming to terms with local environmental pollution.

Keywords: municipal party secretaries; mayors; political incentives; resource-exhausted cities; environmental pollution

1. Introduction

According to the definition provided in Several Opinions on Promoting the Sustainable Development of Resource-exhausted Cities (GF (2007) No. 38), "resource-exhausted cities" are cities where development of mineral resources is already in a late stage and the accumulative recovered reserves have already exceeded 70% of recoverable reserves. There are a number of resource-depleted cities, such as Lorraine, Ruhr, and Montreal, which face difficulties such as the resource curse, unemployment, and environmental pollution. These are issues are of great concern to the academic community [1–6].

Compared with more developed countries, China faces serious problems with respect to resource-depleted cities. Among those problems, environmental pollution needs to be addressed most urgently. China established the first list of 12 resource-exhausted cities in 2008, including Fuxin, Shizuishan, and Baiyin. Based on the provisions of policy articles in 2009 and 2013, China now has 69 resource-exhausted cities and regions. Development in these cities (or regions) has brought about a serious problem of environmental pollution and this has become a barrier to urban transformation. We looked at data concerning 37 resource-exhausted cities from 2004 to 2014 and it was revealed that the average acreage of forest in built-up areas was far lower than that of the country overall, with the gap growing ever wider with time. The multipurpose waste utilization rate in 37 prefectural-level resource-exhausted cities in 2004 was 63.83%, while the rate for the whole country in the same year was 71.37%, indicating a notable increase. In terms of pollution emission, the average industrial fume emission rate in these cities in 2014 was 59,389.89 tons per city, far higher than the average yearly emission rate for cities in the country overall (43,783.12 tons). Under such circumstances, the transformation of resource-exhausted cities is an urgent task. Although China has promulgated several opinions from the State Council on Promoting the Sustainable Development of Resource-Based Cities (2007) and the Notice on the Transformation Evaluation of First Batch of Resource-Depleted Cities (2010), etc., future work is required with respect to the driving factors of environmental pollution.

Many studies confirm that both the characteristics and the incentives of officials often drive economic growth [7–13]. Similarly, local officials are also likely to play an important role in the pollution control of resource-exhausted cities. China has been carrying out the "championship system" of GDP for a very long time, that is to say, GDP is taken as one of the incentives for the promotion of officials. Against this background of central and local government fiscal decentralization, local officials also seek to advance their chances of promotion [14,15]. If, in resource-exhausted cities, party secretaries and mayors cooperate with each other, they may promote economic growth and employment. However, because this incentive system may result in only short-term economic growth, officials consider economic growth as more rewarding than the control of environmental pollution. This often aggravates environmental pollution. In 2003, Hu Jintao, the former General Secretary of the CPC of China, proposed "the scientific outlook on development", emphasizing the comprehensive, coordinated and sustainable development of the economy. The central government set aside its GDP-centered performance-based assessment of officials and began to focus assessment on environmental and ecological protection. In 2014, the General Office of the State Council printed and issued Performance Assessment Measures for Air Pollution Prevention and Control Action Plan (For Trial Implementation), marking the official establishment of both strict responsibility and assessment of management over the atmospheric environment in China. To a certain extent, paying attention to the ecological environment facilitates improvement in the environment of resource-exhausted cities.

As a whole, the changes to evaluation standards for local government officials show how control of environmental pollution in resource-exhausted cities can differ. Accordingly, based on respective consideration of senior local communist party committee and municipal government leaders, we attempt to answer the following questions: Do political incentives significantly impact the environments of resource-exhausted cities? What are the differences in their impacts?

The rest of this article is organized in the following way. First, hypotheses are put forward with regard to the impact of political incentives on environmental pollution in the resource-depleted cities. Second, a comparative study between the municipal party secretaries and the mayors is carried out.

2. Literature Overview and Theoretical Hypotheses

2.1. Literature Overview

Political incentives refer to the reelection or promotion of policy executives in exchange for loyalty to their superiors [16]. As for the political system of Chinese communist party, promotion/reelection is the most important political incentive for local cadres. The top-down cadre index evaluation system dominated by the organization department is used for the regular examination of party and government officials at all levels. This is an institutional arrangement reflecting the party's managing cadres and supervising local officials who implement the central policies. In contrast to material incentives for individuals, political incentives for officials are mainly embodied at the psychological level.

As mentioned above, the present literature on local political incentives is generally focused on economic growth, while research on urban resource development is focused on the weak economic growth of cities, reduced social and economic welfare [17], Dutch disease and concentration of manufacturing in the same region [18], low efficiency of resource utilization [19], and evaluation of environmental pollution in resource-oriented cities [20,21]. Research directly or indirectly related to this thesis is grouped into two types. The first type focuses on the relationship between political incentives for local officials (or local politics) and environmental pollution. The second type focuses on the pollution factors of resource-oriented cities.

Politics play a very important role in the projects of environmental improvement [22]. The political influence of lobby groups [23], government rent-seeking corruption [24], bureaucracy [25], and local policy agenda [26] are all manifestations of local politics, possibly producing impacts on environmental pollution. Among numerous manifestations of politics, little attention has been paid to the relationship between the political incentives and environmental pollution. According to Maskin [27], although officials in the administrative pyramid should first prioritize local fiscal revenue, they attach more importance to their promotion opportunities and their political careers. This implies that they are in pursuit of economic growth and overlook environmental improvement. As found by Zhou, being the incentive mode of government officials, promotion championship has not only brought rapid development to the Chinese economy, but also a series of problems to China, including environmental deterioration [28]. Similarly, Qiao [29] also held the opinion that China had a mechanism of official "promotion championships" with economic growth as a major part of the assessment. This mechanism is characterized by "layer-by-layer overcharge", that is to say, competition escalates gradually from top to bottom, and from the provincial to municipal level. Under this competitive mechanism, lower-level officials have a strong motive and desire to get promoted politically by developing the economy, and overlook environmental protection and improvement. Based on the provincial panel data from 2003 to 2011, Yu et al. [30] inferred that the claim for political achievement was an important factor that results in the frequent occurrence of environmental accidents in their administrative areas. Based on investigation, Ran [16] found that the opportunities for flow and promotion for officials in departments of environmental protection were far fewer than for those for officials in core government departments with economy as their major function. This phenomenon indicates that although the central government presently encourages local officials to improve the environment rather than developing the economy as a systematic mode of political incentives for cadre assessment, this assessment system is obviously characterized by a "pressure-based system", which tends to make local officials try their utmost to show their own political achievements to their superiors through superficial and visible "economic achievements", namely "political achievement engineering", thus overlooking environmental protection. Taking municipal party secretaries and mayors of 109 Chinese cities as samples, Zhang and Lu revealed that the vertical exchange of officials was not conducive to improving the quality of urban environment. The environmental performance incentives were ineffective because the vertical exchange officials had the advantage of political promotion [31]. Some scholars studied political incentives with respect to decentralization of the central and local governments. For example, James et al. showed that decentralization made local governments lower environmental standards in order to obtain competitive capital. This would probably promote the rapid development of regional economy while aggravating pollution [32–34]. Employing regional air data in the year 1999 and 2000, Konisky and Woods investigated the impact of decentralization on environmental pollution. They found that decentralization contributed to pollution level across the countries and borders [35]. Political incentives may also reduce pollution. Oates argued that the lateral government competition could provide effective regional public service, which would reduce regional environmental pollution [36]. According to Sigman's studies, decentralization was negatively correlated with regional water pollution [37].

There are number of factors influencing environmental pollution in resource-depleted cities, which mainly include industrialization or natural resources. For example, Fang and Chen established a model using the panel data of prefecture-level resource-depleted cities between 2003 and 2011 to analyze the impact of industrialization, fixed asset investment, economic growth, urbanization, and technological progress on environmental pollution [38]. Tang et al. [39] and Liang et al. [40] examined the polluting elements of Chinese coal cities. The former investigated the pollution characteristics of heavy metals in Huai'nan, and held the opinion that metal dust mainly came from industrial emissions, vehicle-related activities, coal dust, natural soil weathering, and coal burning. The latter authors revealed with the case of Lianyuan City in Hunan Province that industrial activities, natural resources, aerial sediment, and agricultural activities are important pollution factors of this coal-mining city. Miners are also of concern to some scholars, for example Li et al. [41] and Zeng et al. [42]. Li et al. employed data from 1999 to 2013 and used a data envelopment analysis model to assess the post-transformation development of Jiaozuo City. Therein, input indicators included quantity of year-end work staff, investment in fixed assets, local fiscal expenditure, annual water consumption, and annual power consumption. Environmental development is one of the output indicators. Zeng et al. investigated the environmental, economic, and social features of these cities, and found out that most of coal-mining cities have a large percentage of mining practitioners, implying a stern challenge for reducing the emission of dust pollution. Evidently, similar to the opinions of Fang and Chen, Li et al. argued that fixed asset investment was also an important factor.

As a whole, a number of studies on the relationship between political incentives and environmental pollution in the general cities, or the factors causing pollution in resource-oriented cities have been conducted, but regrettably, few scholars have paid attention to the political incentives in resource-exhausted cities. This gap will be filled, which is our major contribution.

2.2. Theoretical Hypotheses

The attention paid by the Chinese government to ecology has gone through a process of evolution. In the early period, under the impact of orientation to GDP and the reform of fiscal decentralization, and driven by political achievements, officials were able to, on the one hand, promote the rate of economic growth of resource-exhausted cities and solve local employment problems in local resource-based enterprises. However, on the other hand, due to the pursuit of GDP and fiscal decentralization, officials tended to neglect environmental protection. After Hu Jintao came into power, the emergence of the idea of scientific outlook on development, to some extent, changed the standards for assessing the political achievements of officials. In contrast, under the rule of Xi Jinping, attention has also been paid to ecological civilization.

In theory, the complicated impacts of political incentives on the environmental improvement of resource-exhausted cities are also embodied in the comparison of the effects of "the last attempt" and "tranquil life". "The last attempt" refers to the phenomenon whereby local officials take measures to control environmental pollution before leaving their office. The "tranquil life" is the opposite phenomenon, whereby local officials have no desire to improve environmental quality at the end of their terms. In China, the engagement system of Party and government leading cadres is explicitly stipulated in Article 40 of Chapter 7 of The Work Regulations on the Selection and Appointment of Party and Government Leading Cadres. There is an explicit provision in Article 40 "*The System of Engagement is Tentatively Implemented among some Professional Leading Positions in Party and Governmental*

Organs": Under the system of engagement, each term for a leading position shall last no more than five years, but re-engagement can be carried out upon the expiry of the term. In general, almost all local officials desire to serve two terms of office in succession or be promoted to a higher level of administration. Along with the extension of terms of office, especially within the second term of office, political incentives are weakened relatively. This is particularly true with regard to those officials whose probability of promotion is small and who face the auditing of economic responsibility before leaving their office, and for whom a "tranquil life" is the optimal choice for their remaining political career. Such cases tend to be unfavorable for the environmental improvement of resource-exhausted cities. The opposing viewpoint suggests that, before leaving their office, officials also have the impetus to expand investment, and respond to promotion assessment by triggering economic growth and controlling environmental pollution, and in so doing, make "a last-ditch attempt" at a promotion. Therefore, Hypothesis 1 is put forward:

Hypothesis 1 (H1). *The longer an official has been in his current post (i.e., the closer he/she is to the end of their term), the stronger his or her incentive for political achievements, which will facilitate the environmental improvement of resource-exhausted cities.*

In China, the top leaders in local governments are mayors and municipal party secretaries. Although they are at the same administrative level, municipal party secretaries are officials within the party, as the top leaders in the municipal party committees. In contrast, mayors are the top leaders in municipal governments. The party committees are chiefly responsible for publicizing the guidelines, policies, routes and ideas of the party, leading and supervising the normal operation of other institutions, ensuring the implementation of the guidelines, policies, routes and ideas of the party, and deciding on important topics related to local social affairs at the same time. In contrast, municipal governments are mainly responsible for administrating urban affairs according to laws (the constitution, laws, administrative regulations and local regulations). Under the current administrative system of China, party committees are in charge of the governments. Therefore, in theory, municipal party secretaries play a more significant role than mayors in the environmental improvement of resource-exhausted cities.

Hypothesis 2 (H2). *In comparison with mayors, the political incentives for municipal party secretaries produce more remarkable impacts on the environmental pollution of resource-exhausted cities.*

3. Model and Variable Selection

3.1. Model and Variables

As there are 37 samples and the time span is between 2004 and 2014, it is reasonable to use the panel data model to analyze the factors influencing explained variables. Equation (1) is built and the impacts of political incentives for the local officials are examined:

$$\mathrm{InY_{it}} = \alpha_0 + \beta \mathrm{Perf_{it}} + \lambda \mathrm{Control_{it}} + \varepsilon_{it} \quad (1)$$

where i denotes various resource-based cities, and t represents years. Y and Perf denote the explained variable (the environmental pollution indicators of resource-exhausted cities) and the explaining variable (the political incentives). There are different methods to measure environmental pollution. Yu et al. [43] carried out principal component analysis to five indicators, including unit SO_2 emissions, unit smoke emission, unit waste water emissions, unit industrial waste gas emissions, and unit industrial solid waste emissions, obtaining the local overall level of environmental pollution. Zheng et al. [44] and Wu et al. [45] used PM10 concentration and PM2.5 to measure the degree of environmental pollution. In the opinion of this thesis, based on the availability and conciseness principles of Chinese data, SO_2 emissions are selected, because integrated indicators will distort some information after principal component analysis. The measurement scales of political achievements of officials chiefly include: the difference between the actual average growth rate of accumulative GDP of a given official in office and the actual average growth rate of average GDP of his/her predecessor, and the amount of investment in control of environmental pollution [46]. However, these indicators, to a certain extent, display the results of political achievements, rather than standing in for political ambition or desire for political achievement. We draw on the opinion of Li and Zhou [14], and use the office-serving term of mayors or municipal CPC committee secretaries to measure the key explanatory variables, namely, the political incentives for the officials. This is because of following consideration: When an official is not promoted when his/her term of office is about to expire or when he/she is about to be 65 years old, the objective function of his/her decision-making may change, thus influencing the environmental pollution control of resource-exhausted cities.

The control variables are as follows. Firstly, there is investment in fixed assets (fixed). In the investment structure of fixed assets, if the investment in energy saving and emission reduction accounts for a large percentage, this will help reduce environmental pollution to a certain extent; on the other hand, if investment, for example, is in the heavy chemistry industry and accounts for a large percentage, pollution will be aggravated. Secondly, the percentage of the amount of foreign direct investment in regional GDP (Fdi) is used to control the impacts of the differences in degrees of openness and market orientation on environmental pollution. Foreign direct investment produces some impacts on the environmental pollution of developing countries [47]. In order to attract foreign companies and capital, local officials lower environmental standards, which may, as GDP rises, aggravate environmental pollution. Although this is true, the introduction of some foreign capital may actually also bring in advanced technology to prevent and control environmental pollution. Thirdly, there is the industrial structure (Indus). The value of tertiary industry as a percentage of output is used to measure industrial structure. The higher the value, the more effective the lowering of environmental pollution levels. Fourthly, there is per-capita educational expenditure (Edup). The higher the per-capita educational expenditure, the more attention is paid to the environment. This occurs with rises in staff knowledge, educational levels, and academic levels, and forces the local government to make control of environmental pollution a priority. Fifthly, there is population density. The larger the population density, the larger the population per square kilometer is, and the higher the local environmental pressure. Sixthly, the personalities of officials include their previous work history, terms of office, and age. Here, "government officials with backgrounds in companies" (Company) refers to municipal party secretaries or mayors who once served as party committee secretaries, factory directors, board chairmen, or general managers or assumed other important posts in enterprises. The term, however, excludes deputy posts, middle-level cadres, or lower posts in general. Government officials with enterprise background tend to boast greater experience in environmental protection. The term "Improve" refers to the level of improvement made locally by officials. The officials' major (Major) in postgraduate school may also affect environmental pollution in the resource-depleted cities. An official with a major in economics or management will be more aware of the importance of industrial upgrading and is more likely to take measures to control pollution. The term "Cons" is the constant term. In order to reduce the impact of price changes, we have adjusted the above-mentioned control variables for inflation, starting with 2004 as the base year.

3.2. Data Source

The starting year of 2004 for this study is the year following which Hu Jintao introduced the concept of scientific development, and correspondingly the duration of our research is from 2004 to 2014. The data of the environmental pollution of resource-exhausted cities come from The Statistical Yearbook of Chinese Cities (2005–2015). In 2013, the State Council promulgated The Plan for the Sustainable Development of Chinese Resource-based Cities (2013–2020), in which 262 resource-based cities are defined, 69 of which are resource-exhausted ones. Restricted by the difficulty in obtaining the data of county-level cities and lower administrative levels, we consider only prefectural cities (a total of 37).

The term of office, age, and other personality data of municipal party secretaries and mayors come from Baidu, people.com.cn, xinhuanet, and local government websites. It should be noted that the number of office-holding years of local officials is calculated from the current year if they take office during first half of a given calendar year. Otherwise, the starting year is the following year.

4. Empirical Results and Discussion

4.1. Descriptive Statistical Analysis

A descriptive statistical analysis is conducted. As shown in Figure 1, from 2004 to 2014, the average value of SO_2 emissions of the 37 resource-exhausted cities was 77,517 tons per city, with the minimum and maximum values being 1245 tons and 331,863 tons, respectively.

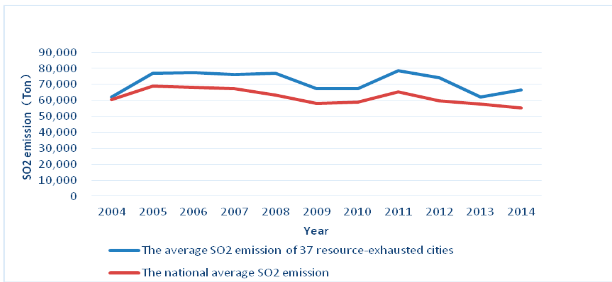

Figure 1. Comparison of SO_2 emissions/per city between resource-exhausted cities and the nation overall.

The minimum value of foreign direct investment was USD 230,000, and the maximum value was about USD 2,410,250,000, with an average value of USD 285,630,000 (see Table 1). The average value of industrial structure is about 33%, meaning that the percentage accounted by tertiary industry is low. The per capita educational expenditure was RMB 1920, with the minimum value being RMB 726.400. The average value of population density was 387.188 people/square kilometer, with the minimum and maximum values being 37.195 and 1013.610 people/square kilometer, respectively. In terms of average value, the average value of population density in resource-exhausted cities is greater. The average number of office-holding years of mayors and municipal party secretaries was 2.700 and 2.800 respectively, far lower than the two-term expiry value of 10 years.

Table 1. Descriptive statistics of major variables.

Variable	Mean	Standard Deviation	Minimum	Maximum
SO_2 (ten thousand tons)	7.7517	6.3649	0.1245	33.1863
Fixed (billion yuan)	484.9572	522.2806	21.2472	3096.893
Fdi (billion dollars)	2.8563	4.1386	0.0023	24.1025
Indus (percentage)	33.0312	5.8968	16.99	48.29
Edup (yuan)	0.1920	0.1197	0.07264	1.0641
Density (people/square kilometer)	387.188	270.4572	37.1951	1013.61
Position year (mayor) (year)	2.70	1.51	1	9
Improve (mayor)	0.6143	0.4874	0	1
Company experience (mayor)	0.3587	0.4802	0	1
Major (mayor)	0.6830	0.4659	0	1

Note: Cons: the constant term; Indus: industrial structure; Fixed: investment in fixed assets; Fdi: foreign direct investment in regional GDP; Edup: per-capita educational expenditure; Density: the popularity density; Position year: the political incentives for the officials; Improve: the level of improvement made locally by officials; Company experience: municipal party secretaries or mayors who once served as important posts in enterprises; Major: the officials' major in postgraduate school.

The Regressive Results

First, correlation analysis is conducted with respect to the variables. The correlation coefficient between investment in fixed assets and foreign direct investment and between investment in fixed assets and per-capita educational expenditure is 0.7720 and 0.6466, respectively. All the correlation coefficients of other variables are less than 0.50, indicating a weak correlation between explaining variables and control variables. Panel data regression can be conducted.

In order to ensure the robustness of results, we successively adopt ordinary least square (OLS), fixed effect, and random effect tests to investigate the impact of political incentives on the environmental pollution of resource-exhausted cities. As shown in Table 2, although all the impact coefficients of the number of office-holding years of mayors in the above models have negative values, they are not significant, with the conclusions being highly consistent. With regard to control variables, the empirical result of the OLS model is different from that of the other models. The analysis of the former indicates that, along with the increase in investment in fixed assets, environmental pollution is aggravated, while the analysis of the latter indicates that the environmental pollution of resource-exhausted cities correlates with foreign direct investment and per-capita educational expenditure. Clearly at odds with analysis of the mayors, with increases in the number of office-holding years of municipal party secretaries, the environmental pollution level of resource-exhausted cities will decline, and pollution will be effectively controlled. There is a significance level in the OLS model of 10%, with an impact coefficient of −0.0290. As inferred from the Hausman inspection value of fixed effect and random effect (0.0000), we should reject the original hypothesis and select the fixed effect. In the fixed effect, the impact coefficient of the office-holding years of municipal party secretaries is −0.0344. Therefore, against the political incentives for municipal party secretaries, the conclusions of OLS and fixed effect model are relatively consistent with each other. Other control variables, however, show significant differences between the OLS and fixed effect models. Such differences include investment in fixed assets, per-capita educational expenditure, the percentage of foreign direct investment in GDP, whether municipal party secretaries have work experience in enterprises, and the specialty of municipal party secretaries. The results of Table 2 verify the marked differences in the impacts of mayors and municipal CPC committee secretaries on the environmental pollution in Chinese resource-exhausted cities. The possible reasons are that in China, in terms of appointment, municipal party secretaries are decided and appointed by provincial party committees, or generated through election at the plenary meetings of municipal party committees, and approved by provincial party committees. In contrast, mayors are decided by provincial-level party committees, recommended by municipal party committees to municipal people's congresses, and generated through election at the plenary meetings of municipal people's congresses. Although they are at the same administrative level, municipal party secretaries are officials within the party, as the top leaders in the municipal party committees. In contrast, mayors are the top leaders in municipal governments.

In the process of environment governance, the party committees are chiefly responsible for publicizing the guidelines, policies, routes, and ideas of the party, leading and supervising the normal operation of other institutions, ensuring the implementation of the guidelines, policies, routes and ideas of the party, and deciding on important things related to local social affairs at the same time. In contrast, municipal governments are mainly responsible for administrating urban environment pollution affairs according to laws (the constitution, laws, administrative regulations and local regulations). Under the current administrative system of China, the party committees are in charge of the governments. Therefore, municipal party secretaries play a more significant role than mayors in the environmental improvement of resource-exhausted cities. If the elected municipal party secretaries have a strategic vision and the ability to handle complicated problems, the pollution governance decision of municipal party secretaries can be well implemented by the mayors, improving the environment effect to a certain degree.

Table 2. The regressive results of samples.

Explanatory Variable	Mayors			Municipal Party Secretaries		
	OLS Test	Fixed Effect	Random Effect	OLS Test	Fixed Effect	Random Effect
Cons	4.7652 *** (5.31)	8.8889 ** (2.66)	8.6042 *** (8.40)	4.5745 *** (5.35)	7.5783 ** (2.26)	8.9268 *** (8.44)
Fixed	0.3638 *** (4.56)	−0.0548 (−0.70)	0.0698 (0.90)	0.3808 *** (4.67)	−0.0467 (−0.60)	0.0515 (0.67)
Fdi	0.0347 (0.74)	−0.0949 ** (−2.33)	−0.0442 (−1.13)	0.0270 (0.53)	−0.1076 ** (−2.69)	−0.0681 * (−1.73)
Indus	−0.0011 (−0.13)	−0.0065 (−0.75)	−0.0026 (−0.32)	−0.0029 (−0.32)	−0.0070 (−0.80)	−0.0032 (−0.38)
Edup	0.0088 (0.28)	0.0610 ** (2.29)	0.0311 (1.16)	0.0075 (0.24)	0.0609 ** (2.24)	0.0380 (1.40)
Density	0.0991 (1.49)	0.6492 (1.10)	0.2909 ** (2.63)	0.0952 (1.41)	0.9053 (1.53)	0.3331 ** (2.66)
Position year	−0.0282 (−1.03)	−0.0157 (−0.78)	−0.0211 (−0.99)	−0.0290 (−0.89)	−0.0344 * (−1.71)	−0.0347 * (−1.66)
Improve	0.0895 (0.97)	0.0844 (1.24)	0.0790 (1.11)	−0.0624 (−0.68)	0.0493 (0.73)	0.0383 (0.56)
Company experience	0.1620 (1.64)	0.0098 (0.12)	0.0553 (0.68)	0.0999 (0.98)	−0.1290 * (−1.84)	−0.0852 (0.0720)
Major	−0.5870 *** (−7.00)	−0.1273 * (−1.72)	−0.2094 ** (−2.73)	−0.2826 ** (−3.22)	−0.1185 * (−1.73)	−0.1406 ** (−1.18)
F	20.11	15.69		15.21	17.90	
Prob > F	0.0000	0.0296		0.0000	0.0066	
R-squared		0.0522	0.0272		0.0641	0.0470
Hausman	-	Prob > chi2 = 0.0000			Prob > chi2 = 0.0000	

Note: The figures in brackets are the t statistics; *, **, and *** denote passing the test with 10%, 5% and 1% significance levels, respectively. Cons: constant term.

