Exploring Intra-Island Population Mobility and Economic Resilience: The Case of Hainan Island, China

Xiaomeng Fang 1 and Weili Liu 2,*

1 China Center for Special Economic Zone Research, Shenzhen University, Shenzhen 518000, China; fangxiaomeng2020@email.szu.edu.cn
2 College of Economics, Shenzhen University, Shenzhen 518000, China
* Correspondence: liuwl@szu.edu.cn

Abstract: Islands may be more resilient than we realize when responding to shocks. As COVID-19 lessens international tourism to islands, it is valuable to explore whether island recovery can be accredited to the interactive behaviors within the island. Therefore, this research takes 18 administrative regions within Hainan Island as the research object, uses population migration big data to show the intra-island interaction network, and focuses on the impact of population mobility on economic resilience under the pandemic shock. Overall, population mobility contributes to the recovery of economic resilience under the pandemic shock, but this effect is regionally heterogeneous between the economic circle and the ecological conservation area. During the study period, there is a local spatial autocorrelation between economic resilience and population mobility, showing sporadic scattered distributions of the H-H, H-L and L-L cluster. The research findings offer practical strategies to improve island resilience.

Keywords: island resilience; Hainan Island; COVID-19; population mobility; economic resilience; regional coordination

1. Introduction

Natural disasters and public health crises have sparked speculation about how islands will respond [1]. While ‘islandness’ may be advantageous in the short term for enhancing resilience to health-related crises, views based on ‘vulnerability’ or ‘islandness’ to characterize islands are often limited [2–4]. The impact of these shocks on an island society is a matter of scale, but again depends on the ability of that society to hedge against such impacts [5]. In reality, islands are not passive victims [6]. They utilize local knowledge, tight-knit social structures, and advanced big data management mechanisms to deal with sudden external shocks [7,8]. Additionally, they implement a range of stimulus policies to achieve the sustainable development of island economies [9,10].

The outbreak of COVID-19 has had an unprecedented impact on the global tourism industry due to its dependence on human mobility [11,12]. According to the UNWTO Tourism Data Dashboard, international tourist arrivals are estimated to have fallen 72.1 percent in 2020 compared to 2019, and there is still a 37.4% shortfall in 2022 compared to 2019 [13]. Under the shock of the COVID-19 pandemic and the instance of government’s mobility restrictions, the island’s external mobility is reduced, the intra-island intricate interaction between the populations should be further investigated [3]. So, we tried to find out whether island’s resilient recovery was due to the movement of people within the island or other factors.

In this paper, we take Hainan Island as a case study object mainly for the following reasons: Firstly, in recent years, Hainan Island has attracted attention in China for its high economic growth rate. The average growth rate of Hainan Island in 2020 to 2021 reached...
7.3 percent, ranking first in China, with the global tourism industry suffering from the pandemic. And in the first three quarters of 2023, Hainan’s GDP grew by 9.5% year-on-year. Hainan Island’s marine resources and unique climatic conditions offer broad prospects for tourism and agriculture development. Second, Hainan has a unique development orientation. Hainan is China’s only free trade port with Chinese characteristics, being used as a ‘living laboratory’ to test policy [4]. Building a high-quality and high-standard free trade port with Chinese characteristics is an important development goal for Hainan Island. Hainan Island has a significant role in China’s foreign cooperation and trade. The Boao Forum for Asia (BFA), an international organization founded in Hainan in 2001, aims to facilitate economic cooperation, exchanges, and development among Asian countries, and regularly hold annual meeting in Boao, Hainan. A study on the economic resilience and population mobility of Hainan Island provides some policy implications for the development of Hainan Free Trade Port. Furthermore, ecological protection of islands needs to be taken into account along with economic construction. The distinction between different functional areas in Hainan’s development plan allows us to analyze the regional heterogeneity and synergistic relationship [14]. Exploring these issues provides scientific guidance for regional coordination, which may also provide ideas for the sustainable development of other subnational island jurisdictions (SNIJs).

Our research is to observe the spatial distribution pattern of population flow within Hainan Island based on migration big data and to analyze the impact of the pandemic on population flow within Hainan Island. Additionally, by assessing the regional economic resilience, we also discuss why some regions within the island can withstand the shock and then restore economic operation more quickly, whereas others are not? And does the relationship between population mobility and economic resilience present different paradigms depending on regional development patterns? Exploring these issues not only provides early warnings for pandemic prevention and control, but also extends the current research on economic resilience presupposed by the COVID-19 pandemic as a scenario.