Differing from China in environmental governance modes of resource-depleted cities, the United States focuses on the rule of law, market mechanisms, and public participation in urban management. The United States firstly established a favorable environmental laws and regulations system at the national level, and then each state developed more detailed and operational legal rules in accordance with their own characteristics. As for the market mechanism, the United States has weak power and there tends to be government–market cooperation. From the perspective of public participation, the public is fully involved in problem identification and the implementation and evaluation of measures [48].

Similarly, Japan also attaches importance to the legal system for the environmental governance in resource-depleted cities. This is highlighted by the three functions of urban management, which are the local autonomy system, enterprise system, and social organization system, respectively. As for the local autonomy system, its decision organs and executive organs are elected by the residents. When a disagreement between the chief executive and the parliamentarian is not resolved, the decision will be made in the form of a referendum in the region [49].

In developing countries, India also has some resource-exhausted cities. While in the process of environmental governance, the Indian local government has a very weak authority to manage the city, and the municipality only is managed according to the opinions of superior government. Although India has established "finance committees" to put forward allocation suggestions for the state's fiscal revenue, the local government, actually, is not really financially independent. It is extremely weak in property management, financial budget and tax rights, which is in significant contrast to China's central and local decentralization [50].

This is demonstrated most prominently in Zaozhuang City, Shandong Province. Since 2008, the environmental pollution of Shizuishan City in Ningxia Autonomous Region, as a resource-exhausted city, has been tremendously reversed, with the SO_2 value declining year by year from 272,076 tons to 89,315 tons in 2014. In particular, in 2011, the newly-appointed municipal party secretary Peng Youdong began to work out policies on optimizing the industrial structure, namely refining the primary industry, reinforcing the secondary industry, and activating the tertiary industry. Since the secondary industry of Shizuishan accounted for more than 60% in 2011, according to the policies worked out by Peng Youdong, Shizuishan should adjust stock and transform and upgrade its traditional industries on the one hand, and should expand the increment and vigorously develop new-pattern industries on the other hand. In terms of investment attraction, Shizuishan set up an access threshold and embodied the adjustment of structure and the promotion of upgrading; transformed the existing six traditional advantageous industries of coal mining and dressing, equipment manufacturing, calcium carbide deep-processing, characteristic metallurgy, carbon-based material, and new-pattern coal chemical industry; and vigorously developed such new-pattern environmental industries such as polyvinyl chloride material and agricultural product deep-processing. In terms of the tertiary industry, Shizuishan planned the construction of "five scenic areas and ten scenic spots" according to the idea of "cultural tourism". In addition, in terms of strategic planning, Shizuishan selected two old industrial parks: Pingluo Industrial Park and Hongguozi Industrial Park, for emphatic industrial upgrading. In terms of regulation policy, Shizuishan improved the widespread markets of coal operation and processing represented by Chonggang Town, reducing environmental pollution. Mayor Zhang Zuoli (2011–2012) and Mayor Wang Yongyao (2013–2014) partnered with Peng Youdong from 2011 to 2014. All the policies on optimizing the industrial structure of Shizuishan were worked out by Peng Youdong, instead of Mayor Zhang Zuoli and Mayor Wang Yongyao, who were only responsible for detailed implementation.

4.2. Robustness Test

The environmental pollution level of resource-exhausted cities of the preceding period may affect the current period, leading to the problem of variables endogeneity. As such, we adopt the Generalized Method of Moments (GMM) system to re-estimate models for maintaining the robustness of results. This method also applies the information in differential and horizontal formula. Therefore, it is more effective than the differential generalized method of moments. In addition, considering that the number of samples is small and the problem of overfitting tends to arise, we only select the differential or horizontal items in the period after endogenous variables as instrumental variables during estimation.

The results of Tables 2 and 3 are similar: the number of office-holding years of mayors has non-significant impacts upon the environmental pollution of resource-exhausted cities. However, as indicated by the regressive results of municipal party secretaries, their office-holding years are negatively correlated with the level of environmental pollution, and the significance level of the regressive coefficient -0.0541 is 5%. This implies that, along with the increase of the number of office-holding years, municipal party secretaries tend to effectively manage the environmental pollution of resource-exhausted cities. The instrumental variable of foreign direct investment can remarkably reduce the emissions of SO_2, possibly because foreign direct investment will bring an effect of technology spillover and enhance the level of pollution control technology. The emissions of SO_2 with a lag phase, investment in fixed assets, industrial structure, per-capita educational expenditure, population density, officials' characteristics, and all other control variables produce a weak impact on the SO_2 emissions of resource-exhausted cities. Obviously, as for the key variables, the impact coefficient of political incentives for the mayors and municipal party secretaries and its significance level are consistent with those in Table 3, proving the robustness of the empirical analysis.

Table 3. GMM test results.

Explanatory Variable	Mayor	Municipal Party Secretaries
L. Y	−0.0116 (−0.20)	−0.0085 (−0.15)
Fixed	−0.0256 (−0.23)	0.0080 (0.07)
Fdi	−0.0950 * (−1.96)	−0.1245 ** (−2.60)
Indus	−0.0182 * (−1.75)	−0.0163 (−1.54)
Edup	−0.0013 (−0.01)	−0.0262 (−0.29)
Density	0.5811 (0.85)	0.6866 (1.01)
Position year	−0.0168 (−0.77)	−0.0541 ** (−2.47)
Improve	0.1366 * (1.82)	0.0595 (0.76)
Company experience	−0.0508 (−0.58)	−0.1098 (−1.37)
Major	−0.0940 (−1.07)	−0.0990 (−1.25)
AR(1)	−12.94 (0.000)	−12.69 (0.000)
AR(2)	−0.28 (0.778)	−0.08 (0.936)
Sargan test (*P*-value)	0.068	0.076

Note: AR denotes Arellano-Bond test. * and ** indicated that passing the test with 10% and 5% significance levels, respectively.

5. Conclusions and Policy Suggestion

The system for assessment of Chinese officials has been changing substantially since 2003, not only attaching importance to economic growth, but also emphasizing ecological protection. Compared with other cities, Chinese resource-exhausted cities face more serious levels of environmental pollution. While addressing these problems, local officials, especially local top leaders, play a very important role, because the political incentives for them may, to a certain extent, impact environmental pollution control. For this reason, a study of the relationship between political incentives and environmental pollution of mayors and municipal party secretaries by applying the 2004–2014 panel data of 37 resource-exhausted cities has been conducted. Results indicate that: (1) the number of office-holding years is negatively correlated with environmental pollution, although this correlation is not significant under certain circumstances; and (2) the significant impacts of political incentives for the local officials on the environmental pollution of resource-exhausted cities depend on whether the officials are municipal party secretaries or mayors. Therefore, Hypothesis 1 is supported only partially. The findings also reveal that municipal party secretaries play a greater and more dynamic role in urban transformation and have a stronger robustness than mayors, which supports Hypothesis 2. Among the factors that impact the environmental pollution of resource-exhausted cities, investment in fixed assets, foreign direct investment, industrial structure, per-capita educational expenditure, and population density are not significant, proving that the local openness level, industrial upgrading degree, and local investment in fixed assets are not key variables that boost the control of environmental pollution.

Obviously, our results are different from those of [31,43]. All of them considered the general cities instead of resource-depleted ones. Furthermore, they measured environmental pollution with different indicators, for example, the comprehensive index or PM10.

The conclusions verify the current authority structure of China and its effectiveness to the environmental improvement of resource-exhausted cities. Evidently, the party committees under the ruling of the Communist Party of China have a strong consciousness of political achievements, which becomes stronger and stronger as the day the officials leave their offices approaches. "Localized management" and "administrative contract-awarding systems", which have existed in China for a long time, determine that the authority of local governments is concentrated in local party committees. As the top leaders of party committees, municipal party secretaries work out environmental policies compatible with their own benefits so as to promote their political achievements, for example selecting strategic emerging industries which can optimize the industrial structure and trigger employment, closing environment-polluting enterprises or meting out fines to them, or increasing investment in the control of environmental pollution. In contrast with principles of party committees, the mayors in charge of governments lie in a subordinate position in the authority structure, failing to exert their effective function in the process of environmental improvement. The policy implications are as follows. First, it is obvious that the current authority structure poses a challenge to the selection and appointment of municipal party secretaries, instead of those of mayors. That is to say, we should appoint people with a strategic vision and a strong ability to solve complicated problems, such as local municipal party secretaries, and try to enable them to hold office until the expiry of their term. Second, the stability of party committee leadership should be maintained. There are some municipal party secretaries from resource-exhausted cities who have been promoted from the position of mayor. This kind of promotion may be more conducive to the stability of party committee leaders. When they were in the position of mayors, the municipal party secretaries were in an auxiliary position; once they were promoted to a communist party secretary, they could use the power better because of the experience accumulated in the environmental governance of resource-exhausted cities.

The following areas need to be addressed in the future: (1) A comparison the impacts of political incentives between the first term and second term of the top officials in the resource-depleted cities should be performed, as well as (2) an investigation of the relationship between political incentives of officials of both genders and environmental pollution in these cities.

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Estimation of Ecological Compensation Standards for Fallow Heavy Metal-Polluted Farmland in China Based on Farmer Willingness to Accept

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Abstract: In the context of China's trial fallow policy; the heavy metal pollution of farmland is addressed via field surveys in Hunan Province, where the fallow policy has been implemented, and in Jiangxi Province, where it has not been implemented. We measured and analyzed willingness to accept (WTA) using the contingent valuation method (CVM). The conclusions of this study are as follows: (1) Farmer awareness of heavy metal pollution and pollution sources is higher in Jiangxi Province than in Hunan Province; (2) Ignoring the impact of other factors, the WTA of farmers is 902 (yuan /mu) in Jiangxi Province and 902.26 (yuan /mu) in Hunan Province. Considering the influence of the basic characteristics of the respondents using the parameter estimation method, the WTA of farmers is 839.34 (yuan/mu) in Jiangxi Province and 934.39 (yuan/mu) in Hunan Province. There is little difference in WTA between the two provinces, but both estimates are higher than the national compensation standards; (3) The factors that affect the WTA of farmers in Jiangxi Province are gender, education level, average annual income and per capita arable land. The factors that affect the WTA of farmers in Hunan Province are age, education level, family size, average annual income, per capita arable land area and farmer occupation; (4) At present, the means and methods of compensation for the implementation of the fallow policy are recognized by most farmers. The paper concludes with some policy suggestions based on above findings.

Keywords: fallow; heavy metal-polluted farmland; ecological compensation; farmer willingness; CVM; China

1. Introduction

Over the past 50 years, approximately 22,000 t Cr, 9.39×10^5 t Cu, 7.83×10^5 t Pb and 1.35×10^6 t Zn were emitted into the global environment. Most of this heavy metal pollution entered the soil, causing heavy soil pollution [1]. Urban development and the modernization of industry and agriculture have been accompanied by an excessive exploitation of minerals, which has led to substantial emissions from metal processing, machine manufacturing, smelting, electroplating and other industrial wastes [2,3]. Additionally, the excessive application of pesticides and fertilizers, leaching from feed waste, and the emission of other pollutants have resulted in the enrichment of heavy metals in farmland [4]. Heavy metal pollution in arable land can affect the quality and safety of agricultural products and cause serious harm to human health [5]. Therefore, farmland that is contaminated with heavy metals must be fallowed and reclaimed. Fallow refers to farmland that cannot be cultivated during the crop growing season [6]. Fallowing can restore the quality of cultivated land, allow ecological restoration and treatment, mitigate soil problems and enhance the development potential of agriculture to achieve "possession of the land" [7]. Hunan Province and Jiangxi Province are the major food provinces of China, and grain from these provinces is sold throughout the country [8]. However, frequent food safety incidents have raised concerns. Consequently, the Chinese government, on behalf of the Ministry of Agriculture, Ministry of Environmental Protection and 10 other ministries, issued a pilot land retirement program intended to "explore a pilot scheme for the implementation of a crop land rotation and fallow system". The program designated heavy metal-polluted areas in which to perform the pilot retirement. The primary scope of the project is the Chang-Zhu-Tan area in Hunan Province, which is severely polluted with heavy metals. According to the "2016 Implementation Plan for Heavy Metal-Polluted Farmland Fallow Pilot Management in Hunan", 100,000 mu (1 km^2 = 1500 mu) of heavy metal-polluted farmland in the Chang-Zhu-Tan area was allocated to be fallowed beginning in 2016. The annual subsidy was 1300 yuan per mu per year, with farmers compensated at a rate of 700 yuan per mu, and third parties at a rate of 600 yuan per mu.

Fallowing farmland is a new concept in China for protecting farmland systems. To date, research on the compensation standard for land retirement has not received the systematic attention of academia in China. Chinese scholars have primarily focused on foreign land retirement plans, their associated compensation projects [9–11] and the study of the standards for economic compensation mechanisms for farmland protection [12–14]. Wu et al. reviews and compares the land fallow system in different countries and regions of the world, and give some relevant policy implications for China: it should be based on the different degrees of land damage, the evaluation system and the subsidy accounting standard for fallow land are formulated, and the compulsory fallow and voluntary participation of the niche fallow are targeted [12]. Yang et al., analyzing and summarizing the pilot of crop rotation and fallow in Western countries and East Asia, found that based on the institutional framework of private property rights, the institutional goal of crop rotation and fallowing is mainly composed of regulating the agricultural capacity and preserving the ecological environment, but the background and the target are different between large-scale agricultural economic entity in Europe/America and small-scale agricultural economic entities in East Asia [11]. Also, many scholars in the international summarized the fallow policy in other countries. Suter et al. used data from six states to analyze the binary options involved in the Conservation Reserve Enhancement Program (CREP). Their study results showed that landowners respond positively to incentives, and that one-time incentives (compensation) provided along with the land reserve plan were more cost effective than the annual reduction of incentives (compensation) [15]. Johnson et al. assessed the CRP situation and found that the CRP provided the ecosystem services benefits that exceeded the compensation paid to farmers [16]. Feather et al., as well as Ribaudo, reported similar findings [17,18]. Xie et al. used the opportunity cost method to evaluate the suitability of an ecological compensation standard for a winter-wheat-fallow cropping system in a groundwater funnel area in Hebei. Based on their findings, they proposed a compensation standard of 518 yuan/mu [19].

At present, part of countries has adopted compensation standards for eco-conservation programs based on the opportunity cost method. For example, the Conservation Reserve Enhancement Program of the U.S.A. and China's returning-farmland-to-forest projects all use the opportunity cost as compensation standard [20–23]. However, the opportunity cost approach is rather one-sided because the government generally determines the compensation standard. Therefore, only the real economic interests are considered, while the willingness of the relevant stakeholders is ignored. While this approach may be reasonable with respect to ecological compensation standards, there is little enthusiasm among farmers for participation based solely on ecological compensation.

However, in the process of implementing land retirement of heavy metal-polluted farmland, the farmer is both the primary victim of the pollution and the executor of and a participant in farmland reclamation. One important factor affecting farmers' participation in the policy is the amount of compensation [24]. Economic benefits are the important factors influencing farmers' behavioral decisions and, to a large extent, can determine farmers' willingness to accept a policy. Developing a reasonable farmer-based compensation mechanism for fallow land could encourage the initiative and enthusiasm of farmers. Moreover, protection of the basic production, livelihood and interests of farmers should be considered to comprehensively and effectively facilitate the implementation of fallowing programs for heavy metal-polluted land in China [25]. However, there is a danger that farmers may exaggerate the extent of their losses to receive greater economic compensation. Therefore, the accurate accounting of compensation standards not only protects the basic interests of farmers but also enables the government to maintain reasonable costs while encouraging farmers to participate in policy. To this end, it is of great practical value to develop a rational and consistent compensation mechanism, for example, a compensation standard, and means of fallowing heavy metal-polluted land for implementing land retirement and enabling the remediation of heavy metal-polluted land.

The contingent valuation method (CVM) is a narrative preference assessment method [26]. This method was proposed by Ciriacy-wan trup, and Davis was the first to apply the CVM for assessing the natural environment [27]. The CVM identifies respondents' preferences through questionnaires. It can be used to deduce the distributions of respondent willingness to accept compensation in different environments, access to environmental resources and the value of economic services [28]. Unlike the opportunity cost method, the CVM is based on the willingness of the farmer. The CVM is widely used in the assessment of public resources, renewable energy and a variety of environmental protection projects [29–32]. The willingness to accept (WTA) is the minimum compensation amount required to secure a famer's consent to perform an action he otherwise would not perform (e.g., to participate in a governmental program for providing ecological services). Currently, foreign research primarily focuses on the willingness and behavioral preferences of landowners to provide ecological services [33–35]. The CVM also has a wide range of applications in various fields in China [36–38], particularly in the assessment of ecological compensation [39–41]. For example, based on 633 responses to a questionnaire, Zheng et al. investigated the willingness of residents to pay in the Dahuofang water supply area. The findings indicated that 68.2% of the residents had a willingness to pay for the Dahuofang water source protection area. The average willingness to pay was 93.81–137.55 yuan per person per year [42]. Based on the payment card type (PC) of CVM surveys in the South-to-North Water Diversion Project in Zhengzhou City, Zhou et al. showed that in 302 valid samples, 84.44% of the residents in the water area had a willingness to pay, and 89.8% of these residents were willing to pay a value of 10 yuan/month or less [43]. This study aims to establish an "ecological compensation mechanism for fallow farmland in heavy metal-contaminated areas", namely, a more specific and targeted approach to accurately reflect the environmental preferences of the farmers in fallow farmland in heavy metal-contaminated areas. The survey area involves Hunan Province, which has implemented a fallowing policy in the heavily polluted areas, and Jiangxi Province, which has not implemented a fallowing policy. The surveyed farmers have a wide range of regional characteristics, and we further examined the regional differences in their willingness to accept.

2. Study Area

The study area, Hunan Province, is approximately 21.18 $\times$ 10^{10} km^2 in size and is located along the middle reaches of the Yangtze River in central China between 24°38′–30°08′N and 108°47′–114°15′E. The soil is dominated by red soil, followed by paddy soil and fluvo-aquic soil; the latter two are the main agricultural soils in Hunan Province. The farmland area was 4.15 $\times$ 10^4 km^2 in 2014 in Hunan Province. Hunan is known as the "hometown of non-ferrous metals", and non-ferrous metal mining has led to heavy metal pollution of up to 28 $\times$ 10^4 km^2, which means 13% of the total land area of Hunan Province is polluted by heavy metals. Jiangxi Province is approximately 16.69 $\times$ 10^{10} km^2 in size and is located in Southeastern China between 24°29′–30°04′N and113°34′–118°28′E. Jiangxi Province lies east of Zhejiang Province and Fujian Province, south of Guangdong Province, west of Hunan Province, and north of Hubei Province, Anhui Province and the Yangtze River. It is an important part of the Yangtze River Economic Zone. Jiangxi Province has diverse soil types, mainly red soil, paddy soil and eight other soil types. The total area of cultivated land in the province is 3.08 $\times$ 10^4 km^2, accounting for 18.48% of the total land area. Jiangxi is one of the top 10 producers of non-ferrous metals in China and suffers from industrial and agricultural waste. According to the survey, the heavy metal pollution of paddy soil in Jiangxi Province is the most serious in the central region, with a level of 5.26% moderate pollution [44]. Therefore, the area of farmland affected by heavy metal pollution in Jiangxi and Hunan Provinces urgently requires withdrawal from farming. The development of ecological compensation standards for heavy metal pollution areas is required to make farmland areas fallow.

3. Research Methods and Data Sources

3.1. Research Methods

Many methods can be used to calculate the standard of fallow land ecological compensation, including the payment willingness law, the opportunity cost method, the income loss method, the total cost revision model, and the cost analysis method. Among these methods, the willingness to accept method is based mainly on the value assessment method of environmental value assessment theory. Currently, Chinese research on ecological compensation standards of fallow land primarily assesses the value of the willingness to accept method. Under China's current fallow policy, farmers have the right to choose whether or not to participate (some areas even do not have an option) and no choice of subsidy program opportunities. Therefore, under this provision, farmers' their true willingness cannot be inferred from their participation. By applying the stated preference (SP) method of the CVM, where in the respondents are informed of the purpose and background of the study, the true willingness of respondents can be determined. Therefore, researchers seek to explain the main purpose of this research and the relevant context. In this study, open guidance technology is used with the contingent valuation method (CVM) to analyze the ecological compensation standard of the farmland heavy metal area. Open guidance technology in the early application of CVM provides an easy method for data analysis and requests respondents to report the largest WTA.

3.2. Questionnaire Design

The data of this paper were primarily derived from the questionnaires returned by farmers in the heavy metal-polluted areas in Hunan and Jiangxi. First, the study villages were identified by searching for heavy metal-polluted areas online. Next, the authors met with representatives of the local land sector to discuss the heavy metal pollution of the entire area and other relevant issues. The need to investigate specific villages was determined based on these initial tasks. The author and several master's and doctoral students researched 10 villages with heavy metal pollution from the areas of Leping, Dexing and Guixi cities, and from Jiangxi Province, along with 12 villages that had implemented the land retirement policy in Changsha County, Xiangtan City, Chaling County, and Hunan Province. A total of 532 questionnaires were issued. Of these, 216 questionnaires were returned from Jiangxi Province, and 13 of these surveys were invalid, resulting in an effective rate of 93.98%. Of the 316 questionnaires in Hunan Province, only one was invalid; thus, the effective rate was 99.68%.

The questionnaire was divided into four parts. The first part primarily investigated the characteristics of the decision makers, including the age, sex and education level of the respondents and other basic socioeconomic information. This information was used to analyze the factors influencing farmer participation in compensation construction. The second part primarily investigated the farmers' awareness of farmland heavy metal pollution problems without providing any background material to the respondents. This information makes us know the extent of farmers' understanding of heavy metal pollution. The main question includes: Do you think heavy metal pollution has an impact on you? Do you know where it came from (multiple choice)? The third part was the core part of the survey and investigated farmer awareness of polluted arable land and their willingness to participate in the fallowing policy, which was used to obtain the WTA of local residents. The fourth part primarily investigated the farmers' preference for the form of compensation. The questionnaire was administered using the payment card method, with the content evaluated after all of the questionnaires were completed.

4. Results and Analysis

4.1. Farmers' Awareness of Heavy Metal Pollution in Farmland

(1) Statistical analysis of farmer awareness of the sources of heavy metal pollution in farmland

The Figure 1 shows that 94.09% of farmers from heavy metal-polluted areas in the Jiangxi Province believe that local heavy metal pollution results from the unreasonable disposal of three industries' wastes, 33% of farmers believe the source is actually sewage irrigation, while 2.46% of the respondents did not know the pollution source. No farmers believed that excessive use of fertilizer was the cause of the heavy metal pollution of farmland. According to the author's visit, the primary source of the heavy metal pollution in Jiangxi is derived from industrial waste. The primary reason is that there are many chemical processing plants in proximity to the settlements, and the discharged industrial wastewater directly enters the inhabited area. Even if there were no chemical processing plants near the village, the nearby water system was also contaminated by the sewage discharged from an upstream plant, resulting in the severe pollution of arable land.

Hunan Province is the first batch of heavy metal areas in China fallow pilot area. Fertilizer, sewage irrigation, and three industrial wastes are the sources of heavy metal pollution in this region. However, 22.86% of respondents did not know the source of heavy metal pollution. The farmers in Jiangxi Province had better awareness of the sources of farmland pollution than did those in Hunan Province.

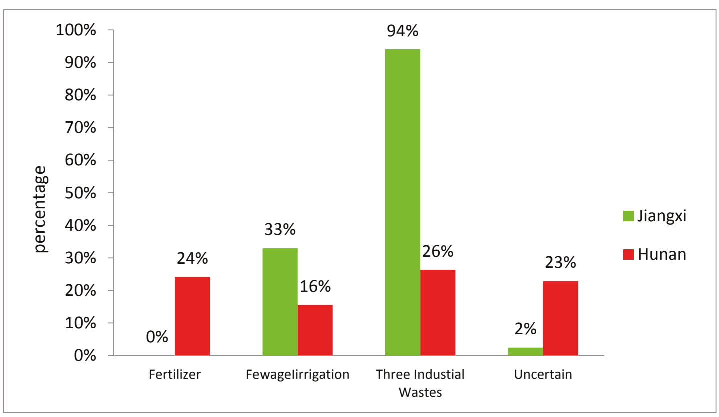


Figure 1. Statistics of farmers' awareness regarding the sources of heavy metal pollution in farmland areas.