The novelty of the paper is mainly reflected in the research perspective and the continuous tracking of COVID-19 epidemic impact. This paper attempts to explore a new question: does intra-island population mobility have a positive impact on island economic resilience? The results of the paper also suggest that islands may be more resilient than we realize when responding to shocks. On the data side, we obtained migration data and related economic statistics data (from the first quarter of 2020 to the third quarter of 2023) to observe the long-term impact of COVID-19. This paper is organized as follows: the second section is the related work; the third section is the data and methods; the fourth section is the results; the fifth section is the discussion; and the last part contains the main conclusions and policy recommendations.

2. Related Work

The discussion of resilience has a long history and has been addressed in disciplinary fields such as physics, disaster science, ecology, economics, and psychology [15,16]. According to the perspective of evolutionary economic geography, regional resilience does not emphasize the realization of equilibrium state, but redefines and analyzes regional resilience according to the impact of shock on the ability of regions to develop new growth paths [17]. Regional economic resilience can be broadly defined as the ability of a regional or local economy to withstand, recover, and reorganize its development growth path in the face of market, competitive, and environmental shocks [18]. And this capacity is not just limited to the short term; its long-term resilience process should be discussed [19].

In the two years from 2020 to 2021, a series of press articles about islands have focused on the health and economic impacts of COVID-19 [20]. This COVID-19 pandemic provides a new shock scenario for the study of regional resilience [21]. Although the WHO director general declared the end to COVID-19 as a global health emergency, its negative impact has clearly not dissipated [22]. There is a high degree of spatial and temporal uncertainty associated with COVID-19, which will have significant long-term behavioral
impacts on mobility and travel [23]. In addition, in the latest studies, significant heterogeneity between the township level and the village level was found in the islands’ sustainability and overall development [24,25].

Some scholars have suggested that island economies on a sustainable path to recovery should pivot on the local people as the core [26–28]. Among the many influencing factors associated with island resilience, the contribution of migration to island resilience has been confirmed [29,30]. However, the relationship between population mobility on a smaller timescale and island resilience remains to be tested, which is the main research focus and innovation point of this paper. Scaling laws of socio-economic outputs of cities focus on the deterministic role of population size within a city, while the effect of connectivity between cities on island economic outputs and overall development cannot be ignored [31,32].

From the perspective of network analysis, cities are regarded as nodes in the network, and population flow is the carrier that usually brings the interaction of information and intelligence [33,34]. From an industry perspective, tourism is an industry that cannot survive without visitor mobility, and mobility is an important indicator of tourism resilience [35]. From the perspective of supply chains, shifts about ‘global to local’ during the COVID-19 pandemic are beneficial to the development of localized food supply chains and attract new immigrants [36]. From the perspective of the polycentric development strategy of the island, it aims to mitigate the controversy between urbanization and ecological sustainability. But in fact, it may bring a new round of construction expansion and ecological occupation to the surrounding area, leading to the weakening of ecosystem service functions and making the island more vulnerable [37,38]. It is worth noting that there is little research on population flow between cities within islands, and therefore, there is a need for focus on intra-island economy interactions, as ‘proximity tourism’, which pays more attention to local behavioral theories, has the potential to become a more sustainable way of development for island economies in the aftermath of the pandemic [39].

On the whole, the research on island resilience has achieved fruitful results, but the existing research still needs further improvements. On the one hand, the impact of the epidemic on island persistence should be discussed; on the other hand, the regional heterogeneity within islands also needs to be tested. A further point for research is that, among the numerous studies on the influencing factors of island resilience, intra-island population mobility has not yet been empirically tested. And a discussion of this issue is necessary in the context of this new crown epidemic shock to help us gain a deeper understanding of island resilience. The three questions above will be responded to in the next sections.

3. Data and Methods

3.1. Overview of the Study Area

Hainan Island (18°09′–20°10′ N and 108°37′–111°03′ E), a tropical island at the southernmost of China, is a regional center connecting Northeast Asia and Southeast Asia, and is a maritime gateway between the Indian Ocean and the Pacific Ocean [40]. Hainan Island was established as a province in 1988 and became the largest special economic zone in China. In June 2020, China issued the Master Plan for Hainan Free Trade Port, planning it as a free trade port of Chinese characteristics with world influence and a model of China’s reform and opening up in the new era. And it will be launching the operation of the whole island’s customs seal by 2025. Natural landscape, climate environment, and duty-free shopping have become important tourism resources of Hainan Island [41].

As is shown in Figure 1, this paper selects 18 administrative regions within Hainan Island as the research object, including Haikou, Sanya, Danzhou, 3 city-level administrative regions, and the remaining 15 county-level administrative regions. Moreover, this paper will focus on the following four areas: The Haikou Comprehensive Economic Circle, The Sanya Tourism Economic Circle, The Danzhou-Yangpu Port Economic Circle, and
The Central Ecological Conservation Area, in which the regional classification standard is derived from the Hainan administration of surveying mapping and geoinformation.

3.2. Data Sources

We capture the immigration index from the AutoNavi Traffic website (https://trp.autonavi.com/migrate/page.do, accessed on 27 November 2023) to analyze the spatial characteristics of population mobility in Hainan Island. AutoNavi immigration index is counted as a ratio. AutoNavi immigration index maps the daily behavior trajectory of users through the changes of cell phone positioning information and shapes the starting and ending urban nodes and connection paths generated in the process of population flow. Since the exact algorithm of the immigration index is not publicly available, we only know that the immigration index is positively correlated with the number of people who actually immigrate.

This paper captured the population immigration index of 18 cities and counties within Hainan Island from 1 January 2019 to 30 September 2023. There is a total of 521,413 data, and the data attributes include the name of the originating (terminating) city and its latitude and longitude coordinates, and the actual migration index. In addition, the data of regional GDP and control variables come from the monthly statistical reports published by Hainan Provincial Bureau of Statistics. Hainan Provincial Bureau of Statistics only published the accumulated regional GDP at the city and county level in the monthly statistical reports of March, June, September, and December. So, the regional GDP data selected in this paper is quarterly.

3.3. Research Methods

3.3.1. Measurement of Regional Economic Resilience

The existing literature has not yet reached a unified consensus on the measurement of economic resilience, such as the construction of a system of evaluation indicators to measure it [42], or use changes in regional GDP and number of employment to measure [43]. This paper focuses on how different cities within the island are affected by the overall recession or recovery of the island, and uses the comparison between the change of the actual economic output of cities and the change of expected economic output to measure regional economic resilience [18,44], which is measured by the following formula:

Figure 1. Administrative map of Hainan Island.
Among them, $Y_r^t$ is the economic output of the region $r$ inside the island at the start time $t$; $g_{r}^{t+k}$ is the change rate of the economic output of the island as a whole during the time $t + k$; $(\Delta Y_r^{t+k})_{\text{expected}}$ represents that the expected change in the regional units of Hainan Island at the same rate as the whole island; $\Delta Y_r^{t+k}$ represents the actual output change of the region $r$ during the contraction period; $(\Delta Y_r^{t+k}) - (\Delta Y_r^{t+k})_{\text{expected}}$ represents the discrepancy between the actual output change and the expectant output change of the region $r$ during the contraction period; and $\text{Res}_r$ represents the level of regional economic resilience, where a result greater than 0 indicates that the regional economic resilience to the shock is higher than the level of the island as a whole, and vice versa. For example, when the value of $\text{Res}$ in place A of Hainan Island is 0.5, it means that the level of economic resilience of the place is 50% higher than the overall level of the whole island; when the value of $\text{Res}$ in place A of Hainan Island is −0.5, it means that the level of economic resilience of the place is only half of the whole island.

3.3.2. Construction of Regression Equation

Multiple regression equations were used to quantify the impact of population mobility on the regional economic resilience:

$$\text{Res}_{rt} = c + \alpha \text{Mgr}_{rt} + \sum_{i=1}^{k} \beta_i X_{rt} + u_r + v_t + \epsilon_{rt}$$

Among them, $\text{Res}_{rt}$ is the economic resistance level of region $r$ under the impact of the pandemic in time period $t$; $\text{Mgr}_{rt}$ is the average migration intensity of other regions within the island to region $r$ during time period $t$; $X_{rt}$ represents a series of control variables; $u_r$ represents the individual fixed effect; $v_t$ represents time fixed effect; $\epsilon_{rt}$ represents random error term; and $c$, $\alpha$, $\beta$ are the parameters to be estimated.