(2) Statistical analysis of farmer's awareness of the dangers of heavy metal pollution in farmland areas

The results show responses to the question, "How much do you think land pollution affects you and your family's health?": A. seriously; B. slightly; C. not at all. As shown in Figure 2, among the sampled farmers in the heavily polluted areas of Jiangxi Province, 87% believed that the heavy metal pollution caused minor health damage, 9% said that physical health had been seriously affected, and only 4% believed that heavy metal pollution did not cause any damage to the body. Among the sampled farmers of the heavy metal-contaminated areas in Hunan Province, 45% believed that heavy metal pollution caused minor damage to the body. However, 41% of the respondents said they were not harmed. Only 14% of households indicated that they believed the body was seriously injured.

According to the above comparative analysis, most farmers from the Jiangxi heavy metal-polluted area clearly understood the dangers of heavy metal pollution. However, nearly half of the farmers from the heavy metal-contaminated areas in Hunan did not know that heavy metal pollution in farmland can cause harm to the body. These results show the level of the farmers' understanding of heavy metal pollution in the environment. The farmers were more concerned about the direct impacts of arable land and food, but did not see the indirect effects of heavy metal pollution as human health hazards.

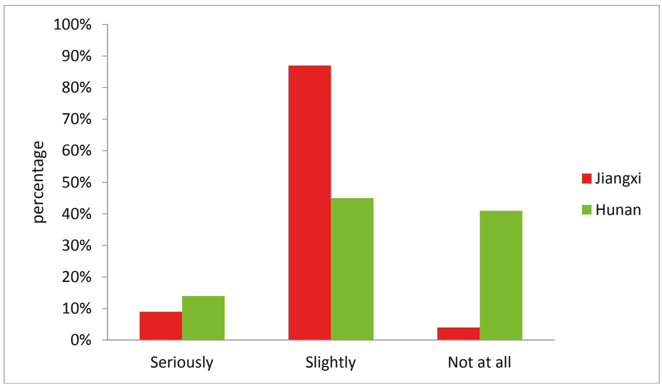
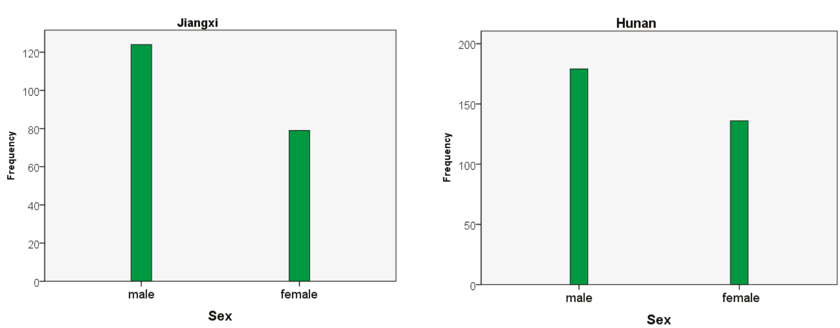


Figure 2. Statistics of farmers' awareness of the risk of heavy metal pollution in farmland.

4.2. Characteristics of WTA of Surveyed Farmers in Jiangxi and Hunan Provinces

Figure 3 shows the frequency distribution of social and economic characteristics of 203 respondents from Jiangxi Province and 315 respondents from Hunan Province. As can be seen from Figure 3, the proportion of men and women in Hunan Province is similar, the main age distribution of two provinces is in the range of 45–59, primary school students and junior high school students are the most numerous, the per capita income of Jiangxi Province concentrated in the area of 5001–6000 yuan; and that of Hunan Province concentrated around 4001–5000 yuan; the family size of the two provinces averaged 4–6 persons, and the average land area of the respondents was 0.6–1 mu, and most of these are part-time farmers.



(**a**)

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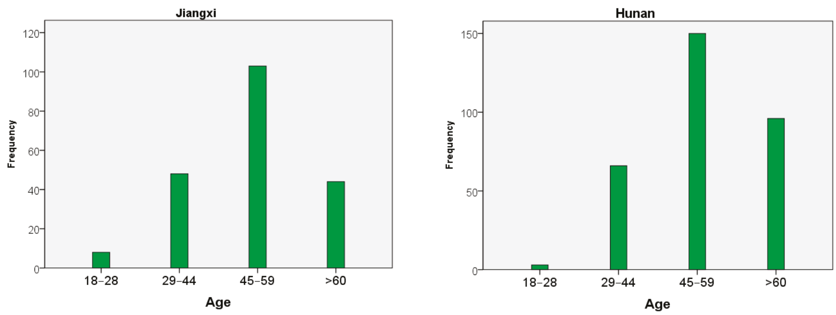

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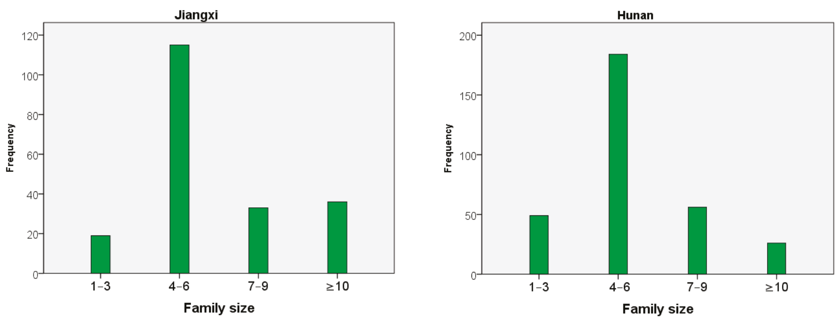

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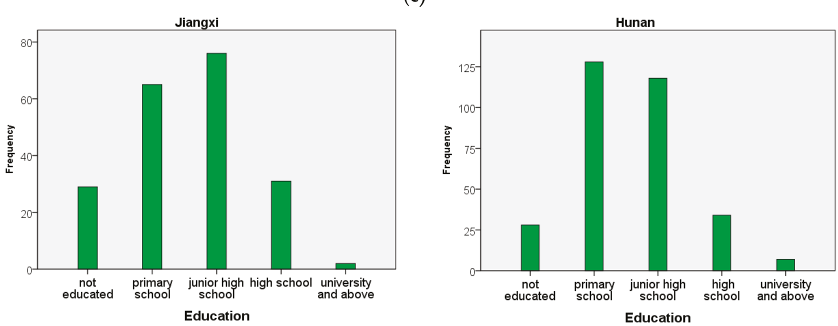

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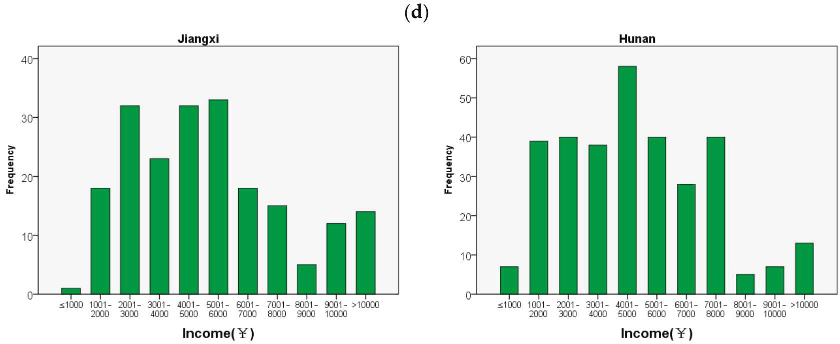

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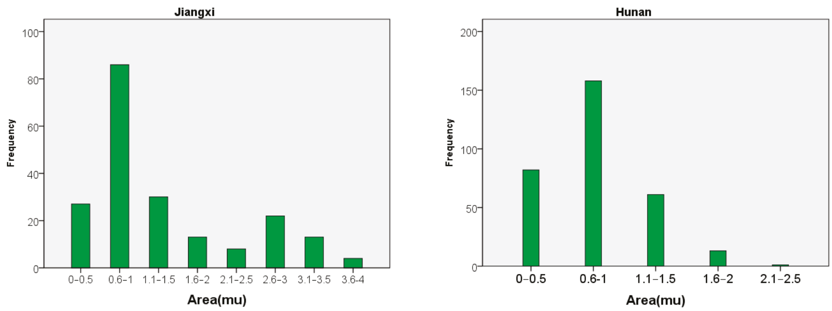

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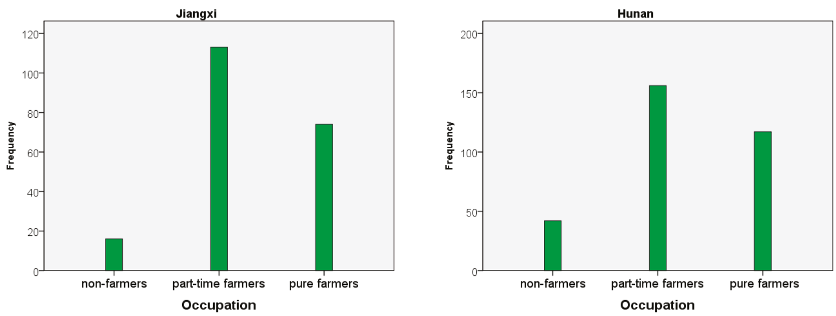

(**g**)

Figure 3. Frequency distribution of social and economic characteristics of 518 respondents. (**a**) Frequency distribution of sex; (**b**) Frequency distribution of age; (**c**) Frequency distribution of family size; (**d**) Frequency distribution of education; (**e**) Frequency distribution of income; (**f**) Frequency distribution of area; (**g**) Frequency distribution of occupation.

By investigating the WTA valuation problem in the questionnaire, we obtained the WTA distribution for the Jiangxi and Hunan Provinces, as shown in Table 1. Table 1 shows that in Jiangxi Province, the tender value is concentrated in the amounts of 500 yuan, 600 yuan, and 1000 yuan, whereas in Hunan Province, the tender value is mostly concentrated in the amounts of 700 yuan, 800 yuan, and 1000 yuan, three large amounts.

Regardless of the impact of the relevant variables such as the basic characteristics of the interviewee, only the expected value of *WTA* can be calculated using the following model:

$$E(WTA) = \sum_{i}^{k} AWTA_i N_i \tag{1}$$

where N_i represents the i-th bid value selected by the interviewee, and $AWTA_i$ indicates the probability that the respondent selects the i-th bid value. The data are shown in Table 1. The calculation was used to obtain the average *WTA* in Jiangxi Province = 902 (yuan/mu) and the average *WTA* in Hunan Province = 902.26 (yuan/mu). The *WTA* of the two provinces are nearly identical, possibly because they are located adjacent to each other, and food prices are highly comparable, separated by a few cents.

Table 1. Accumulative frequency distribution of willingness to accept (WTA).

Jiangxi			Hunan		
WTA (Yuan/mu)	**Absolute Frequency (Number)**	**Relative Frequency (%)**	**WTA (Yuan/mu)**	**Absolute Frequency (Number)**	**Relative Frequency (%)**
100	1	0.5	100	1	0.3
300	9	4.4	400	3	1
400	5	2.5	420	4	1.3
500	30	14.8	450	3	1
600	37	18.2	500	17	5.4
700	23	11.3	600	19	6
800	7	3.4	700	92	29.2
900	4	2	800	34	10.8
1000	31	15.3	900	16	5.1
1100	1	0.5	1000	86	27.3
1200	12	5.9	1200	12	3.8
1300	6	3	1300	5	1.6
1400	4	2	1400	2	0.6
1500	18	8.9	1500	11	3.5
1600	3	1.5	2000	9	2.9
1800	1	0.5	10,000	1	0.3
2000	11	5.4			

4.3. Correlations between Respondents' Socioeconomic Background Factors and Willingness to Accept

Theoretically, personal preferences, income conditions, and other socioeconomic characteristics directly affect WTA or willingness to pay (WTP) [45]. Considering the impact of these variables on willingness to accept, the maximum likelihood function estimation method is used to determine the relationship between the WTA of famers and the variables of its economic background. The logarithmic normal distribution of the willingness to accept used as the explanatory variable [46]. The model can be expressed as follows:

$$\ln WTA = \alpha(P, E, S, N) + \mu \quad (2)$$

$$E(WTA) = \exp\left[\alpha(P, E, S, N) + \frac{\delta^2}{2}\right] \quad (3)$$

where P represents personal preference, E represents personal income, S represents individual social and economic information, and N represents the quantity or quality of resources. α represents the coefficient to be estimated; μ obeys $[0,\ \delta^2]$ the random distribution of random variables, lnWTA equals μ; δ^2 is the variance; and α and δ^2 can be derived from Equation (2).

In this study, based on previous research results [47–52] and field observations, factors that influence the willingness of farmers to accept compensation for heavy metal pollution of farmland from three categories: (1) farmer decision-maker characteristics, including gender, age, education, and occupation; (2) family characteristics, including the family size and per capita income; and (3) farmland conditions, comprising per capita arable land area.

The factors that affected the willingness to accept were examined using regression analysis assuming a linear model. The results of Equation (2) were determined using SPSS 20.0 and are shown in Table 2.

As is evident from Table 2, education level, average annual income, and per capita arable land area were significantly associated with willingness to accept the WTA. The estimated coefficient was tested at a significance level of 1%. Among the variables, per capita arable land and the willingness of farmers to accept were positively correlated. This correlation indicates that the farmers' willingness to accept increased with increasing area of per capita arable land [53]. This correlation occurs primarily because a higher average farmland area per household is correlated with a higher profit from farmland and the farmers' willingness to accept. The willingness of farmers to accept is negatively correlated with farmers' education level and average annual income. That is, when their level of education is higher, the farmers' willingness accept is lower. This finding suggests that a higher level of education might increase a farmer's awareness of the dangers of agricultural pollution and, consequently, their support for agricultural land pollution control and ecological compensation policies [54]. The higher the average annual income, indicating that the respondents' income is not entirely dependent on land income, the lower the demand for abandonment of land compensation [55].

Table 2. Regression results of WTA in Jiangxi and Hunan Provinces.

Variable	**Regression Coefficient (Standard Deviation)**		***t* Test Value**		***p* Value**	
	Jiangxi	**Hunan**	**Jiangxi**	**Hunan**	**Jiangxi**	**Hunan**
Constant term	7.481 (79.549)	6.685 (95.261)	40.83	50.305	0.000	0.000
Sex (×1)	−0.086 (15.157)	0.03 (11.387)	−1.953	0.971	0.052	0.333
Age (×2)	0.021 (9.181)	0.037 (12.084)	0.661	1.667	0.509	0.096
Education (×3)	−0.148 (23.37)	−0.071 (12.838)	−4.778	−3.704	0.000	0.000
Family size (×4)	0.006 (3.469)	0.024 (2.999)	0.611	2.152	0.542	0.032
Income (×5)	−0.084 (0.005)	−0.061 (0.008)	−7.693	−9.072	0.000	0.000
Area (×6)	0.057 (4.371)	0.054 (4.833)	4.34	2.893	0.000	0.004
Occupation (×7)	−0.05 (11.72)	0.151 (12.823)	−1.558	5.31	0.121	0.000
Jiangxi R^2 = 0.646						
Hunan R^2 = 0.749						

Gender was a significant mediating factor of the willingness to accept in Jiangxi Province, but not in Hunan Province. This result may be due to the fact that the Hunan Province sample featured a nearly balanced proportion of men to women. Jiangxi Province, by contrast, showed a significant negative correlation, indicating that men are willing to accept a higher level of compensation. This finding may be due to the fact that the proportion of male to female respondents in Jiangxi Province was 2:1. Respondents were mostly male, and men are the main source of labor for farming and are therefore more sensitive to the compensation amount. Neither age nor family size was significant in the Jiangxi model, but both showed a significant positive correlation in the Hunan model, suggesting that farmers' willingness to pay increases with age and household population [56,57]. According to the survey, most of the labor under the age of 45 is not performed by pure farmers but by part-time farmers and non-farmers. Therefore, in the case of additional income, these workers' demand for compensation is not as high as that of farmers, and they moreover believe that fallow land can enable them to liberate the labor force, increasing time to work and earn more money [54]. Furthermore, the larger size of the respondents' household, the greater the pressure on the limited income of farmland. Thus, the impact of farmer relinquishment of part of their economic benefits is high [56]. Therefore, the larger the family size, the higher the farmers' sensitivity to losing the income from agricultural activities. Farmer occupation was significantly and positively correlated with WTA in Hunan Province, with respondents that were exclusively farmers associated with higher compensation amounts. As such, farmers rely exclusively on farming income, fallowing reduces this main source of income; their WTA is therefore significantly higher than that of part-time farmers and non-farmers [57]. In contrast, in Jiangxi Province, occupation was not significantly associated with WTA. Based on our field observations, we speculate that this result might have occurred because the quality of the farmland of the majority of farmers in this province is quite poor; thus, farming entails the risk of financial loss, and farmers might therefore be eager for any compensation, regardless of the amount.

According to the parameters of Table 3, the following WTA model is obtained:

$$E\,(WTA) = \exp(C + \alpha_1\overline{x1} + \alpha_2\overline{x2} + \alpha_3\overline{x3} + \alpha_4\overline{x4} + \alpha_5\overline{x5} + \alpha_6\overline{x6} + \alpha_7\overline{x7} + \frac{\delta^2}{2}) \quad (4)$$

where α_1, α_2, α_3, α_5, α_6 and α_7 represent the coefficients of $\times 1$, $\times 2$, $\times 3$, $\times 4$, $\times 5$, $\times 6$ and $\times 7$, respectively; $\overline{x1}$, $\overline{x2}$, $\overline{x3}$, $\overline{x4}$, $\overline{x5}$, $\overline{x6}$ and $\overline{x7}$ represent average values. Specific values are provided in Table 3.

Based on the above equation, the WTA is 839.34 (yuan/mu) in Jiangxi Province and 934.39 (yuan/mu) in Hunan Province. The WTA in Hunan Province is higher than that in Jiangxi Province. It can be seen from Figure 2 that the farmers in Hunan Province generally believe that the cultivated land they own has not been seriously polluted by heavy metals; thus, the amount of compensation they would accept is higher than in Jiangxi Province.

According to the author's survey, the primary form of agricultural production in the study area was the cultivation of one or two quarters. With the serious pollution of farmland, this form can produce 500–600 jin/mu (1 jin = 0.5 kg) of grain. Less polluted arable land could yield 1000–1200 jin/mu of grain. The rice purchase price was 1.2 yuan/jin in Jiangxi and Hunan Provinces in 2016. The production of more heavily polluted land was calculated at 500 jin. The net income was 600 yuan, and the less polluted farmland output was calculated at 1200 jin. Simultaneously, the net income was 1440 yuan. According to the survey, the local farmers' investment cost of planting the crops was calculated: fertilizer cost approximately 100 yuan/mu; pesticides cost approximately 60 yuan/mu; the annual grain purchase price was approximately 100 yuan/mu; and the machine farming costs were approximately 120 yuan/mu. The total cost was 380 yuan/mu. The average annual net income from agricultural products in the severely polluted areas of farmland was 220 yuan/mu, and on the less polluted land, it was 1060 yuan/mu. These calculations indicate that the local farmers' economic losses ranged from 220–1060 yuan and were caused by the abandonment of the pollution farmland. The average loss was 640 yuan, which means that the amount of the farmer's actual economic loss caused by the farmland fallow, was within the interval indicated by the willingness to accept, as determined by the survey. The difference between the statistical data of the questionnaire and the economic model and the actual economic loss of the affected households is approximately 200 yuan. This difference arises mainly because farmers do not know the exact amount of the resulting deviation. The CVM, the cost estimation method and the country's implementation of the fallow subsidy 700 yuan are closer in result.

Table 3. Sample farmers' preferences for compensation means.

Compensation Means	First Choice (P)		Second Choice (P)	
	Hunan	Jiangxi	Hunan	Jiangxi
Cash	237	116	39	30
Technical support	3	5	9	19
Food subsidies	10	12	57	38
Social security	19	40	43	40
Arrange employment	28	10	15	20
Preferential policies	2	3	3	6
Land compensation	1	4	3	9

4.4. Farmers' Preferences for the Method of Compensation

(1) Compensation method

The compensation method can affect the farmers' implementation of fallowing [58]. Current compensation methods include compensation per losses according to pollution, crop yield output, health damage, crop market price, family population, farmland area, and the degree of loss at the pollution control stage. Currently, the compensation method in China is based on the number of mu. The following question was posed: "When your farmland is contaminated with pollution, how is your loss compensated?" Figure 4 presents the statistical analysis of the results of the compensation method preferred by the sample farmer's willingness to accept in heavy metal-polluted areas from Hunan and Jiangxi Provinces. This figure shows that the proportion of farmers who chose to be compensated for farmland area was the largest, accounting for 53% and 36% of the total number of farmers in Hunan and Jiangxi, respectively. These results indicate that most farmers still want to be compensated per the area of arable land, and the acceptance was relatively high. This outcome was followed by compensation per family population. In Hunan and Jiangxi, the total number of farmers preferring this method accounted for 43% and 33%, respectively. According to the visits, the majority of the farmers' who chose this method did so because of the asymmetry of the household population and the holdings of arable land. The numbers of people who chose to be compensated per crop yield output and losses from pollution was less than 2% of the total number of samples in Hunan Province, while in Jiangxi Province, these values accounted for 13% and 7% of the total number of samples, respectively. The number who chose to be compensated according to the loss of the level of pollution control, and health damage was the lowest. As the numbers of farmers who chose these options were too small, these two options were excluded from the Hunan questionnaire. This result shows that farmers in both provinces are predominantly in favor of the current compensation method.

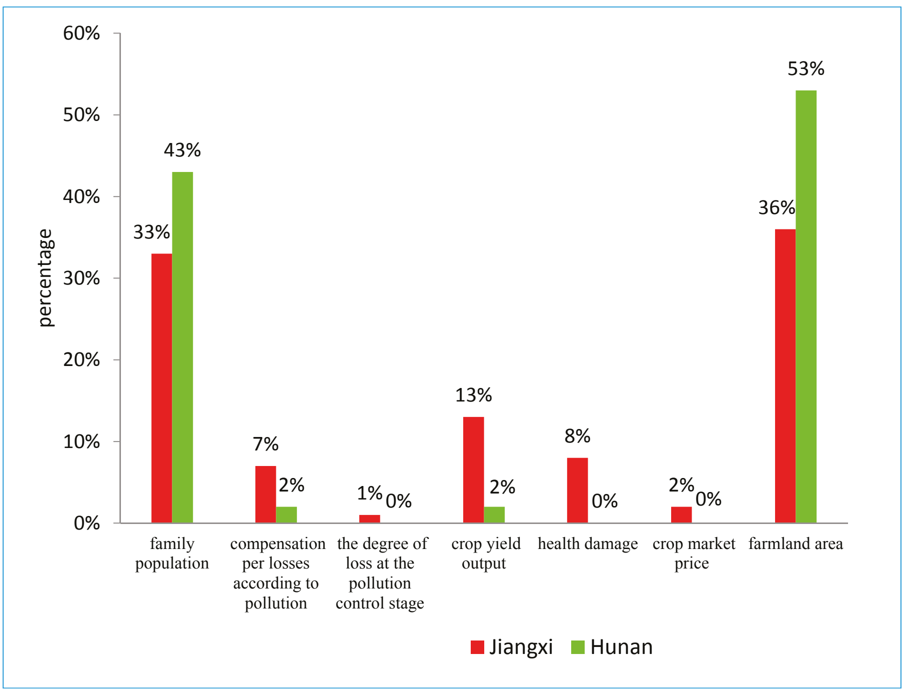

Figure 4. Sample farmers' preferred compensation method.

(2) Means of compensation

In addition to the amount of compensation and the compensation method, the means of compensation was also a key factor in the implementation of the fallow policy [59]. The current compensation means include cash, technical support, food subsidies, social security, arrangements for employment, preferential policies, and land compensation. The current fallow policy is in the form of cash payments. Table 3 shows the results of the statistical analysis of the farmers' willingness to accept by the compensation means. As this table shows, the first choice for the farmers from heavy metal-polluted areas in Hunan was by means of cash compensation, with 237 farmers preferring this method. This choice was followed by the arrangement of employment means, and the choice of land compensation was the least popular choice. In the Jiangxi heavy metal-polluted areas, the same first choice was by cash compensation, with 116 farmers preferring this method. This choice was followed by social security, and the least popular choice was preferential policies. This result shows that most farmers are most likely to accept cash payments.

The second choice of compensation means for farmers from the Hunan heavy metal-polluted areas was by food subsidies. This second choice was followed by social security and preferential policies, while land compensation was the least chosen. The most popular second choice of farmers from the Jiangxi heavy metal-polluted area was social security. This second choice was followed by food subsidies, and preferential policies were the least chosen. Per the comprehensive survey results of Jiangxi and Hunan farmers, most of the farmers preferred cash compensation, and social security and food subsidies were also preferred means of compensation.

5. Conclusions and Policy Suggestions

5.1. Conclusions

In this paper, the CVM method was used to get the farmer's true willingness to accept, a logistic model used to analyze the influencing factors of famers' WTA in the Hunan province and Jiangxi province, and the compensation standard of fallow heavy metal-polluted farmland was obtained. The main results are summarized follow.