Referring to existing studies [45,46], we selected the following control variables: (1) Industrial structure (Ind). The higher the proportion of Tertiary Industry, the more obvious the characteristics of the Jacobs agglomeration economy. Because the COVID-19 is highly sensitive to the economic behavior of spatial agglomeration, the higher the proportion of Tertiary Industry of the region, the impact may be more obvious. But when the pandemic has been effectively controlled, the recovery of Tertiary Industry will become an important force to promote employment and maintain and promote economic development. In this paper, the proportion of value added to Tertiary Industry in GDP is selected as proxy variable. (2) Foreign trade dependency (Ftd). Due to the highly contagious nature of the COVID-19, the global production network, supply chain, and logistics system suffered a blow, resulting in production stagnation, export decline, and deglobalization occurs. Thus, regions with predominantly export-oriented economies will be more vulnerable to the pandemic shock. This paper chooses the proportion of total imports and exports of goods to regional GDP as an alternative. (3) Intensity of government public expenditure (Gov). Government macro-control as a dynamic factor in the operation of the resilience system is critical. In practice, a series of government measures on the public health expenditure after the pandemic shock and the resumption of production and labor support policies and other means contributed to the rapid increase of regional economic resilience. However, the effect of the intensity of government public expenditure on economic resilience may show an inverted U-shaped relationship under the shock of COVID-19 epidemic. Too high an intensity of government public expenditure could mean stronger government mobility restrictions, and this is detrimental to the recovery of regions dependent on mobility. In this paper, local general public budget expenditure is selected as
a specific indicator. (4) Intensity of energy consumption (Ene). Clean production and low carbonization are the way for islands to pursue high-quality economic development and sustainable development. In this paper, energy consumption per unit of GDP is selected as an alternative indicator of this control variable. The higher the value, the worse the energy saving and consumption-reduction level.

3.3.3. Measurement of Bivariate Local Moran’s I

Bivariate Local Moran’s I can be used to analyze the spatial aggregation and divergence characteristics of one attribute of a given spatial unit with respect to another attribute of an adjacent spatial unit. In this paper, we use cluster map of Bivariate Local Moran’s I to characterize the spatial correlation between population mobility and economic resilience. The H-H and L-L clusters are spatially positively correlated, and the H-L and L-H clusters are spatially negatively correlated. The specific formula is as follows [47]:

\[ z_i = \frac{X'_k - \bar{X}_k}{\sigma_k} \]  \hspace{1cm} (4)

\[ z_j = \frac{X'_l - \bar{X}_l}{\sigma_l} \]  \hspace{1cm} (5)

\[ I_{kl} = z'_i \sum_{j=1}^{n} w_{ij} z'_j \]  \hspace{1cm} (6)

Among them, \( X'_k \) is the economic resilience of region \( i \); \( X'_l \) is the population mobility of region \( j \); \( \bar{X}_k \) and \( \bar{X}_l \) are the mean values of economic resilience and population mobility; \( \sigma_k \) and \( \sigma_l \) are the variances of economic resilience and population mobility; \( z'_k \) and \( z'_l \) are the variance standardized values of economic resilience of region \( i \) and population mobility of region \( j \); \( w_{ij} \) is the spatial weight matrix of region \( i \) and region \( j \); \( I_{kl} \) represents the Bivariate Local Moran’s I of region \( i \).

4. Results

4.1. Spatial Patterns of Population Mobility and Evaluation of Economic Resilience

4.1.1. Short-Term Time Series Analysis of Population Mobility

Figure 2 shows the short-term situation of population mobility within Hainan Island in the first quarter of 2020 from the onset of the COVID-19 until it basically recovers to the historical level of the same period in 2019, the analysis of Figure 2 is as follows:

(1) On 22 January 2020, there was a confirmed case of COVID-19 in Hainan Island. On 24 January 2020 and 4 February 2019, the New Year’s Eve of that year, the population immigration index in each region dropped to a low level compared with the previous two days, with a greater decline in 2020 compared to 2019, suggesting that people’s behavior of returning to their hometowns was somewhat hindered by the COVID-19 pandemic.

(2) 25 January to 2 February 2020 is the Spring Festival holiday. It is obvious to find that population immigration index fell rapidly after a weak rebound due to the impact of the pandemic and the implementation of strong pandemic prevention and control initiatives. On the contrary, the historical data of the same period showed a surge trend. The population immigration index in this period reflected the activities of traveling and visiting relatives and friends during the Spring Festival Golden Week, indicating that the impact of the pandemic severely affected the migration of the population within Hainan Island during the Spring Festival.

(3) After the Spring Festival holiday, differently from the gradual decline to the pre-holiday level in 2019, the population immigration index in 2020 continued to decline until it was at a low level due to the continuing number of newly confirmed cases.
(4) With the resumption of work and production, the average weekly population immigration index of Haikou Comprehensive Economic Circle in 2019 maintained a stable level and showed weekly periodic fluctuations, and on Saturdays (23 February and 2, 9, 16, 23, and 30 March) the population migration index reached a peak. However, due to the impact of the pandemic, the peak of 2020 has been significantly weakened. With the effective control of the pandemic, the population migration index in all four areas increased steadily [48], and was close to the historical level in the same period, indicating that the regions were recovering continuously. From the time trend, the population mobility of the Danzhou-Yangpu Port Economic Circle and the Central Ecological Conservation Area recovered more rapidly, while that of the Haikou Comprehensive Economic Circle and the Sanya Tourism Economic Circle recovered more slowly.