(1) The awareness of heavy metal pollution of farmland in Jiangxi Province was greater than that in Hunan Province.
(2) Ignoring the impact of other factors, the WTA of farmers is 902 (yuan/mu) in Jiangxi Province and 902.26 (yuan/mu) in Hunan Province. Considering the influence of the basic characteristics of the respondents, the parameter estimation method determines that the WTA of farmers is 839.34 (yuan/mu) in Jiangxi Province and 934.39 (yuan/mu) in Hunan Province. There is little difference in the WTA between the two provinces, but the WTA in both regions are higher than the national compensation standards.
(3) The factors affecting the WTA of farmers in Jiangxi Province are gender, education level, average annual income and per capita arable land. The factors affecting the WTA of the farmers in Hunan Province are age, education level, family size, average annual income, per capita arable land area and occupation.
(4) At present, the means and methods of compensation for the implementation of the fallow policy are recognized by most farmers.

5.2. Policy Recommendations

(1) Farmland pollution levels should be stratified, and the appropriate compensation for fallowing should be reasonably determined [12]. The results revealed compensation standards of 839.34 (yuan/mu) in Jiangxi Province and 934.39 (yuan/mu) in Hunan Province. However, the pollution levels are not clearly delineated, and this leads farmers to the perception of pollution is not the same, so the willingness to accept is quite different. The different pollution levels of farmland should be associated with appropriate subsidy levels. To ensure reasonable cost outlays by the national government, more seriously polluted areas should receive more compensation; the farmers' willingness to participate would be improved, and this approach could save excess expenses.
(2) A diversification approach to realize the ecological compensation mode of heavy metal pollution in farmland areas. The survey found that some respondents preferred the choice of cash as a single compensation means. Others chose other compensation methods. Therefore, the relevant government departments can adapt to the preferences of local residents regarding ecological compensation to develop and provide a variety of forms of ecological compensation, and to improve the heavy metal pollution ecological compensation mechanism of arable land.

(3) The extent of the heavy metal-polluted farmland fallow policy and farmers' awareness of the hazards of polluted arable land should be increased. As can be seen from this article, the level of education is significantly related to the farmers' willingness to accept. Therefore, improving the quality of farmers' education could generate publicity and help them fully understand the strategic importance of heavy metal-polluted land fallowing. In particular, improving the understanding of a new generation of farmers' with regard to arable land heavy metal pollution is one of the most important tasks for improving the current performance of farmland protection.

5.3. Discussion

In this study, the ecological compensation standard for heavy metal pollution of cultivated land was estimated as 934.39 (yuan/mu) in Hunan Province and 839.34 (yuan/mu) in Jiangxi Province. However, developing a compensation mechanism for fallowing farmland is a complex, multifaceted and multidimensional task. The compensation standard proposed in this paper is different from that proposed by policy. This finding indicates that ecological compensation standards cannot be "one size fits all" and should be determined based on research. The following shortcomings are identified as the key research directions for the future.

First, this article macroscopically measured the compensation standards of heavy metal pollution of cultivated land. However, due to China's vast territory, the region's food prices and economic development and the wide variation in farmland resources, these standards cannot be uniformly approached. The question of how to devise differentiated compensation standards for different regional characteristics is an important research direction for the future.

Second, the compensation standard recommendations are based on the results of the questionnaire. However, since the CVM and estimation of nonmarket value are based on the consumer's choice and behavior in a false market, the CVM data assessment is used in a hypothetical market. Therefore, we must develop an accurate market simulation. Regardless of the respondent's understanding, the quality of the investigators, or other requirements, error must be avoided. However, because the questionnaire was not sufficiently detailed, and for other reasons, it was difficult to eliminate the errors. In the future, we will improve the method for measuring the nonmarket value of cultivated land resources to more effectively set the compensation standards.

The CVM method in this study only consider the farmers' willingness. Otherwise, a good policy should consider all the relevant stakeholders rather than ignoring one or the other. As both the government and farmers are key stakeholders here, the results will be more convincing.

Third, there is a growing body of literature stating that monetary compensation and economic benefits are not the primary motivating force for engagement in ecosystem management. For example: farmers' understanding of ecological protection [60]; fairness of ecological compensation distribution [61]; the spatial conditions of land [62], and; other factors also have important influence on farmers' willingness to participate an ecosystem management. In future research, we need to consider those in detail.

Finally, due to the separation of rural land rights in China, there are many land transfer activities, which means that the landowners and land operators are not always the same people. However, land property rights have a great impact on farmers' willingness to accept [63]. Hence, the compensation object should be clear. This article does not consider this aspect in detail, and thus, the compensation recipient is generalized. Therefore, in the next study, we will examine the compensation recipient and how to balance the economic interests of each compensation recipient for a broad range of study assessments.

Based on the above conclusions, it can be concluded that a change in farmer livelihood will directly impact farmers' decision-making behaviors [64]. Farmer awareness of pollution will also greatly affect farmers' willingness to accept [57]. The authors of the present study argue that the government should strengthen public opinion guidance, promote public participation, augment the roles of rural organizations, publicize and provide education regarding heavy metal pollution and environmental protection knowledge, and improve farmer awareness [65]. The government should scientifically plan and use land to guarantee the provision of public goods such as ecological welfare and food security [66]. In addition, the farmers' own assets should be considered, and the livelihood capital of farmers should be improved. According to the needs of different types of farmers, different types of ecological compensation measures should be developed [64]. By implementing these changes, farmers will actively take the initiative to cooperate with the government to implement the policy, improving the implementation of ecological compensation policy.

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

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Time-Spatial Convergence of Air Pollution and Regional Economic Growth in China

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Abstract: The haze pollution caused by fine particulate matter (PM 2.5) emissions has become one of the most crucial topics of sustainable environmental governance in China. Using the average concentration of PM 2.5 in China's key cities from 2000 to 2012, as measured by aerosol optical depth, this study tested the time-spatial convergence of fine particulate matter pollution in China. The results show that there is a trend of absolute convergence between timespan and China's PM 2.5 emissions. At the same time, in the geographic areas divided by the east, middle and west zones, there is a significant difference in the convergence rate of PM 2.5. The growth rate of PM 2.5 in the middle and west zones is significantly higher than that of the east zone. The correlation test between regional economic growth and PM 2.5 emissions suggest a significant positive N-type Environmental Kuznets Curve (EKC) after considering spatial lag and spatial error effect.

Keywords: PM 2.5; club convergence; non-linear time varying factor model; Environment Kuznets Curve

1. Introduction

After more than 30 years of rapid economic development, China has made significant economic achievements. Since the new millennium, the momentum of this rapid economic growth has not stopped. From 2003 to 2015, after joining the World Trade Organization, China's total gross domestic product (GDP) increased from less than 15 trillion yuan to over 67.6 trillion yuan, and the national per capita GDP from more than 10,000 yuan to over 52,000 yuan.

However, the improvement of material life also brought severe environmental damage. Extensive economic development mode in China created an intensive outbreak of environmental problems within 30 years that took 100 years of industrialization in developed countries. Given this, many researchers in the environmental and economic field have turned their attention to this area, such as research on energy efficiency [1] and environmental impact [2], or the correlation between environmental [3] and economic development [4].

Since 2012, fine particulate matter (PM 2.5) in China's lower atmosphere increased due to stagnant meteorological conditions. This has triggered nationwide haze pollution, which has become the most-watched environmental pollution incident for China. Similar to water pollution and other "public pond" pollution, haze is also considered to be a boundary environmental pollution [5], and is highly correlated with economic activities. However, as a pollutant diffusing in the atmosphere, the diffusion boundary of haze is much larger than the pollution boundary in lakes or rivers. Moreover, human perceptibility of haze is much higher than that of carbon dioxide emissions in high concentrations. Research on environmental science has demonstrated that exhaust emissions from heavy industry production and the extensive use of motor vehicles, dust in open construction sites within the city, and poor air circulation brought by urbanization are all important causes of haze [6].

The above characteristics of haze pollution determine that when studying how to prevent it, on the one hand, we need to examine its main economic factors in order to define the relevant core control elements and on this basis explore the policy management program. On the other hand, it is also necessary to examine the problem from the perspective of pollution diffusion and define its boundaries in order to ensure an appropriate scope of government policy implementation. For the former, many scholars [7] have discussed this issue from the public governance [8], economic [9] or environmental [10] points of view. Some researchers also found that haze pollution was highly correlated to human health, economic development and urban traffic issues [10].

For the latter, recent research mostly studied the existing temporal and spatial convergence or stratified club convergence of diffuse pollutants; further policy discussions will be carried out according to different convergence areas. Current study is divided into two pollutants. One area examines carbon dioxide convergence problems, such as the study of Strazicich and List [11], who measured the carbon dioxide emissions from 21 OECD countries from 1960 to 1997 by time series and cross-sectional analysis, and verified the convergence. Camarero et al. [12] found that per capita carbon dioxide emissions also converge in OECD countries and demonstrated that their decisive factors are convergence of energy intensity and carbonization index. The other area of study relates to the convergence of sulfur dioxide and nitrogen oxides emissions. List [13] used the time series method to prove that the emissions of sulfur dioxide and nitrogen oxides in the United States converged, which is the first attempt of applying convergence theory in the environmental field. Subsequently, more studies were conducted using regional data. Bulte et al. [14] based their research on US state-level data from 1929 to 1999, and investigated the existence of random convergence, β convergence and time convergence of nitrogen oxides and sulfur dioxide.

In China, the detection and statistical work on outdoor PM 2.5 data has been officially carried out since 2013, and subsequently in major cities across the country. The lack of such critical data has led to few authoritative studies on the convergence and the impact of fine particulate matter pollution in the fields of environmental science and economics so far.

This paper uses the non-linear time-varying factor model [15] to examine the time-spatial convergence of Chinese PM 2.5 from the perspective of urban observation. It draws on Geographic Information System data from the Columbia University International Earth Science Information Network Center, the Battelle Memorial Institute's idea of drawing the global PM 2.5 concentration map [16], and the mean data of PM 2.5 concentration of 95 major cities in China from 2000 to 2012, as predicted by aerosol optical depth (AOD) obtained from satellite monitoring. Furthermore, we conducted a spatial econometrics analysis to examine whether an Environmental Kuznets Curve (EKC) exists between the PM 2.5 pollution and economic development in China in the relevant convergence area. Based on our empirical evidence, this paper provides policy recommendations for China's future PM 2.5 pollution control. The other parts are arranged as follows: in the second section, the non-linear time-varying factor model used in the convergence test is introduced; the third section discusses time and spatial dimension convergence of the PM 2.5 pollution in China; the fourth section analyzes the relevance between the PM 2.5 pollution and regional economic development in convergence areas; the fifth section gives policy recommendations and the last section summarizes.

2. Theoretical Model of Pollution Convergence

The convergence issue of environmental pollution has been discussed with the convergence of economic development in the literature. However, there is no in-depth discussion of the existence of absolute convergence in the time-spatial dimension of environmental pollution, especially for PM 2.5. In this study, we use a non-linear time-varying factor model to investigate this issue. The model not only considers the heterogeneity of the individual; it also allows individual heterogeneity over time, and the heterogeneity of the evolution path. In more colloquial parlance, the mean of the individual is allowed to be different, the mean of the individual is allowed to change at different time nodes, and the change could follow different patterns.

In the short term, the development of different individuals varies, but from a longer perspective, individuals may reach a similar steady state through different ways of development. This kind of characteristic of short-term divergence and long-term convergence will be falsely classified as no convergence, according to the traditional methods of convergence. The non-linear time-varying factor model provides a way to test such convergence features in terms of the law of large numbers and the central limit theorem.

This section introduces the overall framework, ideas and main derivation of the non-linear time-varying factor model and its application in this paper. In the next section, we use the model to analyze whether there exists a trend of absolute time-spatial convergence or club convergence of PM 2.5 emissions in Chinese cities. First, we set the following Equation (1).

$$X_{it} = \delta_i \mu_t + \epsilon_{it} \tag{1}$$

For Equation (1), μ_t is the common factor and ϵ_{it} is the disturbance term. The μ_t can be either the cross-sectional mean of X_{it} or other variables. For example, in the process of economic convergence, it can be a cross-sectional mean of each country's economy performance, or a variable that has a big impact on the economy, such as interest rates and exchange rates. δ_i is an individual feature that measures the difference between X_{it} and the common factor.

In Equation (1), it is assumed that the individual characteristics do not change over time. However, in the non-linear time-varying factor model, this assumption is relaxed, allowing flexibility in individual idiosyncratic behavior over time and across sections through a time-varying factor δ_{it} to reflect this heterogeneity, as shown in Equation (2).

Further, we assume that the time-varying factor δ_{it} includes a random part, which could absorb the residual term in Equation (1). In fact, Equation (2) is a Laplace transformation process. δ_{it} can be seen as a transfer function, which translates a physical process described by the time variable μ_t into a process described by the variable X_{it}, but does not affect the nature of the process itself. In the general economic growth model, δ_{it} is called the transitional path.

$$X_{it} = \delta_{it} \mu_t \tag{2}$$

Assuming that the time-varying factor δ_{it} is in semi-parametric form, then it can be decomposed into

$$\delta_{it} = \delta_i + \sigma_i \xi_{it} L(t)^{-1} t^{-\alpha} \tag{3}$$

where δ_i is a non-time-varying individual feature, and ξ satisfies a standard independent identical distribution (i.i.d.) in the cross-section, but is weakly correlated in the time series. L(t) is a slow-varying function for which $L(t) \rightarrow \infty$ as $t \rightarrow \infty$. The function log(t), log(t + 1) conforms to this feature. Equation (3) ensures that for all $\alpha > 0$, the time-varying factor δ_{it} will eventually tend to δ_i. Then, the convergence test for the degree of haze between different regions is translated into the following null hypothesis:

$$H_0 : \delta_i = \delta_j, \text{ and } a > 0 \tag{4}$$

The alternative hypothesis is: H_1: There is at least one i that makes

$$\delta_i \neq \delta_j \text{ or } a < 0 \tag{5}$$

In order to test the hypothesis, Phillips and Sul [15] defined a relative transition coefficient:

$$h_{it} = \frac{\delta_{it}}{\frac{1}{N}\sum_{i=1}^{N} \delta_{it}} \tag{6}$$

This coefficient compares the time-varying coefficient with the cross-sectional mean of the sample, which reflects the deviation degree of the individual relative to the common steady state. If there is a convergence, the relative transformation coefficient $h_{it} \rightarrow 1$. At this time, the cross-sectional variance of h_{it} tends to zero, that is, when $t \rightarrow \infty$,

$$H_t = \sigma_t^2 = \frac{1}{N}\sum_{i=1}^{N}(h_{it} - 1)^2 \rightarrow 0 \quad (7)$$

If there is no convergence, then $\lim_{t\to\infty} H_t > 0$.

Based on this, we can use a fairly simple method to test the σ convergence, and the steps are as follows:

(1) Construct the cross-sectional variance ratio H_1/H_t
(2) Run the regression of the following formula:

$$\log(H_1/H_t) - 2\log L(t) = a + b\ \log(t) + \varepsilon_t \quad (8)$$

where t = [rT], [rT] + 1, ..., T. Phillips and Sul [15] recommended r = 0.3 when the number of samples was greater than 50 after a Monte Carlo simulation. In this article, we followed this setting. The form of the slow-varying function is usually set to L(t) = log(t), so the test is also called log(t) test.

(3) b conditionally converges to 2α. Let $\alpha = 0.5b$, and calculate the t statistic of b using the heteroskedasticity and autocorrelation consistent (HAC)standard. If $\alpha \geq 0$, and the one-sided t test satisfies $t < -1.65$, it is considered that at the 5% significant level, the null hypothesis of convergence is rejected. Otherwise, we accept the null hypothesis that there is convergence.

In this paper, in order to ensure the robustness of the non-linear time-varying factor model, we selected L(t) = log(t + 1) and L(t) = log(t − 1), and the results are shown in the following sections.

3. Time-Space Test of Air Pollution Convergence in China

3.1. Data Description

In this study, PM 2.5 data of China was collected by the Columbia University International Earth Science Information Network Center, the Battelle Memorial Institute, and satellite monitoring. From their raw data, the three-year moving mean value of PM 2.5 from 1998 to 2012, which was calculated by aerosol optical depth measured by Multi-angle Imaging SpectroRadiometer (MISR) [17] and Moderate Resolution Imaging Spectroradiometer (MODIS) [18]. We used ArcGIS10.3 to extract the telemetry data, and obtained PM 2.5 data for 288 cities in China during the same time period. After comparing the average data from 2010 to 2012 with the PM 2.5 test values in national key cities in 2012 published in the *China Environmental Quality Report 2013* of the Environmental Protection Ministry of the People's Republic of China [19], the data was confirmed to be consistent. It can be considered that this data set has a high degree of credibility for further simulation. In general, this database showed that selected cities on average increased from 34.76 in the year 2000 to 51.4 in the year 2012, with a standard deviation of 6.5. The annual growth rate for PM 2.5 increase was 3.3% (We have calculated all selected cites PM 2.5's descriptive statistics, which are not released here. If interested, please ask the author).

For the empirical study, we selected 100 major economic cities on the list of "Top 100 Cities" published in the whole country in 2012 as the research object, and examined the development of PM 2.5 pollution in key cities nationwide. The distribution of specific provinces and city names are shown in Table 1, below. Although the geographical area of these cities does not cover the majority of China, the cities contribute more than 80% of the country's economy. Therefore, these cities in our sample as research objects should represent the situation in China sufficiently.

Table 1. City names.

Province	City	Province	City	Province	City	Province	City
Beijing	Beijing	Zhejiang	Hangzhou	Guangdong	Guangzhou	Hubei	Wuhan
Tianjin	Tianjin		Ningbo		Shenzhen		Yichang
Hebei	Shijiazhuang		Wenzhou		Zhuhai		Xiangyang
	Tangshan		Jiaxing		Shantou	Hunan	Changsha
	Qinghuangdao		Huzhou		Foshan		Zhuzhou
	Handan		Shaoxing		Jiangmen		Changde
	Baoding		Jinhua		Kanjiang	Inner Mongolia	Hohhot
	Cangzhou		Quzhou		Huizhou		Baotou
	Langfang		Zhoushan		Dongguan	Guangxi	Nanning
Liaoning	Shenyang	Fujian	Fuzhou		Zhongshan		Liuzhou
	Dalian		Xiamen	Hainan	Haikou		Guilin
	Anshan		Putian		Sanya	Sichuan	Chengdu
Shanghai	Shanghai		Quanzhou	Shanxi	Taiyuan		Mianyang
Jiangsu	Nanjing		Zhangzhou	Jilin	Changchun	Yunnan	Kunming
	Wuxi		Longyan		Jilin	Shannxi	Xi'an
	Xuzhou	Shandong	Jinan	Heilongjiang	Harbin		Baoji
	Changzhou		Qingdao		Daqing	Gansu	Lanzhou
	Suzhou		Zibo	Anhui	Hefei	Qinghai	Xining
	Nantong		Dongying		Wuhu	Ningxia	Yinchuan
	Lianyungang		Yantai		Maanshan	Xinjiang	Urumqi
	Huai'an		Weifang	Jiangxi	Nanchang		
	Yanchen		Jining	Henan	Zhenzhou		
	Yanzhou		Weihai		Luoyang		
	Zhenjiang		Linyi		Anyang		
Chongqing	Chongqing	Guizhou	Guiyang		Nanyang		

Furthermore, we removed five cities from the sample due to the lack of economic data. The sample used included 95 major cities in China. Other data used in this article are from the *China Urban Statistical Almanac* and the urban database of the National Research Institute DRCNET's regional database.

3.2. Convergence Identification Process

For this study, we will validate the convergence of time dimensions and spatial dimensions of China's PM 2.5 by using the non-linear time varying factor model. The identification steps are as follows:

(1) The model was used to reconstruct Equation (8) across the whole sample selected in the study. If the result satisfies the acceptance criteria of the original hypothesis as described in the preceding sections, it is assumed that there is absolute convergence in time dimension for the whole sample.

(2) If the original hypothesis is rejected, it is assumed that there is no absolute convergence in the time dimension of the original sample. Furthermore, the time convergence club recognition algorithm rule constructed by Phillips and Sul [15] can be used to segment the sample population and distinguish the convergence club in the time dimension. If the recognition result is not significant, then the selected sample has no convergence in the time dimension.

(3) If step (1) is satisfied or step (2) is completed, it is necessary to further examine whether there is convergence in the spatial dimension. First, the global Moran index is used to investigate whether there is a spatial correlation in the whole sample. If the index shows that correlation does not exist, it is considered that there is no need for a further spatial convergence test. If the index indicates that there is a high spatial correlation, then the local Moran index is further used to investigate the convergence of the spatial correlation in the sample, and the appropriate spatial regions are divided.

(4) For the partitioned spatial region, the regression test of the non-linear time-varying factor model is carried out again for samples in each region. If the test result shows that there is a convergence trend, it is determined that there is a convergence of fine particulate matter emission concentration in the designated area. If the results are reversed, then step (2) is repeated to check whether there is an independent club convergence in the domain.

3.3. Time Convergence of Fine Particulate Matter

Based on PM 2.5 data from satellite telemetry, the convergence of PM 2.5 pollution in China's key cities is shown in Table 2. In Table 2, *b* is the estimated convergence coefficient required from Equation (8). The value below the coefficient is t-test result. As can be seen from the contents of the table, the estimate of *b* is positive, and $t > -1.65$, so it can be considered that the test should accept the original hypothesis. In other words, from the city-level data between 2000–2012, China's PM 2.5 has a nationwide absolute convergence. The results of the regression tests of columns one and three in Table 2 show the same trend, indicating that the result of this absolute convergence is robust.

Table 2. Study on convergence and robustness of whole city samples.

	L(t) = log(t + 1)	**L(t) = log(t)**	**L(t) = log(t − 1)**
b	18.41003	18.40986	18.40966
	2.83	2.83	2.83
a	−52.02939	−52.02884	−52.02823
	−2.88	−2.88	−2.88

Data under each coefficient is standard deviation.

Judging from the reality, these test results also meet actual expectations. In recent years, more and more reports have shown that haze pollution caused by PM 2.5 is a common pollution phenomenon within a country. When this pollution occurs, no area can be immune. This also shows that haze cannot be effectively suppressed by simply relying on the management of a single city or regional control. In terms of China, national joint governance can effectively control this pollution. In practice, the improvement of air quality during Nanjing's Youth Olympic Games in the Yangtze River Delta region in 2014 and the "APEC Blue" raised for the holding of the APEC meeting in Beijing in the same year are both embodiments of cross-regional joint governance.

The judgment of absolute convergence towards regression results of the non-linear time-varying factor model of the whole sample data also shows that there is no club convergence of the pollution of the China's PM 2.5 in the time dimension. Does this mean that there is also an absolute convergence of fine particulate matter in China emissions in spatial dimensions? In the next section, we will further examine the spatial correlation of China's PM 2.5 emissions.

3.4. Spatial Correlation Index Analysis of Fine Particles

The first law of geography according to Waldo Tobler [20] is that "everything is related to everything else, but near things are more related than far things" (Tobler W., (2016) "A computer movie simulating urban growth in the Detroit region". Economic Geography, 46(2): 234–240). This means that geographical objects or their attributes exhibit clustering, random, and regular distribution. A large number of literature has begun to pay attention to the spatial correlation between adjacent regions [21]. We use the global Moran index to estimate the spatial correlation of PM 2.5 between regions. The global Moran index is calculated as:

$$I = \frac{\sum_{i=1}^{n}\sum_{j=1}^{n} w_{ij}\left(A_i - \bar{A}\right)\left(A_j - \bar{A}\right)}{S^2\sum_{i=1}^{n}\sum_{j=1}^{n} W_{ij}} \quad (9)$$

where I is the global Moran index, representing the overall correlation of PM 2.5 between regions. $S^2 = \frac{1}{n}\sum_{i=1}^{n}\left(A_i - \bar{A}\right)^2$, $\bar{A} = \frac{1}{n}\sum_{i=1}^{n} A_i$, A_i is the population-weighted concentration value of PM 2.5 in region i, n is the number of regions, and W is the spatial weight matrix. The range of I is $-1 \leq I \leq 1$, and when I converges to 1, the PM 2.5 between regions exhibits a positive spatial correlation. When I converges to −1, the PM 2.5 between regions is negatively correlated. When I converges to 0, there is no spatial correlation between regions. In this study, we set the spatial weight matrix by using the rules shown in Equation (10).

$$W_{ij} = \begin{cases} 1 \text{ when region i is adjacent to region j} \\ 0 \text{ when region i is not adjacent to region j} \\ 0 \text{ when } i = j \end{cases} \quad (10)$$

It should be noted that the aforementioned "adjacent" includes both left and right, upper and lower adjacent, and diagonally adjacent. As long as the two regions have a common border or intersection, they will be defined as adjacent.

Table 3 shows the global Moran index of fine particulate matter emissions in China's key cities from 2000 to 2012. We can see that since 2000, the global Moran indices have been hovering above 0.75, and the Z test is significant. This proves that the fine particulate matter emissions in China have a very high spatial correlation. Particularly after 2009, the global Moran indices are more than 0.8 consecutively for three years, showing a strong spatial correlation.

Table 3. The global Moran index.

Year	Moran Index	E(I)	sd(I)	*p*-Value
2000	0.768	−0.011	0.102	0.000
2001	0.749	−0.011	0.102	0.000
2002	0.786	−0.011	0.102	0.000
2003	0.806	−0.011	0.102	0.000
2004	0.786	−0.011	0.102	0.000
2005	0.764	−0.011	0.102	0.000
2006	0.769	−0.011	0.102	0.000
2007	0.761	−0.011	0.102	0.000
2008	0.777	−0.011	0.102	0.000
2009	0.817	−0.011	0.102	0.000
2010	0.840	−0.011	0.102	0.000
2011	0.820	−0.011	0.102	0.000
2012	0.764	−0.011	0.102	0.000

Anselin [22] pointed out that the overall evaluation might ignore the atypical characteristics of local areas. We need to introduce local correlation index (LISA) to examine whether there is a significant gathering phenomenon of local areas. The local Moran index is used as follows:

$$I_i = \frac{(A_i - \bar{A})}{S^2} \sum_{j=1}^{n} W_{ij}(A_j - \bar{A}) \quad (11)$$

where I_i is the local Moran index, representing the correlation of PM 2.5 between the region i and its surrounding areas. A_i, $\bar{A}$, n, W, S^2 are the same as those of the global Moran index. When $I_i > 0$, the PM 2.5 of region i is positively correlated with its surrounding areas, expressed as high–high type clusters or low–low type clusters; when $I_i < 0$, the PM 2.5 of region i is negatively correlated with its surrounding areas, expressed as high–low type clusters or low–high type clusters.

We further constructed the local Moran index based on the data of particulate matter emissions in China's key cities from 2000 to 2012, to see whether there is a difference between the local Moran indices of different cities. Figures 1–4 show the local Moran indices of key cities in 2000, 2004, 2008 and 2012, respectively (In fact, we have estimated the local moran indexes for each year from 2000 to 2012, which are not released here. If interested, please ask the author).

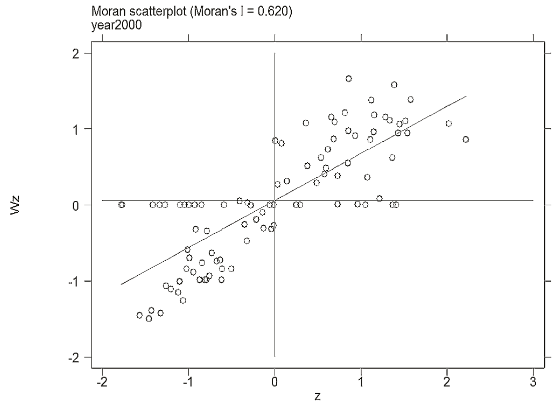

Figure 1. The local Moran index in 2000.

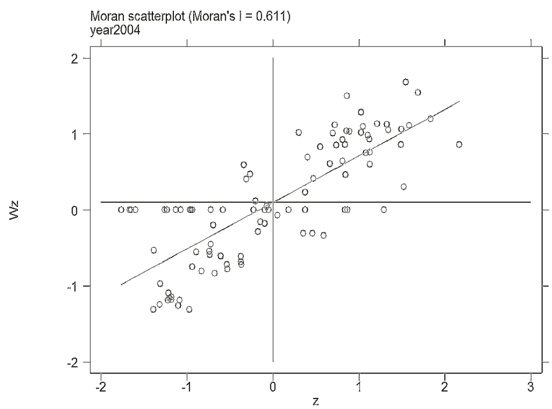

Figure 2. The local Moran index in 2004.

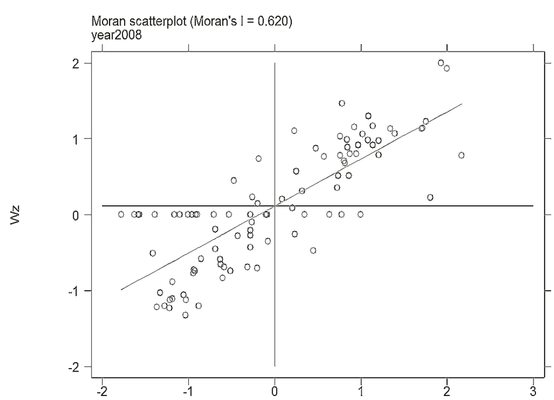

Figure 3. The local Moran index in 2008.

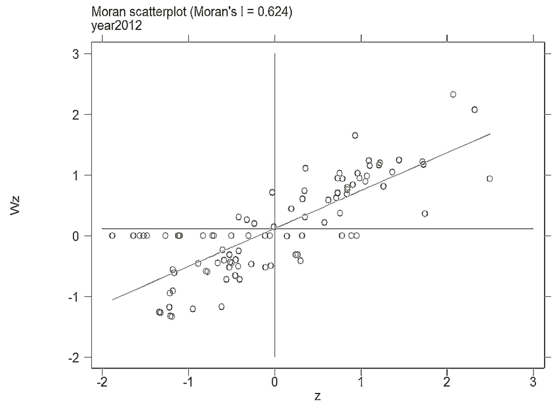

Figure 4. The local Moran index in 2012.

As shown in the figures, the local Moran indices of most cities fall in the first or third quadrants. This represents the existence of positive or negative correlations in the discharge of fine particulate matter in most cities. In the case of 2012, for example, there are only 11 cities displaying no spatial correlation. Through matching the relevant city serial number, there was an obvious correlation in eastern, central and western geographical space divisions.

According to the three economic zone division criteria proposed in "the National Economic and Social Development Seven Five-Year Plan" adopted by the National People's Congress in 1985, we divided the sample of 95 cities into the eastern, central and western regions, and once again tested the convergence of fine particle emissions in different regions.

3.5. Spatial Convergence of PM 2.5

The regression results of the non-linear time-varying factor model of the sub-regional urban agglomeration are classified in Table 4. It can be seen that the three regions show a steady spatial convergence within regions. However, it should be noted that the convergence rate of PM 2.5 in the middle and west sub-regions, especially in the middle sub-region, are significantly higher than that in the east.

Table 4. Sub-regional convergence test and robustness study.

Region	Parameter	L(t) = log(t + 1)	L(t) = log(t)	L(t) = log(t − 1)
East	b	1.434791 0.22	1.434617 0.22	1.434422 0.22
	a	−4.860393 −0.26	−4.859842 −0.26	−4.859232 −0.26
Middle	b	79.61884 4.78	79.61868 4.78	79.61949 4.78
	a	−222.0877 −4.79	−222.0872 −4.79	−222.0866 −4.79
West	b	71.89226 12.09	71.89209 12.09	71.8919 12.09
	a	−200.5981 −12.13	−200.5975 −12.13	−200.5969 −12.13

Data under each coefficient is standard deviation.

Through the sub-regional convergence test, we find that there exists an absolute time-converge of PM 2.5 emissions in 95 sample cities from 2000 to 2012. There has been a growing trend in the PM 2.5 emissions of China. Further, through the spatial converge test, we found that the convergence rates of PM 2.5 emissions in the middle and western regions are significantly higher than that of the eastern region. Since a large amount of previous research showed that China's economic development had an obvious three-regional convergence situation [23–25], the further question is whether there is a different relation between the economic development and the pollution caused by the PM 2.5 emissions in different geographical regions in China. In the fourth section, we are prepared to test this problem.

4. Relationship between Regional Air Pollution and Economic Development

4.1. Test Model Construction of Environment Kuznets Curve

Our basic idea is to use the traditional Environmental Kuznets Curve (EKC) equation to investigate the existence of the EKC curve across the country as well as in different regions, and to further determine the shape of the curve. On the basis of this, in view of the possible spatial influence in different regions and the construction of the spatial panel for different regions, the existence of the EKC relationship hypothesis between PM 2.5 and the regional economic development is examined under the spatial effect.

Based on the idea above, we first construct the standard EKC test model shown in Equation (12):

$$PM25_{it} = \beta_0 + \beta_1 GDP_{it} + \beta_2 GDP^2{}_{it} + \beta_3 GDP^3{}_{it} + \varepsilon \quad (12)$$

where i is the number of the i-th city, and t is the corresponding year. β is the estimated coefficient of the explained variable, ε is residual. $PM25_{it}$ refers to the average PM 2.5 concentration of city i in time *t*. GDP_{it} refers to the per capita GDP of city i in the year of t, expressed in *yuan*. $GDP^2{}_{it}$ is the square of per capita GDP and $GDP^3{}_{it}$ refers to the cube of per capita GDP.

As in all EKC evaluation studies (e.g., Grossman G M, Krueger A B, 1992 [26]), Equation (12) includes the square per capita GDP and cube per capita GDP, with their coefficients β_2 and β_3 representing the solution of the first-order condition and the second-order condition, which help to evaluate the shape of ECK between pollution and economic development [26]. Different shape of EKC could be found from Figure 5, and the decision rule could be shown as follows:

(1) when $\beta_1 > 0$, and $\beta_2 = 0$, $\beta_3 = 0$, it indicates that environmental pollution becomes more serious with economic growth, as shown in straight line a in the following graph;
(2) when $\beta_1 < 0$, and $\beta_2 = 0$, $\beta_3 = 0$, it indicates that environmental pollution is improved with economic growth, as shown by straight line b;
(3) when $\beta_1 < 0$, and $\beta_2 > 0$, $\beta_3 = 0$, it indicates that the quality of the environment in the process of economic growth improves after deterioration, and there is a positive U-shaped relationship, as shown in curve c;
(4) when $\beta_1 < 0$, and $\beta_2 < 0$, $\beta_3 = 0$, it indicates that the quality of the environment in the process of economic growth deteriorates after improvement, there is an inverted U-shaped relationship, which conforms to the typical EKC hypothesis, as shown in curve d;
(5) when $\beta_1 > 0$, and $\beta_2 < 0$, $\beta_3 > 0$, it shows that environmental pollution has a positive N-type curve with the level of economic growth, that is, with economic growth, environmental pollution increases first and then decreases, and then increases again, as shown by curve e;
(6) when $\beta_1 < 0$, and $\beta_2 > 0$, $\beta_3 < 0$, it shows that there is an inverted N-type curve between environmental pollution and the level of economic growth, as shown by curve f;
(7) when $\beta_1 = 0$, and $\beta_2 = 0$, $\beta_3 = 0$, it suggests that there is no environmental EKC curve.

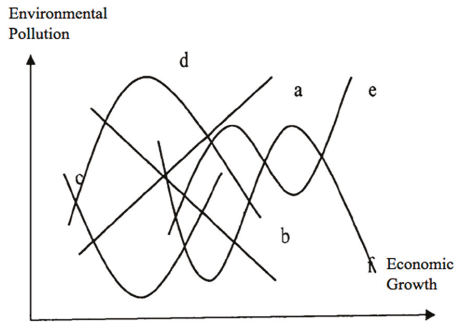

Figure 5. The shape of the Environmental Kuznets Curve (EKC).

After completing the judgment of the common panel model, we further construct the spatial lag model, and the relationship between the PM 2.5 emissions and the regional economic development is further tested. Since the spatial lag model assumes that the dependent variable depends on the weighted average effects of the spatial adjacent unit variables, we construct the following equation:

$$\text{PM } 2.5_{i,t} = \rho \sum W \text{ PM } 2.5_{i,t} + \beta X_{i,t} + \mu_i + \eta_t + \varepsilon_{i,t} \quad (13)$$

where PM 2.5 refers to the dependent variable, X refers to independent variable, W is spatial autoregressive coefficient and ε is expressed as random error terms.

According to the spatial error effect model (SEM), in the setting process of the model, it is likely that some variables related to the explanatory variables will be omitted, and these variables have spatial autocorrelation. At the same time, there may be random error shock space spillover effect among regions. The equation is expressed as:

$$\text{PM } 2.5_{i,t} = \beta X_{i,t} + \mu_i + \eta_t + \phi_{i,t} \quad (14)$$

$$\phi_{i,t} = \rho \sum \phi_{i,t} + \varepsilon_{i,t} \quad (15)$$

where ϕ refers to error of spatial autocorrelation.

4.2. Test Results

Table 5 shows the results of the correlation between PM 2.5 emissions and regional economic development in the urban sample of the whole cities, and sub-regional urban samples shown by panel regression.

According to the EKC judgment rules from the previous section, we can see from the table that there is a positive N-type EKC curve between the economic growth and PM 2.5 emissions of the whole sample. The same result also exists in the middle sub-region. The other test results show that, except for an inverted E-type EKC curve in the eastern region under a fixed effect model test, other test results do not support the hypothesis that correlation between economic growth and PM 2.5 emissions conformed to EKC in the eastern and western regions of China.

However, recent studies on geographic data panel analysis have shown that spatial lag effect and spatial error effect in spatial regional data may also have an effect on panel regression results. Therefore, we attempt to construct the spatial lag effect model (SLM) and the spatial error effect model (SEM) to try to further verify the relationship between economic growth and PM 2.5 emissions in the three regions of China from the perspective of the spatial panel. Before the construction of the relevant models, we consider what kind of spatial model should be tested.

Table 5. Panel estimation of the sub-regional Environmental Kuznets Curve.

	95 Cities			East		
	GLS	Random	Fixed	GLS	Random	Fixed
C	37.95818 *** 2.393372	37.95818 *** 1.314376	42.02255 *** 1.60851	42.80357 *** 4.629631	42.80357 *** 2.752783	60.3849 *** 3.326338
GDP	0.0003144 *** 0.0000671	0.0003144 *** 0.0000548	0.0001439 0.0000662	0.0002078 0.0001927	0.0002078 0.0001743	−0.000649 *** 0.0001933
GDP^2	-1.26×10^{-9} *** 4.16×10^{-10}	-1.26×10^{-9} * 4.70×10^{-10}	-1.75×10^{-10} 5.15×10^{-10}	-9.70×10^{-10} 2.42×10^{-9}	-9.70×10^{-10} 2.81×10^{-9}	7.96×10^{-9} *** 2.89×10^{-9}
GDP^3	1.64×10^{-15} ** 6.58×10^{-16}	1.64×10^{-15} * 9.04×10^{-16}	-9.55×10^{-17} 9.57×10^{-16}	1.06×10^{-15} 8.87×10^{-15}	1.06×10^{-15} 1.23×10^{-14}	-2.76×10^{-14} ** 1.23×10^{-14}
R^2	0.0268	0.0268	0.0289	0.0062	0.0062	0.0174
Hausman		19.39 ***			71.17 ***	
	Middle			West		
	GLS	Random	Fixed	GLS	Random	Fixed
C	35.87851 *** 1.381159	35.87851 *** 2.349397	36.41891 *** 2.601868	30.89278 *** 2.132795	30.89278 *** 5.16157	45.63498 *** 6.787467
GDP	0.0005855 *** 0.0000509	0.0005855 *** 0.0000883	0.0005685 *** 0.0000974	0.0001557 0.0003291	0.0001557 0.0006236	−0.0010218 0.0007374
GDP^2	-2.90×10^{-9} *** 3.72×10^{-10}	-2.90×10^{-9} *** 6.27×10^{-10}	-2.85×10^{-9} *** 6.67×10^{-10}	1.89×10^{-9} 1.10×10^{-8}	1.89×10^{-9} 2.05×10^{-8}	2.37×10^{-8} 2.30×10^{-8}
GDP^3	4.05×10^{-15} *** 6.58×10^{-16}	4.05×10^{-15} *** 1.09×10^{-15}	4.01×10^{-15} *** 1.15×10^{-15}	-4.79×10^{-14} 9.77×10^{-14}	-4.79×10^{-14} 1.90×10^{-13}	-1.82×10^{-13} 2.07×10^{-13}
R^2	0.1932	0.1932	0.1933	0.0077	0.0077	0.0164
Hausman		0.19			8.99 ***	

*, **, *** respectively represented the results were significant at the level of 10%, 5% and 1%, data under each coefficient is standard deviation.

In general, the spatial model study applied SLM or SEM based on the comparison of SLM model and SLM-LM and SEM-LM, as well as SLM-Robust and SEM-Robust. If SLM-LM is more significant than SEM-LM, and SLM-Robust passes the significant test while SEM-Robust does not, SLM will be selected. In the case of the contrary, SEM will be selected. In this study, our test results are shown in Table 6.

Table 6. Test results of the Spatial Lag Effect (SLM) and Spatial Error Effect (SEM) Models.

	East		Middle		West	
	Result	*p*-Value	Result	*p*-Value	Result	*p*-Value
LM Test for Spatial Lag	342.16	0.0000	21.1906	0.0000	20.393	0.0000
Robust	8.7567	0.0031	12.3319	0.0004	4.3701	0.0366
LM Test for Spatial Error	335.5374	0.0000	17.9619	0.0000	17.8563	0.0000
Robust	2.1337	0.1441	9.1032	0.0026	1.8334	0.1757

From the results of spatial lag and spatial error models, there are both spatial lag effect and spatial error effects in the sub-zone sample group. In this paper, we again carried out model tests of spatial lag effect and spatial error effect on the three regions, the results of which are shown in Table 7.

It can be seen from the results that, after considering spatial lag effect and spatial error effect, in the east, middle and west zones divided by study sample, there is a significant positive N-type EKC curve relationship between PM 2.5 emissions and regional economy. This indicates that during the observed period, China's regional PM 2.5 emissions increased first, then declined, and then increased again with the development of the economy. The results of this test are also in accordance with the fact that Chinese residents had more significant physical reactions to haze pollution brought by PM 2.5 after the year of 2012.

Table 7. Results of Spatial Lag Effect and Spatial Error Effect.

	East		Middle		West	
	SLM	**SEM**	**SLM**	**SEM**	**SLM**	**SEM**
GDP	1.251658 *** 22.55061	0.921818 *** 25.39407	0.00049175 *** 12.232792	0.000430432 *** 13.861633	0.001485549 *** 8.427643	0.001329185 *** 8.507777
GDP^2	-1.28×10^{-2} *** −14.1	-9.36×10^{-3} *** −16.2	-1.90×10^{-9} *** −6.86	-1.78×10^{-9} *** −8.75	-3.54×10^{-8} *** −6.04	-3.13×10^{-8} *** −6.07
GDP^3	4.10×10^{-5} *** 10.154337	3.10×10^{-5} *** 12.4	2.45×10^{-15} *** 5.34	2.35×10^{-15} *** 7.06	2.60×10^{-13} *** −3.65	2.30×10^{-13} *** 4.73
R^2	0.8983	0.9552	0.896	0.9344	0.9119	0.9346
w	−0.236068 ***		−0.236068 ***		−0.236068 ***	
e		0.55599 ***		0.334969 ***		0.332994 ***

*, **, *** respectively represented the results were significant at the level of 10%, 5% and 1%, data under each coefficient is standard deviation.

5. Policy Recommendations

Based on the above analysis of air pollution and economic growth, we can get the following revelation on future sustainable governance policy for northeast Asia region and for China. First of all, in northeast Asian countries, resources and environmental issues have become an important factor affecting the economic growth. To some extent, they have even become the bottleneck of a country's economic growth. The conclusion of this paper also shows that haze pollution emissions represented by PM 2.5 keep growing throughout China. Similar to all industrialized countries, China's haze pollution problems are accompanied by industrialization. Environmental problems caused by industrial production are becoming more and more prominent, and the constraints of resources and the environment are becoming increasingly significant. Therefore, whether it is for the use of resource products or air pollution control, we should proceed from the overall situation paying attention to pollution control policy and the top design of resource utilization policy, and strengthening the consistency of policy implementation throughout the nation.

Secondly, although this paper mainly focused on the haze pollution issue inside China, as the first section introduced, haze is a boundary environmental pollution. Considering that most northeast Asian countries are border connected, the more haze pollution China faces, the more potential pollution risk there will be for its neighboring countries. Hence, all of northeast Asia should face such challenges together, and have more interaction through their governments and industries in order to bring out more concerted actions in the future.

Thirdly, economic development is an important driving force for industrial environmental efficiency convergence. China's environmental efficiency and its cities' respective levels of economic development, urban scale, financial capacity, and industrial development characteristics are often highly consistent. From 2000 to 2012, the phenomenon that PM 2.5 emissions increased first and then declined and further increased again with the development of the economy occurred in the east, middle and west regions of China. The selected cities, which again warned that the relationship between the economy and the environment does not necessarily follow a transformation path where the environmental quality improves, then deteriorates and further improves again with the economic growth, as assumed in traditional economic theory. In real world, due to the changes in economic structure and industrial structure, the environmental quality in the region is likely to have many inflection points with the change of the size of an economy.

Therefore, China's future economic development mode must be transformed from quantity to quality to avoid the inhibition effect of China's rising industrial development capacity to the convergence of environmental efficiency, especially for the middle and western sub-regions. As the main carriers to undertake the industrial transfer in the eastern developed areas, the middle and western sub-regions are regarded as the key areas of the development of future industrialization, urbanization, low-carbon industry and green transformation in China. Therefore, we need to start from the beginning to: reinforce the policy guidance of clean industrial production, energy saving, a recycling economy, and other aspects; strengthen the support to capital, technology and personnel of resource conservation and environmental protection; encourage the elimination of backward technology and enhance environmental control to reduce environmental pollution and improve industrial environmental efficiency.

Finally, there are significant differences in the environmental efficiency of industries in the different regions of China, as well as the possible spillover of environmental regulation policies' impact and the diffusion of environmental pollution. In view of this, in the formulation of environmental governance policies, regional coordinated development policies and differentiated measures should be formulated on a case-by-case basis for spatial differences among regions. More importantly, such coordination should be taken into account more for geographically close cities or urban agglomerations. On this basis, it is possible to realize a win–win situation of economic growth and environmental protection by considering the conflict between the development policies of each administrative region and promoting the formation of a good environment cooperation mechanism across regions to gain a sustainable future.

6. Research Conclusions

This study used satellite telemetry data, the non-linear time-varying factor model, and the global and local Moran indices to test the spatial-time convergence of PM 2.5 in China. The results showed that there is an absolute convergence of PM 2.5 emissions in China in time trend, and there is a difference in the convergence rates of the eastern, central and western regions of China. This difference is manifested in the central and western regions, especially in the central region. The convergence rate in the central region of PM 2.5 is significantly higher than that of eastern region.

Furthermore, the results of the general panel model and the spatial analysis model reveal that the relationship between economic development and air pollution is still different in all regions of the country. First, there is a positive N-type EKC curve between economic growth and PM 2.5 emissions in selected sample cities. Secondly, considering spatial lag effect and spatial error effect, the regression model of the Environmental Kuznets Curve shows that there is also a significant positive N-type EKC curve relation between economic growth and PM 2.5 emissions in the east, middle and west sub-regions of China.

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Carbon Reduction Potential of Resource-Dependent Regions Based on Simulated Annealing Programming Algorithm

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Abstract: In recent years, developing countries, especially resource-dependent regions, have been facing the paradox of ensuring both emissions reduction and economic development. Thus, there is a strong political desire to forecast carbon emissions reduction potential and the best way to achieve it. This study constructs a methodology to assess carbon reduction potential in a resource-dependent region. The Simulated Annealing Programming algorithm and the Genetic algorithm were introduced to create a prediction model and an optimized regional carbon intensity model, respectively. Shanxi Province in China, a typical resource-dependent area, is selected for the empirical study. Regional statistical data are collected from 1990 to 2015. The results show that the carbon intensity of Shanxi Province could drop 18.78% by 2020. This potential exceeds the 18% expectation of the Chinese Government in its '13th Five-Year Work Plan' for Controlling Greenhouse Gas Emissions. Moreover, the carbon intensity of the province could be further reduced by 0.97 t per 10,000 yuan GDP. The study suggests that the carbon emissions of a resource-dependent region can be reduced in the following ways; promoting economic restructuring, upgrading coal supply-side reform, perfecting the self-regulation of coal prices, accelerating the technical innovation of the coal industry, and establishing a flexible mechanism for reducing emissions.

Keywords: resource-dependent regions; carbon reduction potential; carbon intensity; Simulated Annealing Programming; Shanxi Province

1. Introduction

The growing concentrations of greenhouse gases (GHGs), especially in resource-dependent regions, has been one of the major global challenges as it brings about environmental degradation and natural disasters threatening human safety and health [1]. To reduce its influence and avoid more dangerous long-term effects, the Intergovernmental Panel on Climate Change (IPCC) called for limiting the increase in average global temperature to no more than 2 °C. To this end, we may need to see a reduction in carbon dioxide (CO_2) by at least 50% until 2050, which means that any future emissions leeway could become extremely constrained according to Pan et al. [2]. Consequently, there is a strong political desire to forecast carbon emissions reduction potential and the best means of achieving it [3]. Accordingly, we need to identify the factors influencing carbon reduction, understand in depth the mechanism of their effects, create a series of predictive models, and optimize carbon reduction potential.