Figure 2. Population mobility in the Haikou Comprehensive Economic Circle (a), the Sanya Tourism Economic Circle (b), the Danzhou-Yangpu Port Economic Circle (c) and the Central Ecological Conservation Area (d) in the first quarter of 2019 and 2020.

4.1.2. Spatio-Temporal Analysis of Population Mobility Networks

The immigration index among 18 cities (counties) of Hainan Island was imported into ArcGIS 10.4 for visualization processing, and the spatial statistical map of population mobility between cities (counties) of Hainan Island in the first quarter of 2019–2022 was derived (see Figure 3), in which: The natural breakpoint method is used for stratification in the first quarter of 2019, and the breakpoint value in the first quarter of 2020–2022 is set and matched with the breakpoint value in the first quarter of 2019 (except maximum and minimum values); the color of the line segment ranges from yellow to red, indicating that the spatial linkage strength is from weak to strong, and the black line segment with arrows indicates the strongest interaction relationship and direction between the local area and other cities (counties) in the quarter.
From Figure 3, there were 306 connections between the 18 cities (counties) in Hainan Island. The most obvious feature is that the north–south vertical links are stronger compared to the east–west horizontal links. Probably because the development of the Haikou Comprehensive Economic Circle and the Sanya Tourism Economic Circle promotes frequent population flow within these two economic circles. In addition, Haikou and Sanya have the second-strongest links in the city-county network, and although the two cities are far apart in terms of geographic distance, they are well-connected by road transportation and have frequent population flow.

The strong degree of city interaction has been formed between two pairs of cities (counties), namely Haikou City–Chengmai County, and Sanya City–Lingshui County. This is consistent with the reality. Chengmai County is known as the “back garden of Haikou”, and the commuting time between Chengmai and Haikou is only half an hour; Chengmai County can give priority to enjoying the urban infrastructure of Haikou; in addition to Chengmai, it also provides Haikou with an industrial open space, such as Haikou Eco-Industrial Park has been relocated to Chengmai, and it has already attracted Tencent, Huawei, Baidu, and many other companies settled. As for the strong connection between Lingshui County and Sanya City, in terms of location, the high-speed rail between the two places only takes about 30 min, and the transportation is convenient.

4.1.3. Evaluation of Regional Economic Resilience under the Pandemic Shock

Based on Formulas (1) and (2), this paper measured the economic resilience of cities (counties) in Hainan Island after the pandemic shock from the dimension of GDP. And the visualization results obtained by GeoDa 1.18 are shown in Figure 4. Overall, when compared to 2020, cities’ (counties) resistance level within Hainan Island have improved in 2021 and 2022. The number of cities (counties) with low levels of resilience in 2022 is the fewest.
From the perspective of sub-regions, the Haikou Comprehensive Economic Circle and the Sanya Tourism Economic Circle are at a better resilience level in 2021, and, compared with 2020, the resilience level of cities (counties) within two economic circles tends to be more coordinated. In 2021, the Danzhou and Yangpu growth pole became the region with the highest level of resilience in Hainan Island, which may benefit from the official implementation of the integrated development policy of Danzhou and Yangpu in 2021. Progress has been made in solving the problems of “having industry but no urban space” in Yangpu Port and “having urban space but no industry” in Danzhou city. It shows that the radiation effects of the “Dan-Yang growth pole” is not obvious.

4.2. Analysis of the Impact of Population Mobility on Economic Resilience

Stata 18 is used for empirical analysis in this part. A descriptive statistical analysis of variables’ data is done (see Table 1). The variance inflation factor (VIF) of the independent variables takes the value interval of [1.25, 3.90], and the mean value is 2.26, indicating that the regression model does not have serious multicollinearity problem. The result of Hausman test Prob > chi2 = 0.0120, which is less than 0.05, i.e., the original hypothesis is rejected, so the fixed effect model is chosen.