The existing research on carbon reduction potential mainly covers the following; carbon emissions measurements [4–7], carbon emissions impact factors and mechanism analysis [8–14], scenario analysis, carbon emissions predictions [15–19], and policy simulations [20–22]. The key to establishing carbon emissions reduction policies and realizing the situation lies in the identification and analysis of carbon impact factors and their underlying driving mechanisms. Existing research shows that many factors affect carbon emissions, of which the most important ones include economic development, industrial structure, technological advance, energy prices, and social investment. Almulali et al. [23] investigate 30 Sub Saharan African countries using panel data. Their results show that economic development is the central driving factor behind increasing carbon emissions in the economies investigated. Almulali [24] investigates the major factors that influenced carbon emissions in 12 Middle Eastern countries and showed that social investment and GDP were the most important factors increasing carbon emissions in these countries. Tunc et al. [9] identified the factors that contribute to changes in CO_2 emissions in the Turkish economy by utilizing the Log Mean Divisia Index (LMDI) method. The results showed that the main component in Turkey that determines changes in CO_2 emissions is economic activity. De Freitas et al. [10] examines a decoupling of the growth rates of economic activity and CO_2 emissions and energy consumption in Brazil from 2004 to 2009. Their results indicate that carbon intensity and energy mix were the main determinants of emissions reduction in Brazil. Li et al. [25] discuss the driving forces influencing China's CO_2 emissions based on the Path–STIRPAT model, a method combining path analysis with stochastic impacts by regressions on population, affluence, and technology (STIRPAT). The analysis showed that GDP per capita was the main factor influencing China's carbon emissions. Yao et al.'s [26] studied on the factors affecting energy consumption in China and major industries recognizes that energy prices were the most important factor influencing abatement costs. Wu et al. [27] used several environmental data envelopment analysis (DEA) models with carbon emissions, showing that the energy efficiency improvement in China's industrial sector is mainly driven by technological improvement. Li et al. [28] discuss the regional differences in impact factors on carbon emissions using the STIRPAT model. Their results indicate that improving technology levels produces a small reduction in carbon emissions in most emissions regions. Overall, the factors that affect carbon emissions can be summarized as economic development, industrial structure, technological advance, energy prices, and social investment.

Among the existing studies, research on carbon emissions reduction potential has mainly focused on a global [29–31], regional [32], or national [33–35] macro scale, while studies on a small or medium scale (such as provincial or urban) are still relatively rare. Domestic research in China on factors affecting carbon emissions at the provincial and municipal levels has only recently appeared. From the perspective of geography, there are significant differences in population growth, household consumption, economic development level, energy resource advantages and technical levels among provinces and among the eastern, central, and western regions of China. Thus, it is important to reveal the multi-factor interaction mechanism of carbon emissions that may be masked by such regional differences.

In terms of research methods, an economic model is the most frequently used means of analyzing each driving factor that has an impact on carbon emissions or the potential to reduce carbon emissions (specific models focus on structure or index decomposition). O'Mahony uses an extended Kaya identity as the scheme and applies the LMDI as the decomposition technique to decompose change in the carbon emissions of Ireland from 1990 to 2010 [12]. In applying the STRIPAT method, Liddle et al. [36] compare the carbon elasticity of income and population of Organization for Economic Co-operation and Development (OECD) countries with that of non-OECD countries. In another recent study, Wang et al. [37] analyze the influencing factors of carbon emissions in energy consumption in Suzhou City by using an index decomposition model. Liang and Zhang [38] analyze the impact factors of carbon emissions in a manufacturing industry based in the eastern coast of Jiangsu Province and show that reduction in energy intensity and improvement in energy consumption structure are key to achieving the goal of low-carbon emissions.

In these studies, a potential assumption in either structural decomposition or exponential decomposition models is that the effects of the driving factors on carbon emissions are isolated and unrelated. However, this assumption is impractical. Wang and Yang [39] and Zhang et al. [40] study the factors affecting carbon emissions in different levels in China. The results demonstrate that the driving factors of carbon emissions affected one another. To separate the interactions, a partial least squares regression and a principal component analysis are used in some studies [41,42]. However, the clustering process brings new problems. The loss of the original information can be inconvenient to subsequent policy development. Therefore, a certain methodology system needs to be constructed that not only takes into account the interactions among factors but also retains the information of the original indicators.

This study contributes to the literature in the following ways: (1) The Simulated Annealing Programming (SAP) algorithm is introduced into carbon reduction research to assess carbon reduction potential. As a result, a new methodological system is constructed that covers gaps in existing studies. (2) In the case example of Shanxi province in China, this study analyzes the carbon reduction potential of a resource-dependent region. The results provide evidence for policy makers in such regions. (3) This study predicts the feasibility of the carbon reduction goals in the Chinese '13th Five-Year Work Plan' and, further, quantitatively calculates the potential of carbon reduction.

The remainder of this paper is organized as follows. Section 2 introduces the prediction method for carbon intensity based on the SAP. Section 3 presents the empirical analysis and results, and finally Section 4 discusses targeted suggestions for the policy-making process as relevant to carbon reduction.

2. Materials and Methods

As the carbon emissions system is a typical composite system composed of a natural and an artificial system, it has the characteristics of openness, being away from an equilibrium state, non-linearity, and the existence of random fluctuation. In order to study the mutual influence of each impact factor in the composite system, to adapt to environmental changes due to economic development and changes, and, ultimately, to be a reasonable state, this study uses complex system theory and methods, including selecting carbon intensity as the system dependent variable and the influencing factors as the independent variables. To solve regional carbon emissions reduction potential, we construct a model to capture the dynamic quantitative relationship between carbon intensity and the system elements and we then examine the prediction and optimization of carbon intensity.

2.1. Prediction Method of Carbon Intensity Based on the Simulated Annealing Programming

Due to the complexity of carbon emissions reduction, it is very difficult to establish a dynamic model that describes the evolution of the emissions reduction system. The traditional method is limited by the rationality of the system structure, the complexity of the parameter calculations, and the accuracy of the final conclusion. The SAP is a stochastic search algorithm that is suitable for solving large-scale combination optimization problems [43]. It can overcome nonlinear, multi-dimensional, and complex system models and also determine the difficult structure of the equation [44]. The simulated annealing programming has been applied in the fields of production scheduling, control engineering, machine learning, neural networks, and signal processing, among others. This study introduces it into the field of carbon emissions prediction.

2.1.1. Simulated Annealing Programming Algorithm

The algorithm is derived from the enlightenment of 'annealing' physical phenomena in thermodynamics. The lower the temperature is, the lower the energy of the object is; when the temperature is low enough, the liquid begins to condense and crystallize. In the crystalline state, the system's energy state lowers to a minimum [45].

The SAP algorithm is based on the simulation of the solid annealing process. Using the Metropolis acceptance criterion, a set of parameter control algorithm processes, namely the cooling schedule, is established to give the algorithm an approximate optimal solution in polynomial time [46]. The physical image and statistical properties of the solid annealing process are the physical background of the SAP. The Metropolis acceptance criterion guarantees the algorithm will escape the local optimal 'trap', and the reasonable choice of the cooling schedule is the prerequisite for the application of the algorithm [47]. The flow chart of the Simulated Annealing Programming Algorithm is shown in Figure 1.

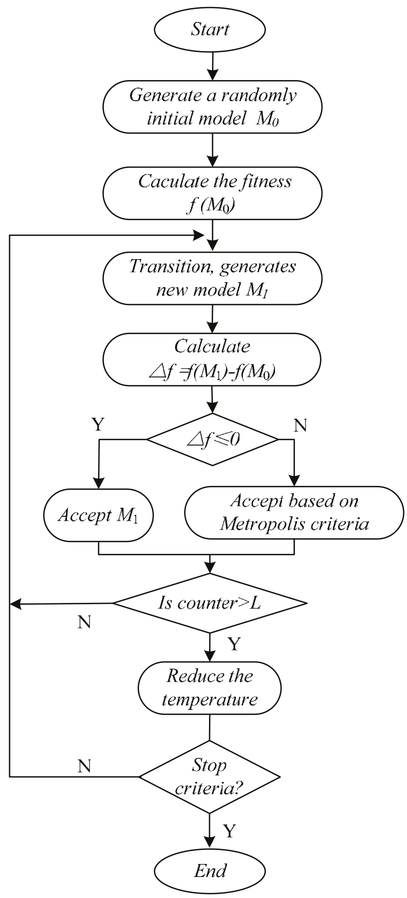

Figure 1. The flow chart of the Simulated Annealing Programming Algorithm.

It is calculated by the initial solution and the initial value of the temperature control parameters; the current solution repeats the 'new solution → calculate the objective function difference → judge whether to accept → accept or discard' iteration and gradually attenuates the T value. The current solution at the end of the algorithm is the approximate optimal solution. The annealing process is controlled by the cooling schedule parameters, including the initial value of the control parameter and its attenuation factor, the number of iterations per value (called the length of a Markov chain), and the stop condition.

The SAP has the following characteristics [48]: (1) to avoid the loss of the local optimal solution, we accept the worse solution with a certain probability. (2) To improve the reliability of the optimal solution, the SAP algorithm slowly reduces the control parameters, improving the acceptance criterion until the control parameters tend to zero. (3) The objective function requirements are fewer and are not subject to continuous micro-constraints, under which the definition domain can be arbitrarily set.

(4) To improve the quality and operation speed of the solution, the introduction of implicit parallelism is employed to solve the nonlinear problem.

2.1.2. Theoretical Model and Variable Selection

The theoretical model to solve the nonlinear model of regional carbon intensity and the key factors is as follows:

$$CI = f(X_{1t}, X_{2t}...X_{it}...X_{nt}) \quad (1)$$

where *CI* is the value of regional carbon intensity, X_{it} is the *t*-th year of the *i*-th key factor, and $f(x)$ is a non-linear function. The key influencing factors are entered into the SAP algorithm in order to find the quantitative relationship between regional carbon intensity and each influencing factor.

Five influencing factors of carbon intensity, including economic development, industrial structure, technological advances, energy price, and social investment, are selected as independent variables for their significance. The mechanism of action is described as follows.

(1) Economic Development. According to Nag and Parikh [49] and Ang [50], there is an inverted U-shaped relationship between economic development and carbon intensity. That is, carbon intensity increases with growing GDP up to a threshold level beyond which carbon intensity drops with higher GDP. The development of the economy not only increases the total amount of carbon emissions, but also improves energy efficiency and reduces carbon intensity levels. Thus, the economy development provides the basic support for the development of technology, laying a strong foundation for the reduction of carbon emission. This study uses per capita GDP indicators to characterize the level of economic development.
(2) Industrial Structure. Yang and Liu [51] believe that the industrial structure is an important factor in differences in carbon emissions levels; Gao [52] believes that the industrial structure, the level of industrialization, and its openness to the public have a significant impact on carbon intensity. This study uses the proportion of tertiary industry to GDP to characterize the impact of industrial structure on carbon intensity.
(3) Technological Advances. It was generally considered that technological advances have a positive effect on CO_2 emissions reduction [53–55]. The effect is mainly manifested in two ways. First, technological advances can improve the efficiency of mechanical equipment, increase the use of artificial proficiency, and increase output in simple ways, directly reducing carbon intensity. Secondly, technological advances can improve unit energy output, increase the efficiency of the use of social resources, and thereby reduce the social needs of products, product prices, and overall investment, forcing the elimination of excess capacity and the adjustment of the industrial structure, evenly reducing carbon intensity. In this study, total productivity indicators are used to characterize the impact of energy technology.
(4) Energy Price. Greening et al. [56] believed that energy prices had a significant impact on carbon intensity in direct or indirect ways. Chen and Tong [55] argued that the direct impact of energy prices was low. As an indirect impact, energy prices have an effect mainly by adjusting the energy consumption structure, thereby indirectly reducing carbon intensity. As a direct impact, a rise in prices can encourage companies to reduce carbon intensity, reduce their quantity of use, and utilize clean alternative energy sources to improve efficiency. This study uses raw materials, fuel, and the power purchase price index as indicators to characterize energy prices.
(5) Social Investment. Research shows that the expansion of investment levels on carbon emissions has bidirectional effects on carbon intensity [57,58]. On the one hand, the expansion of investment can increase total production scale, thus increasing carbon intensity; on the other hand, the investment increase can drive economic development, which plays a positive role in promoting technological innovation. Former studies show that a modest increase in investment can promote an increase in carbon intensity, but excessive growth is counterproductive. This study uses total societal fixed asset investment as the indicator to characterize the level of social investment.

Five indicators such as per capita GDP, the proportion of tertiary industry to GDP, total productivity, raw materials, fuel, power purchase price index, and total societal fixed asset investment were used to characterize the level of economic development, industrial structure, technological advances, energy price, and social investment respectively.

2.2. Prediction Method of Carbon Emissions Reduction Potential Based on the Genetic Algorithm

A genetic algorithm (GA) is a global optimization search algorithm proposed by a group search strategy and the information exchange between the individuals in the group when the adaptive system is established and gradually developed [59]. Its main characteristic is that it does not depend on gradient information and realizes the evolution of the group by iteration under the premise of using the initial population and genetic operation. The result avoids the local optimum, the search scope is wider, and carbon intensity can be optimized under a multi-target constraint scenario.

According to national economic planning and regional economic and social situations, high growth scenarios, benchmark scenarios (planning scenarios), and low growth scenarios (three economic growth model) all set different policy scenarios, and the global parallel optimization of the GA based on the natural genetic mechanism can be used to optimize carbon intensity under different policy scenarios. The specific calculation process is shown in Figure 2 and described as follows.

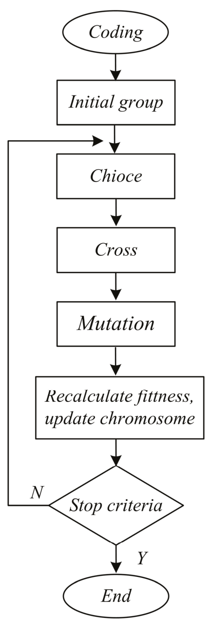

Figure 2. The flow chart of the Genetic Algorithm.

(i) Coding. The problem is described as a string through the fitness calculation, wherein each solution corresponds to a fitness value. The project code string is $(X_{1t}, X_{2t}, \ldots, X_{nt})$.

(ii) Forming the initial group. The initial population is generated by random method, indicating some things such as a random chromosome, the fixed number of groups, and the project is set to 100.

(iii) Calculating the fitness. The fitness is an indicator of measuring the solution (chromosome) as good or bad and relates to the objective function of the algorithm model. The project fitness calculation function is $fitness = f(X_{1t}, X_{2t}, \ldots, X_{nt})$; the corresponding objective function is $CI_{optimization} = Min(fitness)$.

(iv) Choice. This is the process of entering the next generation directly from the old group, choosing the finest individual.
(v) Cross. This is the process of crossing and converting some parts of chromosomes (strings).
(vi) Mutation. This is to randomly rewrite one or several genes representing a chromosome in a string to represent another trait so that the chromosome is updated.
(vii) Termination. This should repeat (iii), (iv), (v), and (vi). When the optimal population reaches a certain requirement or the evolution of the algebra reaches a set value, it terminates. This study intends to stop when the evolutionary algebra reaches 20 to take the optimal value.

Substituting the key factor control range in different scenarios into the multi-objective optimization program of the above-mentioned GA, we get the $CI_{optimization}$ and input this value into Equation (1); namely, we obtain the regional carbon emissions reduction potential. In theory, if several factors can be reasonably regulated and balanced, the regional carbon intensity can reach the optimal value (lowest); that is, there is a certain emissions reduction leeway. At the same time, the value of the independent variables corresponding to the optimal carbon intensity represents the policy path that enables the regional carbon emissions reduction potential.

3. Results

As there are both theory and models as discussed above, it is necessary to explore the carbon reduction potential of resource-dependent regions in a typical region with a resource-based economy. Shanxi, a representative resource-dependent province, is chosen for investigation through the SAP model.

3.1. Study Area

Shanxi Province is located in the middle of the Yellow River Basin, which has a population of 36.64 million and covers an area of 156,700 square kilometers. Shanxi is the largest coal production and transportation province as well as an energy and heavy chemical industry base in China. The total area of coal, which accounts for about 40% of the province, is 64,800 square kilometers. Relying on coal resources, the Shanxi economy has achieved rapid development, but, at the same time, it has also created the phenomenon of a 'coal economy'. The volatility of coal prices has led to swings in regional economies (as shown in Figure 3).

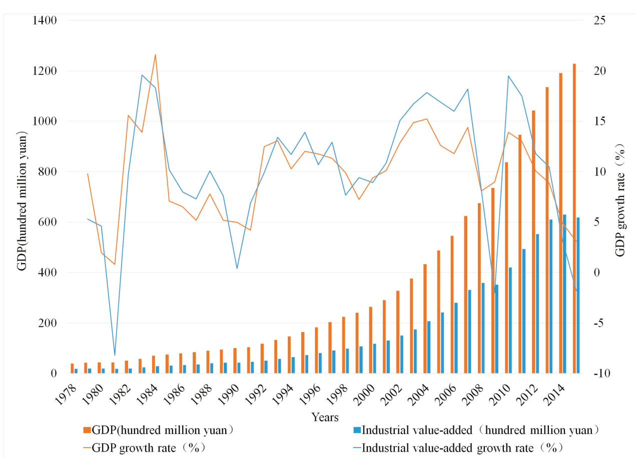

Figure 3. An overview of economic development in Shanxi Province in China. Note: the data for GDP and industrial value-added are obtained from the Shanxi Statistical Yearbook (1979–2015).

At the same time, even more unsettling is that coal resources have brought about environmental pollution and carbon emissions, which has led to Shanxi Province becoming one of the most carbon-dense regions in China. A development model characterized as long-term and highly dependent on coal resources has raised a series of problems and contradictions by creating regional resource waste, capital outflows, the weakening of institutions, and a decrease in innovation capacity. All of this seriously restricts the development of the local society and economics. Thus, the study of carbon emissions reduction potential in Shanxi Province is a great reference point for the theory and practice of carbon reduction in resource-dependent areas.

3.2. Prediction Model of Carbon Intensity for Shanxi Province

In this section, the prediction model of carbon intensity for Shanxi Province was deduced through the SAP algorithm. The valuable values of the SAP algorithm were determined and the data required were collected. More importantly, a fit test was conducted to verify the validity of the prediction model.

3.2.1. Variable Setting and Data Resources

The carbon intensity in Shanxi Province was selected as the dependent variable, expressed as *CI*; the influence factors on carbon intensity were selected as the independent variables. X_0, the per capita GDP, is an indicator of economic development; X_1, the proportion of the tertiary industry in GDP, is an indicator of industrial structure; X_2, the total factor productivity, is an indicator of energy technology; X_3, the raw material, fuel, and power purchase price index, is an indicator of energy prices; and X_4, the total societal investment in fixed assets, is an indicator of social investment. The values of *CI* and X_i are shown as Table 1.

Table 1. The Carbon Intensity and its influence factors in Shanxi Province from 1990 to 2015.

Years	*CI* (t Carbon/10,000 Yuan)	X_0 (Yuan/Person)	X_1	X_2	X_3	X_4 (10,000 Yuan)
1990	11.62	1480.78	32.24	0.202	100.00	123.41
1991	10.83	1520.40	34.31	0.200	108.01	133.04
1992	9.40	1689.20	34.80	0.188	120.86	155.39
1993	9.51	1888.87	34.92	0.171	164.25	193.93
1994	9.39	2060.50	34.89	0.176	189.06	210.02
1995	13.35	2284.24	35.04	0.188	213.82	224.31
1996	12.32	2526.75	35.09	0.199	224.08	235.30
1997	10.68	2784.72	35.76	0.221	228.57	238.83
1998	10.03	3030.79	35.85	0.241	222.40	235.96
1999	8.61	3218.80	36.63	0.264	215.72	235.25
2000	8.23	3472.89	36.83	0.283	219.82	239.49
2001	7.94	3796.03	37.65	0.308	223.78	243.56
2002	8.44	4256.35	37.09	0.353	229.60	244.78
2003	8.36	4858.86	37.30	0.400	247.51	251.87
2004	7.98	5564.06	37.50	0.448	283.39	264.97
2005	8.06	6277.36	37.43	0.509	306.63	272.92
2006	7.98	7040.28	36.50	0.582	314.61	277.01
2007	7.37	8116.32	36.63	0.661	331.28	288.37
2008	6.56	8759.57	38.01	0.665	391.90	326.73
2009	6.12	9194.59	40.11	0.637	378.58	320.52
2010	5.84	10,047.33	38.61	0.753	412.65	332.38
2011	5.78	11,280.38	37.29	0.871	446.08	350.66
2012	5.46	12,361.70	37.32	0.924	437.60	354.87
2013	5.21	13,391.54	37.02	0.981	417.91	356.64
2014	5.07	13,977.79	37.80	0.996	419.33	355.21
2015	4.87	14,278.4	38.78	1.000	439.47	348.82

Considering the availability of data and the difference in the statistical caliber of each year, this study chooses time-series data from 1990 to 2015. The original data of variables in Table 1 were collected from the Shanxi Statistical Yearbook (1991–2016) and the China Energy Statistical Yearbook (1991–2016) and were standardized to eliminate the effect of dimensions. The detailed CI calculation and the carbon emissions coefficients of fossil fuels are provided in Appendix A. The detailed total factor productivity calculations and raw data are provided in Appendix B.

3.2.2. Prediction Model of Carbon Intensity

The data in Table 1 are input into the SAP model given in Section 2.1. The parameters are defined as: initial temperature T_0 = 200, termination temperature T_{min} = 0, and temperature drop coefficient α = 0.95. The resulting fit coefficient R^2 is 0.91, and the fitted equation is given as follows:

$$\hat{CI} = \frac{\frac{x_4+99.96}{x_3-95.78} - 0.014x_0 + x_2 + 395.67}{2x_1 - 27.676 - \frac{x_3-99.81}{57.04x_2}} \quad (2)$$

3.2.3. Model Fit Test

In this section, goodness of fit tests are performed to verify the superiority of the SAP, and the results are shown in Table 2.

Table 2. Goodness of Fit tests for the Simulated Annealing Programming model.

Years	Simulated Annealing Programming Fit Results		Years	Simulated Annealing Programming Fit Results	
	Fit Value $\hat{CI}$	**Residual $\hat{\varepsilon}$**		**Fit Value $\hat{CI}$**	**Residual $\hat{\varepsilon}$**
1990	11.637	0.021	2003	8.169	−0.196
1991	9.785	−1.044	2004	7.978	0.002
1992	9.570	0.171	2005	7.740	−0.319
1993	10.508	0.993	2006	7.706	−0.273
1994	11.148	1.758	2007	7.210	−0.158
1995	11.538	−1.809	2008	6.769	0.207
1996	11.509	−0.808	2009	5.997	−0.119
1997	10.689	0.007	2010	6.083	0.241
1998	10.147	0.114	2011	6.007	0.230
1999	9.333	0.722	2012	5.545	0.082
2000	9.081	0.853	2013	5.177	−0.035
2001	8.517	0.576	2014	4.785	−0.281
2002	8.462	0.017	2015	4.509	−0.361

As we can see in Table 2 and Equation (2), the maximum absolute residual of the SAP model is 1.809 in 1995, the minimum absolute residual is 0.002 in 2004, and the fitting degree is 0.91, which is greater than 0.9. Thus, the advantages and feasibility of using the SAP model to construct the prediction model of carbon intensity can be verified. The fitting chart of the carbon intensity prediction model is shown as Figure 4. Obviously, the trend line of the prediction value is similar to that of actual value in Figure 4.

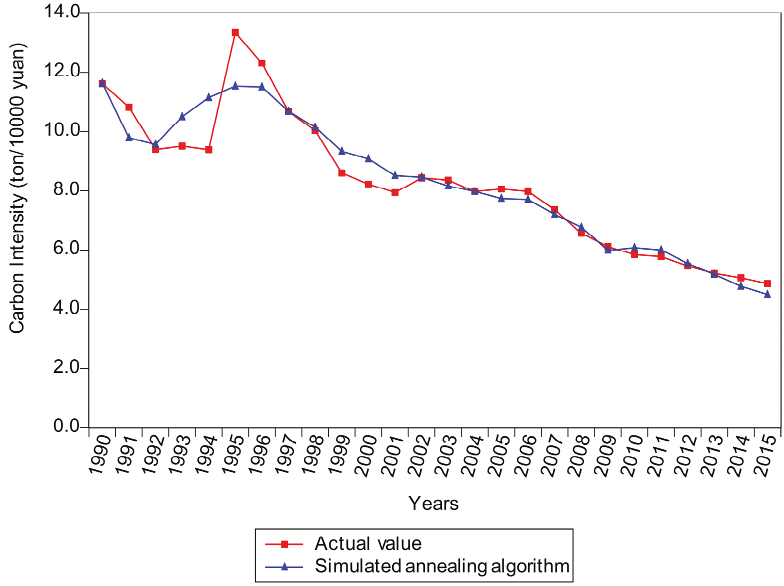

Figure 4. Fitting chart of the carbon intensity prediction model.

3.3. Analysis on Reachability of Carbon Reduction Targets of 13th Five-Year Work Plan in Shanxi Province

As already stated, according to the '13th Five-Year Work Plan for Controlling Greenhouse Gas Emissions', Shanxi Province has had a target of carbon emissions reduction that translates to a carbon intensity reduction of 18% by 2020. We now estimate whether the carbon emissions reduction target is achievable using the following formula. Q denotes the reachability of the carbon reduction targets of '13th Five-Year Work Plan' in Shanxi Province.

$$Q = \frac{CI_{2015} - \hat{C}I_{2020}}{CI_{2015}} \times 100\% \tag{3}$$

According to the '13th Five-Year Work Plan' of Shanxi Province, the Shanxi Province Development and Reform Commission '13th Five-Year Work Plan' and development program, the Shanxi Province energy development planning, and other '13th Five-Year' control targets, X_0 to X_4 predictions of Shanxi Province are as follows. X_0 = 16,154.7 yuan/person, X_1 = 38.25%, X_2 = 1.15, X_3 = 440.51, X_4 = 561.78 billion yuan; input them into Equation (2), the result is $\hat{C}I_{2020}$ = 3.955 t/10,000 yuan. Table 1 shows the actual carbon intensity in 2015 as 4.87 (t/100,000 yuan); when input it into Equation (3), the result is Q = 18.78%.

As we forecast, the carbon intensity of Shanxi Province in 2020 would be about 18.78% less than that in 2015. This result indicates that the target of carbon reduction, 18% declared in the new five-year (i.e., the '13th-Five-Year Work Plan') will be achieved.

3.4. Estimation of Carbon Emissions Reduction Potential in Shanxi Province during the 13th Five-Year Work Plan

The above assessment shows that the carbon emissions reduction targets in the '13th Five-Year Work Plan' for Shanxi Province can be achieved. However, there appears to be room for additional reduction; we now use the GA to solve this. After taking into account the energy development trend in Shanxi Province, adopting the suggestions of authorities involved and targets set in the '13th Five-Year

Work Plan', and holding expert hearings, we reached the expected value of carbon intensity in 2020 in Shanxi Province as follows in Table 3.

Table 3. Expected/predicted values of carbon intensity in 2020 in Shanxi Province.

Variable \ Type	Predicted Value in 2020	Expected Value in 2020
X_0 (yuan/person)	16,154.7	14,539.23–17,770.17
X_1 (%)	38.25	31.02–46.54
X_2	1.15	0.7–1.3
X_3	440.51	351.58–527.36
X_4 (10,000 yuan)	561.78	279.06–453.47

After the expected value range of Table 3 is input into the GA optimization program (Figure 1), the results are shown in Table 4.

Table 4. Comparison of carbon intensity prediction models before and after optimization.

State	$\hat{CI}$	X_0	X_1	X_2	X_3	X_4
Before	3.955	16,154.7	38.25	1.15	440.51	561.78
After	2.985	17,182.56	42.66	1.28	440.66	506.29

As can be seen in Table 4, according to the SAP model of 2020, the carbon intensity prediction value is $\hat{CI}$ = 3.955 t/10,000 yuan; after further optimization of influencing factors input into the GA program, we find a better carbon intensity value, namely, $\hat{CI}_{optimization}$ = 2.985 t/10,000 yuan; this means that for each additional 10,000 yuan of GDP, emissions can be reduced by 0.97 t.

4. Discussion

This study follows the streams of system analysis, system prediction, system optimization and system decision-making. As such it combines the key influencing factors on carbon emissions found in the literature of economic development, industrial structure, energy technology, energy price, and social investment, and then uses a per capita GDP, tertiary industry as a proportion of GDP, total factor productivity, raw materials, fuel, power purchase price index, and total society fixed assets investment as characterization indicators.

(1) The study introduces a SAP algorithm to solve the quantitative relationship between carbon intensity and five influencing factors in Shanxi Province, and establishes a prediction model for carbon intensity. According to the model's test, the fit degree is strong and the residual values are low. The conclusion is that the SAP algorithm is superior for the prediction of carbon emissions.

(2) According to the model's forecast, in Shanxi Province, at the end of the '13th Five-Year Work plan', a carbon intensity of 3.955 t/10,000 yuan will be achieved, which is 18.78% lower than the carbon intensity level in 2015; thus, as promulgated by China in its '13th Five-Year Work Plan for Controlling Greenhouse Gas Emissions', the Shanxi Province carbon intensity reduction task of 18% can be achieved.

(3) In Shanxi Province, through the comprehensive evaluation of the policy direction, controlling objectives during the '13th Five-Year Work Plan' and optimizing the influencing factors, the GA can be used to further lower the carbon intensity and thereby further reduce the carbon intensity in Shanxi Province by 0.97 t/10,000 yuan; this means that each additional 10,000 yuan of GDP can achieve a further 0.97 t reduction of emissions in Shanxi Province.

According to the above analysis, we suggest that several measurements are identified in resource-dependent regions to enable carbon reduction potential.

(1) As a big coal region, Shanxi Province has a responsibility to the country; thus, when it implements a carbon emissions reduction policy, several factors should be taken into account, including its actual economic development, population density, and technological advancement, which all contribute to the establishment of a proper low-carbon industrial system. With a low-carbon industrial system, Shanxi not only can solve its outstanding problems, but can also promote equilibrium between coal supply and demand in China, which will promote continuous and scientific development throughout its regional economy, society, and energy and emissions reduction.

(2) In order to provide a big impetus for the province's coal supply-side structural reform, which will promote its transformation and the upgrade of its economic structure, we should focus on the province's coal industry by decreasing production capacity, inventories, leverage, and costs, thereby making up for any shortage. In accordance with the law, a number of coalmines have been closed. According to regulations, the reorganization and consolidation of a number of coalmines, reductions, and the withdrawal of the need for excess coal capacity can generate an orderly exit through a market mechanism. In 2016, Shanxi closed 25 coal mines, reducing coal production capacity by 23.25 million tons. By 2020, the province will reduce excess coal capacity by more than 100 million tons.

(3) The coal price formation mechanism needs improvement. A coal price mechanism that can correctly reflect the market supply and demand, the scarcity of resources, and the cost of environmental damage should be explored and established. The role of industry associations should be fostered and a coal pricing self-discipline mechanism should be established. To improve such a price self-discipline mechanism, pilot programs can be established through the Yang Coal Group and the Shanxi Coal Group. In addition, a coal price supervision mechanism could be established and promoted. Further, some reforms can be extended, including reform of the electricity price, the power trading system, the electricity plan, and electricity side sales. To that end, we can cultivate the main electricity sales market, establish and improve the electricity market trading mechanism, and also expand the field and scope of direct supply and raise the electricity market scale in and out of the province. We should also innovate the coal trading mechanism, striving to become a national coal-trading pilot in the near future.

(4) The pace of scientific and technological innovation in the coal industry should be increased. We should establish the Shanxi Coal Clean Utilization Investment Fund. Among other projects, we should focus on supporting coal and electricity integration, the modern coal chemical industry, coal bed methane (gas) extraction and utilization, and carbon trading and carbon emissions reduction. Moreover, to emphasize the clean and efficient use of coal, we should implement a group of major technology innovated coal-based and low-carbon projects. In addition, among other new energy industries, we should foster the development of wind power, photovoltaic power generation, and biomass power generation, which will hasten the development and utilization of new energy industrialization.

(5) In view of our regional economic development characteristics, a flexible carbon emissions reduction mechanism should be built. The Chinese government, over the years, has implemented an extensive administrative control mechanism. Under this system, local government administrations utilize mandatory means to meet the required targets for carbon emissions. As it can directly help these regions to more readily attain these goals, the system is unlike any other, especially in terms of the control of industrial emissions reduction and the elimination of single enterprises. However, among other challenges, the system's shortcomings lie in issues such as information asymmetry, the high cost of environmental management, the inefficiency of government decision-making, and the inefficiency of government agencies. As for the implementation efficiency and the carbon emissions reduction effect, selecting a reasonable market-based policy tool is still the key to carbon emissions reduction; market-oriented regulatory policies are of two primary types, a price-based carbon tax regime and an aggregate control-based

emissions trading scheme. The lack of market-oriented regulation means that enterprises still follow a cost-benefit principle in their investments in carbon emissions reduction, which generates environmental externalities. Compared with the above two policies, the effect of public participation regulation is more lasting, although it is slow. The most important characteristic of the control mechanism is that the driving force is endogenous. If the public's behavior is insufficient or irresponsible, the mechanism will fail. Only through the comprehensive use of these policies can a flexible mechanism of carbon emissions reduction be established, which will engender greater enthusiasm among the relevant subjects and ensure the realization of carbon emissions reduction targets.

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Appendix A

The detailed carbon intensity calculation and the carbon emissions coefficients of fossil fuels are shown as follows.

According to the Shanxi Statistical Yearbook (1991–2016), the China Energy Statistical Yearbook (1991–2016), and the China Entrepreneur Investment Club (CEIC)database, carbon dioxide emissions are calculated using the Standard Coal Coefficient and the Carbon Emissions Coefficients based on the estimation of nine fuel categories (coal, coke, gasoline, crude oil, kerosene, diesel, fuel oil, natural gas, and electricity). At the same time, in order to eliminate the impact of price changes, 1990-based GDP is used; the ratio of the two is the annual value of carbon intensity in Shanxi Province. The formulae are shown as follows:

$$C = \sum_{i=1}^{n} (CO_2)_i = \sum_{i=1}^{n} E_i \times CEF_i \tag{A1}$$

$$CI = \frac{C}{GDP} \tag{A2}$$

where i in Formula (A1) is the fossil fuel type (i = 1, . . . , 9), E_i is the i-th fuel terminal consumption, and CEF_i is the carbon emissions coefficient for each of the nine fossil fuels (see Table A1).

Table A1. The Carbon Emissions Coefficients of fossil fuels.

Energy Type	Standard Coal Coefficient (kgce/kg)	Carbon Emission Coefficient kg CO_2/kgce
Coal	0.7143	0.7476
Coke	0.9714	0.1128
Gasoline	1.4714	0.5532
Crude oil	1.4286	0.5854
Kerosene	1.4714	0.3416
Diesel	1.4571	0.5913
Fuel oil	1.4286	0.6176
Natural gas	1.3300	0.4479
Electricity	0.1229	2.2132

Note: The unit of the Standard Coal Coefficient of natural gas is kgce/m^3 (IPCC).

Appendix B

The detailed total factor productivity calculation and raw data are shown as follows.

The DEA method is used to measure total factor productivity. The model used is the traditional Charnes & Cooper & Rhodes (CCR) model and is shown as follows.

$$\max h_{j0} = \frac{\sum_{r=1}^{s} u_r y_{kj0}}{\sum_{i=1}^{m} v_i x_{ij0}}, u \geq 0, v \geq 0 \quad \text{(A3)}$$

$$s.t. \frac{\sum_{r=1}^{s} u_r y_{kj}}{\sum_{i=1}^{m} v_i x_{ij}} \leq 1, j = 1, 2, ..., n, u \geq 0, v \geq 0 \quad \text{(A4)}$$

where X_{ij} represents the *i*th input of the *j*th decision unit and y_{kj} denotes the *k*th output ($y_{kj} > 0$) of the *j*th decision unit. The CCR model can be established by aiming at the efficiency index of the decision-making unit j_0 and using the efficiency index of all decision-making units as constraints.

In this study, the output variable is the Total Output Value of State Holding Industrial Enterprises (SHIE) and the inputs are the net value of the fixed assets of SHIE and the mean annual employees of SHIE (see Table A2). Considering the availability of data and the difference in the statistical caliber of each year, this study chooses time-series data from 1990 to 2015; the indicators are from 1990 as the base period was reduced.

Table A2. The Total Factor Productivity of Shanxi Province from 1990 to 2015.

Year	Total Factor Productivity	Total Output Value of SHIE (100 Million Yuan)	Net Value of Fixed Assets of SHIE (100 Million Yuan)	Mean Annual Employees of SHIE (10,000 People)
1990	0.202	95.36	568.96	168.68
1991	0.200	117.73	617.48	164.36
1992	0.188	145.35	670.13	160.16
1993	0.171	179.46	727.28	156.06
1994	0.176	221.56	789.30	152.06
1995	0.188	273.54	856.60	148.17
1996	0.199	337.71	929.65	144.38
1997	0.221	416.94	1008.92	140.68
1998	0.241	514.76	1094.95	137.08
1999	0.264	733.23	1186.86	133.57
2000	0.283	837.80	1208.21	134.04
2001	0.308	954.26	1477.74	128.42
2002	0.353	1075.90	1565.59	119.90
2003	0.400	1375.43	1628.87	111.47
2004	0.448	1950.52	1768.87	119.04
2005	0.509	2534.62	2050.57	119.84
2006	0.582	3048.27	2455.02	117.98
2007	0.661	4038.18	2787.29	107.79
2008	0.665	5199.80	3454.90	114.56
2009	0.637	5188.06	3984.60	118.35
2010	0.753	6614.18	4130.20	119.16
2011	0.871	8207.82	5023.63	120.47
2012	0.924	9620.06	5472.79	126.48
2013	0.981	11,522.96	6188.69	129.35
2014	0.996	13,802.25	7155.48	132.89
2015	1.000	14,257.18	7599.46	136.32

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An Empirical Analysis of the Impact of Agricultural Product Price Fluctuations on China's Grain Yield

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Abstract: In recent years, food security, especially supply, has been an important issue in China's agricultural production. The stability of grain prices is related to the stability and development of the grain market. Based on agricultural production data from 1970 to 2015, this paper explores the influence of agricultural product price fluctuation on grain production by using the cobweb theory and vector error correction (VEC) model. The results show that changes in grain production in China are affected by fluctuations in agricultural product prices, that the production change lags behind the price change, and that there is a long-term equilibrium relationship between grain yield and agricultural product price. A Granger causality test shows that the change in agricultural product price is the Granger cause of grain yield change.

Keywords: agricultural product price; grain yield; cobweb theory; VEC model; food security; China

1. Introduction

The most important problem in Chinese agriculture is the well-being of farmers, and farmers' most important protection comes from food production. Since the economic reforms and policies of opening up beginning in the late 1970s, China's agricultural prices have shown a trend of frequent fluctuations, which has had a very negative impact on farmers' grain production and China's agricultural economy [1]. Frequent fluctuations in food prices are not conducive to farmers forming stable food price expectations; thus, farmers cannot use food prices to make a reasonable grain production plan for the next year. In addition, a rise in food prices causes other commodity prices to rise, which leads to inflation and is not conducive to China's economic stability [2]. When the price of agricultural products rises, the stabilization of prices will become a key concern of the government. The government will often take measures to suppress this process. However, when the prices of agricultural products fall, the lack of policy assistance measures will often come at the expense of the interests of farmers, seriously damaging the enthusiasm of farmers [3]. Once farmers' production incentives are diminished, the effective supply of food is difficult to protect. The pricing of agricultural products is an important part of China's macro-control policies for economic development, and the implementation of such policies has a very important role in the supply and demand of agricultural products in China. Food pricing also has a crucial impact on China's economic development and the welfare of farmers. Frequent fluctuations in food prices will make it difficult for the government to implement effective macro-control measures for the grain market. Thus, the fluctuation of the price of agricultural products is closely related to China's grain production and food security. The goal of this paper is to explore how the volatility of agricultural prices affects grain production.

The empirical study of the price fluctuation of agricultural products began in the early 20th century. The economist Henry L. Moore described the concept of "business cycles" in 1914 and "cotton income and price forecasts" in 1917. These studies were pioneering works on price fluctuations of agricultural products. Moore's work also directly promoted the development of agricultural product prices and the academic content related to supply and demand. CSC Sekhar analyzed the characteristics of agricultural product price fluctuations based on monthly data from 1970 to 2001. The results showed that the international agricultural product price cycle is longer than the domestic agricultural product price cycle [4]. Lu showed that food demand is constantly increasing, while the food supply is decreasing due to rising food costs; thus, the resulting imbalance in food supply and demand is the main cause of food price volatility [5]. Gilbert argued that the impact of climate factors on major grain-producing areas can lead to unpredictable food production [6]. Abbott agreed with this view [7]. In addition, Xie and He think that ecological land changes [8] and cultivated land use intensity [9] (including the multiple cropping index [10]) will also make production forecasting complex. Xie and Wang's paper shows that the variables associated with the agricultural products yield are significantly correlated with farmland abandonment [11]. Rayner and Reed found that a series of policies adopted by the government, such as trade intervention policies and price support policies, helped to improve food price volatility [12]. This is also recognized by Denver Colorado [13], Hennessy [14] and John Baffes's [15] articles. Zhang and Chen show that grain indices did not significantly respond to the expected volatility in oil prices, in contrast to the petrochemicals and oil fats indices [16]. Ceballos used the GARCH model to study the transmission mechanism of international grain prices on the domestic food price [17]. Shuqin also used this method to discuss transmission relationships of price volatility relationships between the international and domestic prices of three grains in 24 developing countries [18]. Lee's results suggest that the volatility of oil and grain markets are very persistent since the common factor generating the stochastic volatilities of oil and commodity markets is highly persistent [19].

Since the reform and opening up, although the overall trend of China's grain production has exhibited rapid growth, in the short term, there have been large price fluctuations that have led to food production declines [20]. The National Bureau of Statistics published the article "China's food supply and demand and the 'thirteen five' trend forecast," which noted that during the period 1999–2003, grain production continued to decline, and in the past few years, there was not only a large reduction in grain-sown area, but yield levels were also reduced. In 2003, the national grain output was only 430.7 million tons, down 15.9% from 1998 and down 3.4% annually, to the lowest level since 1990. Jiang using a local adjustment model, concluded that China's grain price elasticity is relatively low, and an excessive supply of labor is one of the reasons why China's grain production reflects the weakening of prices [21]. Liao and Li using the main rice-producing areas in central China as the research object, found that the use of fine varieties and fertilizers is an effective way to improve food production [22]; Sun and Yu used the Granger causality test to analyze the intrinsic relationship between grain yield and price and found that the impact of grain purchase price on grain production is greater than the impact of retail prices on grain production [23]. Wen and Wang showed that China's grain prices are not only affected by traditional factors such as inflation, grain production, labor price and exchange rates but also by national financial and other agricultural policies [24]. Tokgoz believes that the rise in crude oil prices will also affect food prices to a certain extent [25]. Zhan and Feng used the C-D function to analyze the relationship between grain price and sown area in China and concluded that an increase in the grain price will cause farmers to increase the planting area to increase the input of grain production [26]. Luo using the Nerlove model of China's food supply response to conduct an empirical analysis, showed that China's grain supply elasticity is not high in the short- or long-term, indicating that China's grain production is difficult to change quickly according to the sown area [27]. Wei and Wang based on a VEC model study, found that in the short term, the previous period of food prices, farmer income and the previous period of grain yield have negative effects on the current grain yield; the negative effects of grain production in the previous period are the greatest, but in the long run, grain prices have positive effects on grain production [28]. Han and Wei based on the cobweb model, showed that food prices with market supply and demand changes gradually deviated from the equilibrium point, and this fluctuation cannot be resolved based on market regulation [29]. Wu and Li used the univariate EGARCH model and the VAR model to study the asymmetry of China's single grain market price and the asymmetry between different grain markets based on the weekly data of wheat, maize and soybean grain market prices. The results show that only corn market prices are asymmetric; the asymmetric price of different food market prices showed that the price increase in the wheat market would trigger a rise in corn and soybean market prices, whereas increased corn and soybean prices would not trigger an increase in wheat prices [30]. Wu and Huo used the VAR model to analyze the characteristics and fluctuation relationship between the two-track system and the marketed grain price fluctuation. They found that the price volatility of the wheat market and the corn market under the market was significantly less than the price volatility of the two-track system [31]. In the face of food price volatility and food security instability, safeguarding food security is very important [32]. Fraser and Legwegoh believe that national policies are needed to ensure adequate food storage [33]. Paul [34] and Sckokm [35] also thinks so.

The study of food prices and food production is of great practical value to the maintenance of food security and the promotion of food market development. Through the review of these documents, we can find that most scholars use the supply and demand point of view to research food production problems. These researchers use the supply reaction model to study the relationship between grain prices and yield, and some research is based on the price of a single grain variety, but there is a lack of empirical research on agricultural prices for food production. Therefore, based on the data of agricultural product prices and grain yield in the past 30 years, this paper conducts an empirical analysis of the relationship between agricultural product price and grain yield by using a VAR model and Granger causality test on the basis of descriptive analysis of agricultural product price and grain yield. Based on the relevant results, the paper presents policy advice to reduce the frequent fluctuations in China's agricultural price situation.

2. The Transmission Mechanism of Agricultural Products' Price Fluctuations and Grain Production

The cobweb theory is a dynamic analysis theory that uses the elasticity principle to explain the different fluctuations in some commodities with long production periods when they lose balance [36]. The basic assumption of the cobweb theory is that the current production of the commodity is determined by the price in the previous period. According to the assumptions of the cobweb model, farmers will determine the current grain-sown area according to the price of the previous period before the grain production is carried out. Then, the current grain price will have determined the grain yield of the next period to a certain extent. Thus, in the food supply and demand model, the impact of price changes on the supply of food will be substantial. The higher the price of agricultural products, the stronger the enthusiasm of farmers, and the food production will increase. In contrast, lower prices of agricultural products will dampen the enthusiasm of farmers to increase grain production so that farmers will reduce the next year's planting plan, which will lead to a reduction of that year's grain production.

Based on the cobweb theory, the price transmission mechanism of agricultural products takes the price as the link. When the price of an agricultural product fluctuates abnormally, the farmers will spontaneously adjust the agricultural planting structure in the next period. If the prices of agricultural products continue to fall, the farmers will choose other crops with a high economic value, and this will ultimately affect the supply of grain production in China. Figure 1 shows the transmission of agricultural product price fluctuations in food production. Through the analysis of the price transmission mechanism of agricultural products, we can find the interaction effect and transmission effect of each link in the industrial chain, adjust the reasonable distribution of the stakeholders of each link, maintain the income level of the agricultural producers and the living standard of the consumers, stabilize the agricultural market price, and achieve a smooth transition in China's socio-economic transformation. As the most effective means of agricultural market regulation mechanism, the price of agricultural products plays an important role in regulating production and consumption.

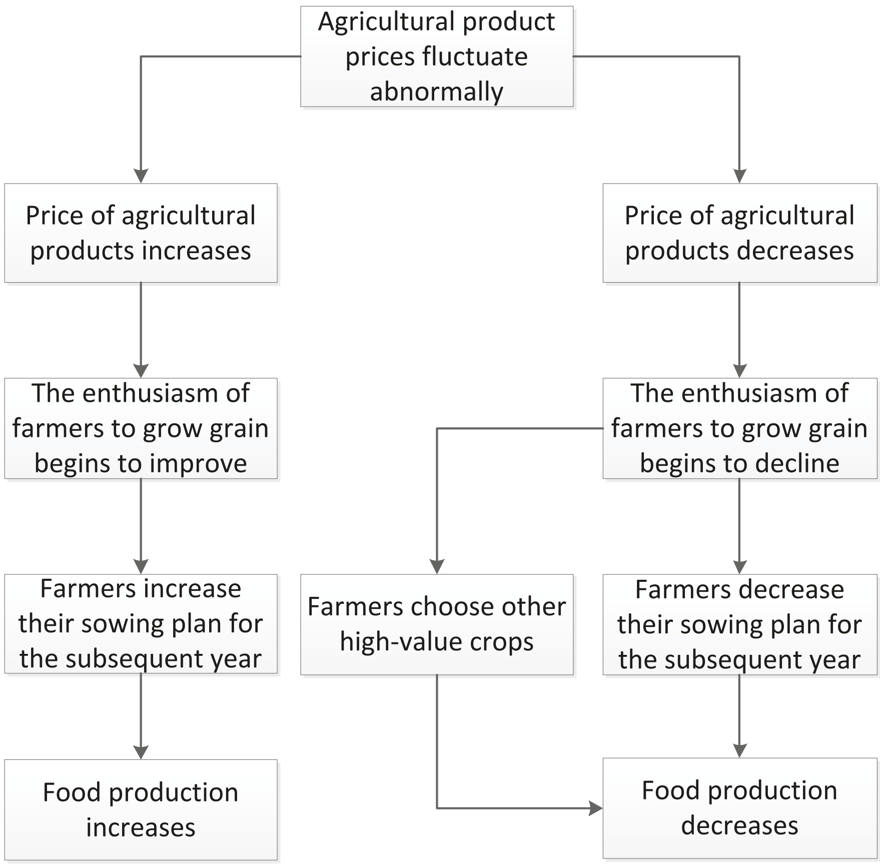

Figure 1. The transmission mechanism of agricultural product price to grain yield.

3. Data Sources and Research Methods

3.1. Index Selection and Data Sources

In this paper, the time series data of grain yield, planted area and agricultural price index from 1970 to 2015 were used as samples to analyze how the price changes of agricultural products affected food production.

To study the relationship between agricultural prices and food production, we regard grain production as a representative indicator of food production. Analysis based on economic theory shows that food production and agricultural prices are closely related. In this paper, we set the basis as 1985 (1985 = 100). The agricultural production price chain index was found according to the "China Statistical Yearbook [37]". We can derive the agricultural production price fixed index by the calculation and conversion, denoted as P. Grain production is denoted as Q_i, and grain sown area is denoted as S_i, where i = 1, 2, 3, ... The data are from the "China Statistical Yearbook" (1970–2015) [37].

3.2. Model Building

Based on the VEC model, this paper examines the relationship between agricultural product price fluctuation, grain yield and sown area. The mathematical expression of the VEC model is as follows:

$$\Delta \mathbf{y_t} = \mathbf{a}_0 \boldsymbol{VECM_{t-1}} + \boldsymbol{\alpha}_1 \Delta \mathbf{y_{t-1}} + \ldots + \boldsymbol{\alpha}_\mathbf{p} \Delta \mathbf{y_{t-p}} + \boldsymbol{\beta} \Delta \mathbf{x_{t-1}} + \boldsymbol{\varepsilon}$$

In the equation, $\mathbf{y_t}$ is the endogenous variable column vector, $\mathbf{x_t}$ is the exogenous variable column vector, and p is the lag order. $\boldsymbol{VECM_{t-1}}$ is the error correction term.