Table 1. Descriptive statistics of variables.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Specific Indicator</th>
<th>Observations</th>
<th>Mean</th>
<th>Std. Dev.</th>
<th>Min</th>
<th>Max</th>
</tr>
</thead>
<tbody>
<tr>
<td>Res</td>
<td>economic resilience level</td>
<td>270</td>
<td>-0.002</td>
<td>0.951</td>
<td>-2.382</td>
<td>3.423</td>
</tr>
<tr>
<td>Mig</td>
<td>AutoNavi immigration index</td>
<td>270</td>
<td>0.0728</td>
<td>0.080</td>
<td>0.008</td>
<td>0.570</td>
</tr>
<tr>
<td>Ind</td>
<td>Tertiary Industry’s added value/GDP</td>
<td>270</td>
<td>0.505</td>
<td>0.143</td>
<td>0.224</td>
<td>0.850</td>
</tr>
<tr>
<td>Ftd</td>
<td>total imports and exports of goods/GDP</td>
<td>270</td>
<td>0.102</td>
<td>0.228</td>
<td>0</td>
<td>1.352</td>
</tr>
<tr>
<td>Gov</td>
<td>local general public budget expenditure energy consumption per unit of GDP</td>
<td>270</td>
<td>0.197</td>
<td>0.194</td>
<td>0.022</td>
<td>1.272</td>
</tr>
<tr>
<td>Ene</td>
<td>0.262</td>
<td>0.528</td>
<td>0.000</td>
<td>2.597</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 2 reports the results of the impact of population mobility on the economic resilience of Hainan Island as a whole, as well as in different regions. The two-way fixed-effect model is used for analysis to control for the impact of time trends and geographically characterized factors such as culture and on economic resilience. From model (1), population mobility has a positive impact on the island’s economic resilience at the 5% significant level. In addition, from the coefficients of the control variables, cities (counties) with higher foreign trade dependency within Hainan Island have worse economic resilience under the impact of pandemic; in the industrial structure, the higher the proportion
of service-oriented economy, the more conducive to improving the resilience of island economy. Models (2)–(5) is a two-way fixed-effects model under subregion. In the statistical sense, the impact coefficient of population mobility on economic resilience in the Danzhou-Yangpu Port Economic Circle is significantly positive at the 5% significant level. The influence coefficient of population mobility on economic resilience in the Haikou Comprehensive Economic Circle and the Sanya Tourism Economic Circle is insignificant, and the influence coefficient of population mobility on economic resilience in the Central Ecological Conservation Area is significantly negative at the 10% significant level. In the economic sense, taking model (5) as an example, when the population mobility increases by one standard deviation (0.080), the resilience of island cities (counties) will change by $-4.606 \times 0.080$ units, that is, 0.365 units, which is equivalent to $-4.606 \times 0.080 \div 0.951$ of its standard deviation, that is, $-38.75\%$. For the Central Ecological Conservation Area, the negative impact of population mobility on the economic resilience cannot be ignored. In addition, Table 2 show that the intensity of government public expenditure has a negative impact in the Danzhou-Yangpu Port Economic Circle, which is different from the Haikou Comprehensive Economic Circle. The intensity of government public expenditure is significantly positive at the 1% significant level in the Haikou Comprehensive Economic Circle. The intensity of government public expenditure has a negative impact of population mobility on the economic resilience.

**Table 2. Regression results on the impact of population inflow on regional economic resilience.**

<table>
<thead>
<tr>
<th></th>
<th>(1) Haikou Comprehensive Economic Circle</th>
<th>(2) Sanya Tourism Economic Circle</th>
<th>(3) Danzhou-Yangpu Port Economic Circle</th>
<th>(4) Central Ecological Conservation Zone</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mig</td>
<td>0.298 ** (0.128)</td>
<td>0.240 (0.215)</td>
<td>0.066 (0.044)</td>
<td>1.113 ** (0.274)</td>
</tr>
<tr>
<td>Ind</td>
<td>0.422 ** (0.179)</td>
<td>-0.036 (0.172)</td>
<td>-0.150 (0.456)</td>
<td>0.438 (0.558)</td>
</tr>
<tr>
<td>Ftd</td>
<td>-0.175 *** (0.041)</td>
<td>-0.003 (0.402)</td>
<td>-0.924 *** (0.074)</td>
<td>-0.192 (0.116)</td>
</tr>
<tr>
<td>Gov</td>
<td>-0.083 (0.225)</td>
<td>0.167 *** (0.024)</td>
<td>0.056 (0.420)</td>
<td>-1.345 * (0.422)</td>
</tr>
<tr>
<td>Ene</td>
<td>-0.054 (0.282)</td>
<td>-0.700 (1.330)</td>
<td>1.557 (0.762)</td>
<td>0.070 (0.519)</td>
</tr>
<tr>
<td>cons</td>
<td>-0.000 (0.000)</td>
<td>-0.380 (0.504)</td>
<td>0.379 (0.324)</td>
<td>0.596 (0.992)</td>
</tr>
<tr>
<td>Regional controls</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Quarter controls</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>N</td>
<td>270</td>
<td>75</td>
<td>60</td>
<td>60</td>
</tr>
<tr>
<td>R-squared</td>
<td>0.170</td>
<td>0.186</td>
<td>0.059</td>
<td>0.446</td>
</tr>
</tbody>
</table>

Note: Robust standard errors are report in parentheses; *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

In addition, we replace the core explanatory variable population inflow intensity with population outflow intensity for robustness testing, and the regression results are shown in Table 3. Among them, the overall coefficient of population outflow on the economic resilience of cities and counties in Hainan is 0.232, which passed the test of 5% significant level. The influence coefficient and significant level of population mobility in the overall are basically consistent with the previous result, suggesting that the conclusion
that population mobility positively affects the regional economic resilience after the pandemic shock. We also find that in Tables 2 and 3, the influence coefficient of intensity of energy consumption (Ene) is significantly negative at the 1% and the 5% level. This suggests that the Central Ecological Conservation Zone have more stringent requirements for cleaner production.

In Tables 2 and 3, the regression results have a low R-squared, possibly for several reasons. One is that during the sample period, the island experienced more than one epidemic shock, with varying degrees of intensity and geographic areas of outbreak, causing the data to be more discrete. Second, the existence of extreme values in the sample negatively impacts the model’s fitting effect. But in order to retain the true sample information, we did not delete or winsorize the extreme values. Third, the model interpretation is insufficient due to certain omitted influencing factors. Regional policies and external interactions of the island could be important influence factors, yet this study omits their inclusion due to data retrieval challenges.

### 4.3. Local Spatial Autocorrelation Analysis of Population Mobility and Economic Resilience

In this paper, Geoda 1.18 is used to draw the Bivariate Global Lisa Scatter diagram and inspection in Hainan in 2020, 2021, and 2022 in Figure 5. The results show that the values of the bivariate Global Moran’s I are 0.222, 0.300, and 0.283; the results passed the test at the 5% significance level. It indicates that population mobility and economic resilience in Hainan Island have positive spatial correlation, and the probability of clustering distribution is more than 95%. Further bivariate local spatial autocorrelation analysis, the spatial visualization results are shown in Figure 6. It can be seen that the correlation between economic resilience and population mobility in Hainan Island exhibits four types of cases: high resilience-high mobility (H-H), low resilience-low mobility positive
correlation (L-L), and high resilience-low mobility (H-L) negative correlation, as well as non-significant. And the results are significant at the $\alpha = 0.05$ level.

![Figure 5. Bivariate Lisa Scatter diagram and inspection in Hainan in 2020 (a), 2021 (b), and 2022 (c).](image)

![Figure 6. Bivariate LISA cluster map of Hainan’s 18 cities (counties) in 2020 (a1), 2021 (a2), and 2022 (a3); Bivariate LISA significance map of Hainan’s 18 cities (counties) in 2020 (b1), 2021 (b2), and 2022 (b3).](image)

Among them, the H-H cluster is located in Haikou City, provincial capital of Hainan Island, indicating that the high economic resilience of Haikou City is related to the high population mobility of adjacent areas. Haikou City is the core city of Hainan Free Trade Port. It was selected by the World Health Organization as the first “World Healthy City” pilot site in China. The L-L cluster in 2020 is distributed in Changjiang County in the west of Hainan Island, Wuzhishan City in the middle of Hainan Island, and Baisha county, which rank lower in economic level and have poor accessibility among cities (counties) in Hainan Island. H-L cluster in 2020 is distributed in Qiongzhong County and Tunchang County.

By comparing the cluster map of Bivariate Local Moran’s I for 2020, 2021, and 2022, it can be found that Qiongzhong county and Tunchang county has changed from H-L cluster in 2020 to L-L cluster in 2021 and 2022, the possible reason for this shift is that there
is a lag in the impact of the pandemic shock in Qiongzhong County. Moreover, we find that the situation of the L-H cluster does not exist in the cluster map of Bivariate Local Moran’s I, which is consistent with the actual situation, because on the whole, adjacent regions with high population mobility tend to have relatively high local population mobility and are more prone to economic recovery. Therefore, it is difficult to occur the counterfactual situation of low resilience-high mobility cluster.