4. An Empirical Analysis of the Impact of Agricultural Product Price Changes on Grain Yield

4.1. Descriptive Analysis of Food Price Volatility

4.1.1. China's Basic Trends in Food Production over the Past 45 Years

In general, China's grain production includes corn, wheat and rice. Before the reform and opening up (1978), China's grain production growth rate was extremely slow, and the yield was always below 300 million tons. After the reform and opening up, China's grain output soared to over 300 million tons, but the volatility was also greater than before, and the range also became larger. In 1997, China's total grain output exceeded 500 million tons for the first time, reaching 504.53 million tons, an increase of 8.13% over the previous year. However, in 1999, grain output began a continuous reduction for several years, with the production dropping to 430.69 million tons, and people worried about this. Beginning in 2004, China's grain production increased for 10 consecutive years. In 2013, food production reached 601.938 million tons. Since the reform and opening up, grain yield has been the most concerning problem in China's agricultural sector. China's gradual reform and purchasing system of unified marketing reduced the number of orders to improve the purchase price of grain. These measures caused food production to rapidly grow. To study the problem, the grain yield data for 1985 to 2015 were selected, and the grain yield trend chart was drawn from the sample data. It can be seen from Figure 2 that China's grain production has been very unstable, showing cyclical fluctuations in its characteristics. The food production in China can be divided into the following five stages: the first stage is from 1970 to 1977,when grain production was growing slowly in volatility, the second stage is from 1978 to 1984,when food production began to grow rapidly, the third stage is from 1985 to 1998, when grain production fluctuated within a small range; the fourth stage is from 1998 to 2003, when grain production fell for five consecutive years after reaching its highest point in 1998 and reached its lowest point in 2003, resulting in food problems, appeals to the government and concern among policy-makers. Food production continued to decline until 2004. The fifth stage is from 2005 to the present, when, with the efforts of government and the majority of farmers, food production began to rise. In 2005 and 2006, the production continued to increase. Since then, grain production has been steadily rising. In the case of such a cyclical fluctuation of grain production, the study of fluctuating characteristics and its relationship with the price of agricultural products is of great importance to national food security and the operation of the agricultural products market.

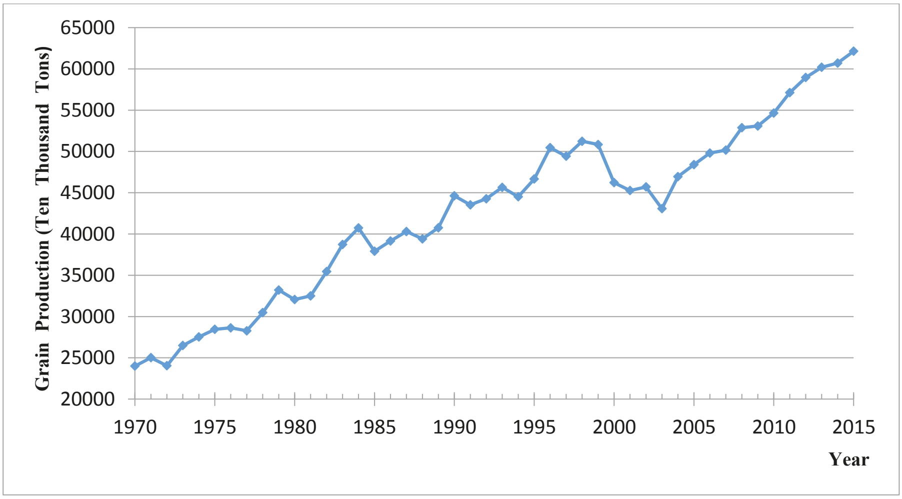

Figure 2. China's basic trend of grain production during the period 1970–2015.

4.1.2. Analysis of Food Price Volatility from 1970 to 2015 (Data Are Derived from "China Statistical Yearbook" [37])

The fluctuation of grain prices is affected by government regulation and market supply and demand changes. This section selects the grain relative price index from 1970 to 2015 as a measure of food price volatility; the food price before 2000 is the grain purchase price index. After 2000, due to the end of the preparation of the purchase price index, the data denote the grain production price index. Figure 3 shows that the fluctuation trajectory of grain prices has obvious stages.

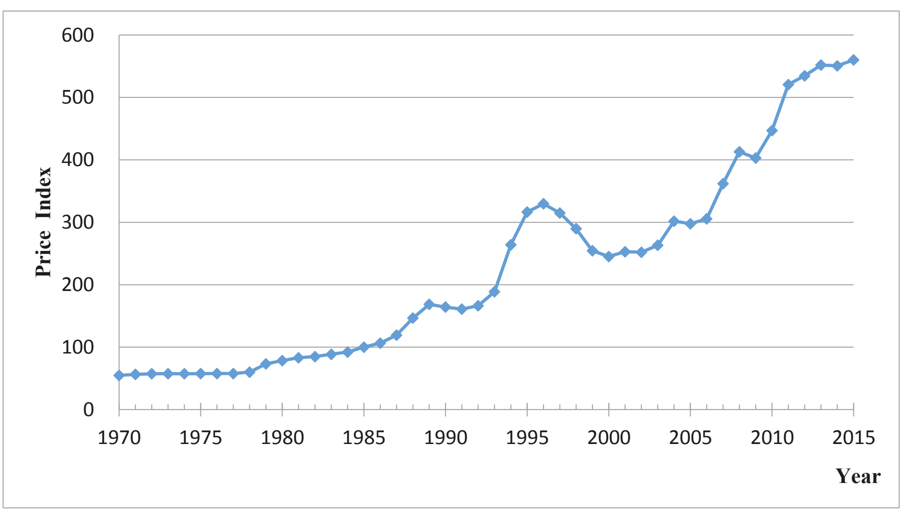

Figure 3. Grain production price fixed index for 1970–2015.

According to the "trough-trough" division method, China's grain price fluctuation trajectory can be roughly divided into three stages:

The first stage is from 1970 to 1991. In this stage, food prices rose steadily, reaching their highest point in 1989. This was mainly because in 1985, the central government carried out a major reform of the long-term policy of grain purchase and marketing, which was changed to contract orders. The price of the grain ordered by the contract is the “three or seven” price (that is, 0.3 as the original purchase weight, 0.7 as the overweight order), and additional food could be sold freely by farmers following the market price [38]. When the market grain prices were lower than the original purchase price, the government purchased at the original purchase price. Although the grain purchase price index rose 1.8%, the contract purchase price fell more than 10% below the purchase price, which, to a certain extent, inhibited grain production, creating a hidden risk for a sharp rise in food prices. At the same time, the system of contract acquisition combined with market acquisition was formally established. That is, the quantity, manner and price of a portion of the total amount of food commodities were determined by the government. Another aspect of the acquisition quantity, channel and price was determined by the market supply and demand, which made the market regulation and food price volatility increase.

The second stage was from 1992 to 1999. In this stage, food prices rose sharply and then declined significantly. Specifically, food prices continued to rise, reaching their peak in 1996. In the face of a substantial increase in food prices, the State Council stipulated that other units and individuals were not allowed to procure food directly in rural areas, except for departments that were responsible for the national grain purchase tasks and food wholesale enterprises that were qualified and approved. In October 1994, the state established the China Agricultural Development Bank and began to close the management of grain purchase funds. Since then, the government has summarized a series of management experiences on food price volatility and adopted a series of macroeconomic management and control measures to curb food prices. The protection of the price of open access to food at the core of the control method is seen as the most essential measure. After these measures, food prices began to fall in 1996, reaching their lowest point in 1999.

The third stage is from 2000 to the present. Between 2000 and 2004, food prices rose in recovery, food prices fell slightly from 2004 to 2005, and since that time, food prices have risen constantly. The reason the food prices continue to rise, from the perspective of supply and demand, is that China’s grain production has been steadily increasing for many years. The living standard of residents is also steadily improving, and the demand for food is also increasing, which is the basis for the gradual increase on food prices in China. Furthermore, as people’s lives improve, the national economic level increases, and the price of agricultural means of production is also increasing. In addition, due to the gradual increase in migrant workers caused by the transfer of labor, rural labor costs have increased, which has indirectly caused food prices to rise year after year.

4.2. Empirical Test on the Impact of Agricultural Product Price Changes on Grain Yield

In this paper, the covariance test method is used to study the correlation between the variables. Cointegration theory involves the correlation between non-stationary time series, proposed by Engel and Grange in 1987, and consummated later by Johansen. However, before the cointegration test, the required time series data must be stationary; otherwise, they may produce a pseudo-regression situation. To ensure the smoothness of the time series data, it is necessary to carry out the unit root test to avoid the occurrence of pseudo-regression.

4.2.1. Unit Root Inspection (ADF)

In this paper, the unit root test of the stationary sequence of time series is carried out by using ADF test method. The results show that $\ln P \sim I(2)$; $\ln Q \sim I(2)$; and $\ln S \sim I(2)$; the specific test results are shown in the following Table 1. Thus, each variable can be cointegrated.

Table 1. Unit Root Test Results.

Variables	ADF Value	Critical Value			Conclusion
		1%	5%	10%	
lnP	−0.436979	−3.592462	−2.931404	−2.603944	non-stationary
ddlnP	−6.539919	−3.596616	−2.933158	−2.604867	stationary
lnQ	−1.409086	−3.584743	−2.928142	−2.602225	non-stationary
ddlnQ	−9.786633	−3.596616	−2.933158	−2.604867	stationary
lnS	−1.973158	−3.588509	−2.929734	−2.603064	non-stationary
ddlnS	−8.441276	−3.596616	−2.933158	−2.604867	stationary

4.2.2. Johansen Co-Integration Test

Co-integration tests can be used to determine the cointegration relationship between variables. To determine the optimal lag order of the model before the cointegration test, we use the AIC information criterion and the SC information criterion to select the lag order. Based on the parallel independent distribution of the residuals, the AIC reaches the minimum value of −10.65700 and the SC is −10.09518 when the maximum hysteresis is 2; the optimal lagged order is the second order, and the established VAR model is denoted as VAR (2).

After the Johansen test method, there is a long-term cointegration relationship between agricultural product price fluctuation, grain yield and sown area. From the Table 2 below, we reject the original hypothesis that there is no cointegration relationship. The Johansen cointegration test proves that there is a cointegration relationship between the variables.

Table 2. Johansen cointegration test results.

Hypothesized No.of CE(s)	Eigenvalue	Trace Statistic	0.05 Critical Value	Prob. **
None *	0.530996	65.17189	29.79707	0.0000
At most 1	0.415342	34.12896	15.49471	0.0000
At most 2	0.255979	12.12130	3.841466	0.0005

* denotes rejection of the hypothesis at the 0.05 level; ** MacKinnon-Haug-Michelis (1999) *p*-values.

4.2.3. Granger Causality Test

The Granger causality test is used to describe which sequence of fluctuations in the time series can cause another sequence of fluctuations. The test was initiated by Clive W. J. Granger, winner of the 2003 Nobel prize in economics, and was used to analyze the Granger causality between economic variables. In the case of time series, the Granger causality relationship between the two economic variables X and Y is defined as if the prediction effect of the variable Y under the condition that the past information of the variables X and Y is included is better than the condition that the past information of only Y is included, that is, the variable X can help explain the future variation of the variable Y; then, the variable X is the Granger cause that causes the variable Y. Using Eviews v8.0 (Quantitative Micro Software Co.: Irvine, CA, USA) to test the relationship between the price of agricultural products, grain yield and sown area by Granger causality, the results are the following Table 3:

According to the results of the Granger causality test, there is a one-way Granger relationship between agricultural product price fluctuation and grain yield, and the price fluctuation of agricultural products is the Granger cause of grain production change. The relationship between price fluctuation and sown area of agricultural products is a one-way Grainger relation, and the fluctuation of agricultural products is the Granger cause of the change in the area. In other words, changes in agricultural prices have a significant impact on changes in grain production and acreage, but the impact of changes in grain production and acreage on prices is not obvious.

Table 3. Granger causality test results.

The Original Hypothesis H0	F-statistics	Prob.	Conclusion
Sowing area is not the Granger cause of the change in production	0.35804	0.5530	Accept H0
Yield is not the Granger cause of the change in the area of the plant	0.16662	0.6853	Accept H0
Price is not the Granger cause of the change in production	1.05586	0.0103	Reject H0
Production is not the Granger cause of price changes	0.79597	0.3776	Accept H0
Price is not the Granger cause of the change in the area of the crop	3.39915	0.0726	Reject H0
Sowing area is not the Granger cause of price changes	2.42502	0.1273	Accept H0

4.2.4. The Establishment of VEC Model

On the basis of cointegration test, we obtain the cointegration relationship among the variables. In order to further analyze the long-term dynamic equilibrium relationship among the variables, we need to establish the vector error correction model. The VEC model is estimated from the Johansen cointegration test. Then we use the estimated error correction term to construct the cointegration relation and estimate the VAR model of the second order difference form including the error correction term as the regression variable, that is VEC model.

The VEC model estimates the results as follows:

$$\begin{bmatrix} \Delta ddlnP \\ \Delta ddlnQ \\ \Delta ddlnS \end{bmatrix} = \begin{bmatrix} 0.0042 \\ 0.0047 \\ 0.0006 \end{bmatrix} + \begin{bmatrix} -0.4835 & 1.2277 & -2.0842 \\ 0.0963 & 0.8073 & -1.4578 \\ 0.0211 & 0.1272 & -0.9316 \end{bmatrix} \begin{bmatrix} \Delta ddlnP_{t-1} \\ \Delta ddlnQ_{t-1} \\ \Delta ddlnS_{t-1} \end{bmatrix} + \begin{bmatrix} -0.4679 & 0.6639 & -0.9612 \\ 0.0697 & 0.2144 & -0.9869 \\ 0.0329 & 0.0436 & -0.6881 \end{bmatrix} \begin{bmatrix} \Delta ddlnP_{t-2} \\ \Delta ddlnQ_{t-2} \\ \Delta ddlnS_{t-2} \end{bmatrix} + \begin{bmatrix} -0.0786 \\ -0.1233 \\ -0.0105 \end{bmatrix} VECM_{t-1} + \varepsilon$$

Among them, $VECM_{t-1} = ddlnP_t + 21.1077ddlnQ_t - 21.4203ddlnS_t$.

4.2.5. Impulse Response Function

The VAR (VEC) model is a non-theoretical model. When we analyze the VAR (VEC) model, we do not directly analyze the impact of a variable on another variable. However, by analyzing when the error term of the VAR (VEC) model changes, we can see the dynamic impact of this change on the system. In this paper, this dynamic effect is analyzed by means of the impulse response function.

The horizontal axis in Figure 4 represents the number of periods, the vertical axis represents the impulse response function, and the red dotted line indicates the confidence interval. As can be seen from Figure 4, the price for their own standard deviation impact immediately made a response. In the first period, the price of this response is about 8.5, after the impact of such a disturbance on the price slowly reduced. In addition, the sown area immediately responds to price disturbances, the first phase response is about −2.5, and reaches the positive maximum (about 3.0) in the second period, then the response of the sown area to the price disturbance decreases. It can also be seen from the figure that the yield of the disturbance for the price in the first phase is not obvious, in the fourth period reached the negative maximum. In general, however, in the impulse response diagram, since 0 is within the confidence interval, the impulse response is not significantly different from zero.

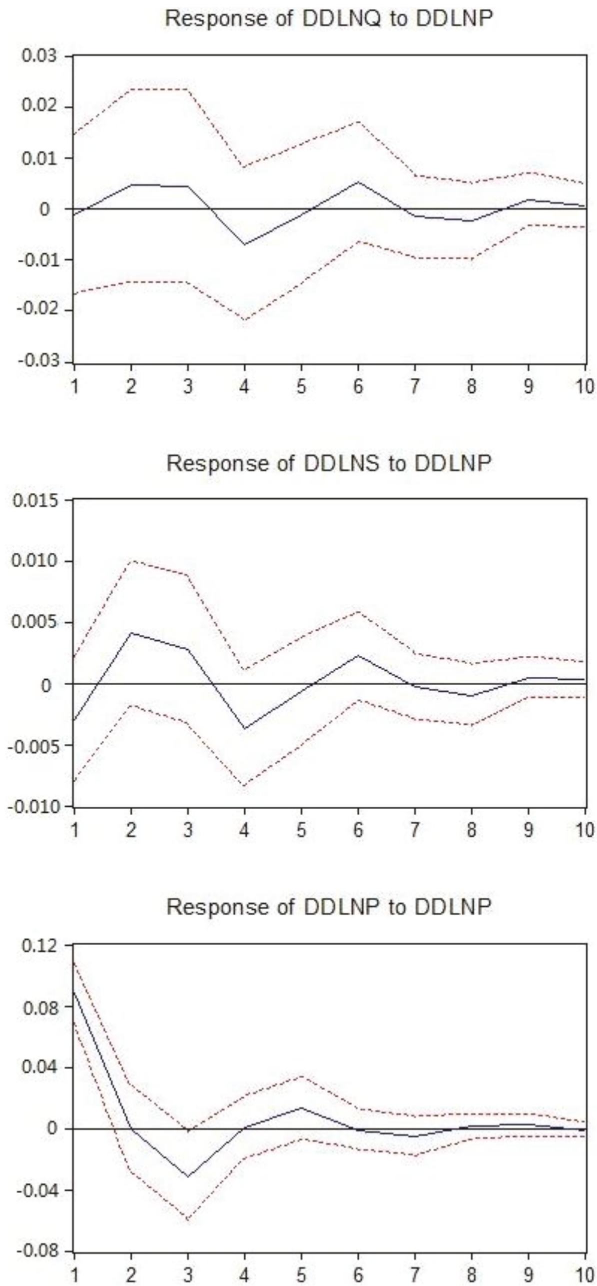

Figure 4. The impulse response function diagram of yield and sowing area on the price.

4.2.6. Results and Analysis

Through the above empirical analysis, we know that the time series data of agricultural product price fluctuation, grain security and grain sowing area belong to second-order single products, and there is a long-term equilibrium co-integration relationship between them. In addition, there is a one-way Granger relationship between agricultural product price fluctuation and grain yield, and the price fluctuation of agricultural products is the Granger cause of grain production change. The relationship between price fluctuation and sown area of agricultural products is a one-way Granger relation. Second, the VEC model estimates that the price fluctuation of agricultural products will affect the sown area and its yield, that the degree of influence in different lag periods is diverse. Nevertheless, the impact of agricultural prices on food production has the following problems:

First, after China's grain reform, agricultural prices accelerated, the market supply and demand intensified, and many food policies were not implemented well for farmers and thus did not provide farmers with any benefits. However, by 2008, most of the farmers had received the loss of economic interests because of the impact of sharp decreases in global agricultural and food prices. China's agricultural market information is not perfect. Whether in the planned economy era or food reform period, macro-control measures are not infallible; thus, the food market price mechanism is not mature. This information asymmetry situation makes the farmers slow to respond to the price information in the case of difficulty selling grain; therefore, the price mechanism has trouble fulfilling its function.

Second, in recent years, in order to protect the interests of farmers, the state has repeatedly adopted a minimum price support policy to improve the purchase price of grain, making food prices rise year after year. This condition also makes the food market stakeholders raise their expectations for food price increases. Some speculators have increased their reserves after grain harvests, creating food supply and demand tensions and thus exacerbating the rise in food prices. This process is not conducive to the stability of the price mechanism.

5. Conclusions and Policy Recommendations

From the previous empirical data and research, we can see that fluctuations in agricultural prices have a certain impact on food production, and food production changes should significantly lag behind the changes in agricultural prices. Domestic grain is the main body of the grain supply in China, and if the country's market is not sound, the food production fluctuations will cause greater fluctuations in agricultural prices, and fluctuations in agricultural prices will, in turn cause fluctuations in production. This phenomenon is revealing a "divergent cobweb" state, causing production to move away from the equilibrium point. The main reasons for the frequent fluctuations in agricultural prices are summarized as follows:

First, the information dissemination channels are not smooth. Although there is a relatively complete agricultural price information network and information on agricultural prices is released in a timely fashion, the limited knowledge of farmers, as well as the inability of farmers in some poor areas to receive timely agricultural price signals, prevents them from using price information to develop a reasonable grain production plan. Second, China's planned economy has a policy of unified purchases and marketing; that is, when the government decides to increase prices, the central bank will issue equal money to regulate this, and inflation caused by the rise in agricultural prices leads to an increase in the amount of currency. Currently, the currency circulation is based on foreign exchange investments and other factors; too high of a currency issuance will cause agricultural prices to increase. Third, the economic cycle is also an important factor in the volatility of agricultural products. In an economic boom, the demand for agricultural products is greater than the supply. This will lead to a "cobweb effect": where demand exceeds supply by 1%, agricultural prices will rise by 1%. Fourth, there is the impact of international agricultural price fluctuations. Since the implementation of reform and opening up in China to all aspects of international standards, the agricultural products market is affected, and all aspects are in line with international standards. The volatility of agricultural prices in the international market also have a natural impact on the price of agricultural products in China. In addition, climate factors such as natural disasters impact the fluctuations of agricultural prices to a certain extent.

Therefore, to ensure the safe and stable operation of agricultural products and the food market, it is necessary for China's government to adopt a series of measures to improve the enthusiasm of farmers for producing grain to maintain the stability of agricultural products. Specific measures that can be taken are as follows:

First, reform the food subsidy policy. Extensive experience has shown that increasing farmers' food subsidies is one of the most effective ways to mobilize the enthusiasm of farmers and improve the efficiency of agricultural production [39]. The policy of the minimum purchase price of grain and the temporary storage of important agricultural products is the main agricultural product price support policy. This approach is to protect the interests of farmers when the food market price is below the minimum purchase price. The drawback of this approach is that it will impact the formation of market prices and will not help the market to play a role. In addition, government procurement of grain will cause extensive reserve pressure and will, therefore, entail a very large financial expenditure. There is an urgent need for reform of this situation in China. Specifically, we need to establish a counter-cyclical food subsidy policy with the target price as the core. The key to this policy is that the government establishes the target price in accordance with the relevant laws and regulations. Unlike the existing minimum purchase price, when the grain market price is lower than the grain target price, the government subsidizes the farmers according to differences between the market price and the target price. The advantage of this design is that by making the food market mechanism really play a role, we can reduce the large amount of financial expenditure arising from the storage of food. The most important measure is to streamline the grain market mechanism, which can alleviate the abnormal fluctuations in food prices caused by human factors.

Second, reduce the cost of grain to protect the interests of farmers. In recent years, the price of major agricultural means of production generally rose, such as fertilizer and pesticide prices rising 30% to 40%over the previous year. Continued price increases for agricultural production will lead to an increase in the costs of farming and thus will eliminate the enthusiasm of farmers to plant grain and decrease food production. A sharp reduction in food supplies will lead to rising food prices, and food price volatility will break the long-term stability of the food market, thus affecting food production. In this regard, the relevant government departments should play a role in supervision and control, taking measures to stabilize the market prices of a series of agricultural production materials, such as fertilizer and pesticides, and preventing agricultural production prices from fluctuating in order to avoid disrupting the market order. At the same time, this will ensure the quality of the production materials to protect the vital interests of farmers.

Third, strengthen the protection of arable land on an agricultural scale. There is a close relationship between the stability of agricultural products and the area of cultivated land. Cultivated land resources in food production have an irreplaceable role. Strengthening the protection of arable land and stabilizing grain-sown area can help ensure grain production and price stability. Presently, the situation with cultivated land is that the cultivation is small and the degree of commercialization is not high. This has become an important factor affecting the efficiency of grain and farmers. The household contract responsibility system ensures that farmers share average land, but this also affects the scale of land cultivation. Rural farmers' farming technology and mechanization are relatively low, and production costs are relatively high. For these scattered farmers, grain is mainly grown for subsistence; thus, the food commodity rate is low. In recent years, with the acceleration of industrialization and urbanization, the area of cultivated land in China has gradually decreased. Pollution problems have led to a serious decline in the quality of some cultivated land, which has a serious impact on food production and the stability of agricultural prices [40]. Therefore, it is urgent to make full use of the limited cultivated land area, strengthen farmland protection, and use science and technology to improve farmland efficiency. This is also an effective way to stabilize the market price and increase grain yield.

Fourth, strengthen the agricultural market information channel construction and complete the collection of agricultural product prices for analysis and release. Due to the low level of farmers' own information and the low coverage of some rural networks, they lack a convenient way to obtain agricultural product prices and cannot make next year's grain plan based on the prices of previous agricultural products. This shortcoming, that information is difficult to obtain, is also one of the reasons that prices fluctuate. To prevent price fluctuations caused by the inability to reasonably know how much grain to plant because of the difficulty in determining the price, the government should promptly publish information on agricultural prices for farmers and establish a channel to facilitate the rapid access to price information for farmers, to strengthen the regulation of market conditions, and improve the farmers' market economy awareness so that farmers can easily adjust the price of agricultural products for the subsequent year's grain plan.

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