5. Discussion

The research perspective of this paper is a new perspective derived from previous studies. First, based on the research of Telesford [3] and Kelman [2,4], ‘islandness’ has limited efficacy in explaining the resilience of islands. Then, with regard to the discussion of resilience in small island regions, previous research explored the resilience speed of islands and the factors affecting the resilience of islands in the face of shocks [49,50], which are also analyzed to some extent in this paper. Pereira and Steenge [51] explain the role of economic and political external connectivity in reducing the economic vulnerability or increasing the economic resilience of small island states. Subsequently, Peterson [52] focused on the over-tourism in small island tourism economies, which makes the islands vulnerable. Moreover, in the case of the COVID-19 pandemic shock, many islands were poorly connected to the outside countries. Therefore, we focused our research perspective on the interior of the island and emphasize that intra-island interaction is an important consideration for island resilience.

We will also examine some of the findings presented in this study. In terms of our result in Figure 4, we find the resilience level of cities (counties) within two economic circles tends to be more coordinated, which is consistent with the assessment result of urbanization in Hainan Island by Liang et al. [53]. And they consider this regional coordination may derive from the radiating effect of Haikou City and Sanya City. Besides, an interesting finding is that for the Central Ecological Conservation Area, population mobility shows a negative impact on economic resilience. Promoting positive interactions among indigenous peoples, local communities and government have been a key of island sustainable development [54,55]. We provide a convincing reason for the result: the arrival of reverse migration from urban to rural areas due to the COVID-19 pandemic will increase the pressure on the Central Ecological Conservation Area to play its role as a safety net. In addition, the intensity of government public expenditure shows a negative impact in the Danzhou-Yangpu Port Economic Circle, which is different from the Haikou Comprehensive Economic Circle. We think this needs to be discussed. For Danzhou-Yangpu Port Economic Circle, more government spending could mean stronger government regulation, which would be detrimental to the recovery of ports.

In terms of data, we know that large data constraints are a major hindrance in the assessment of island SDGS [56]. In order to get reliable results, we use migration big data to evaluate the real-time impact of COVID-19. Migration big data have the characteristics of real-time, high precision, and wide coverage results, and is now widely used to analyze urban connectivity and urban network structure [57], as well as COVID-19 related research [58]. And it has an application prospect in the real-time impact assessment of major public health emergencies [59]. Therefore, we advocate that, on the one hand, the availability and accessibility of relevant data and statistical systems, as well as the management of geospatial data platforms, could be strengthened according to the priorities of the island. Of course, using the migration big data to represent population mobility has some limitations. Firstly, in light of the representation issues of migration data source, the data may not capture real-time population flows during acute phases of emergencies when mobility is most affected. Besides, in our study, the AutoNavi Traffic website only publishes data for the top 20 migrating regions, and the migration intensity of island destinations moving from certain regions within the island during post-epidemic phases may be ranked lower and not published. As a result, the information collected may not include all the regions where there is flowing in and out. Moreover, considering possible biases in
migration data, the data likely over-represent certain demographic groups' mobility (e.g., tech-savvy smartphone users). And there may be a reality where users in the migration group delay or do not turn on the location, causing the recorded migration data to deviate from the real population mobility data. It may not record the passenger transfer behavior, resulting in some data that cannot be recorded. Lastly, in terms of the extended analysis of migration data, it is only a single mobility indicator based on the changes of smartphone positioning information, which cannot identify people’s traffic modes and travel purposes, as well as some demographic characteristics of migrating individuals. And the study of population mobility is not only based on changes in geographic location, but also includes mobility based on culture, information, technology, etc., carried by people as nodes in mobility networks. Regions with a high migration index also do not imply high absorption capacity. In addition, in the use of method, considering Tobler’s First Law (TFL), we apply bivariate spatial autocorrelation to the relevant research in this paper. This method can help us find out which regions' economic resilience is related to population mobility in neighboring regions, and the result will provide ideas for building a sustainable island.

6. Main Conclusions and Policy Recommendations

This paper takes 18 administrative regions within Hainan Island as the research object. Based on the daily migration big data of AutoNavi and the data of government's statistical bulletin, by using the two-way fixed effect model and bivariate local spatial autocorrelation model, we explore the population mobility and economic resilience of the 18 administrative regions within Hainan Island from the occurrence of the pandemic in Hainan on 22 January 2020 to 30 September 2023. Our main conclusions are as follows:

(1) In the short term, the impact of the pandemic severely affected the movement of people in Hainan Island during the Spring Festival, and among the three major economic growth poles in Hainan, the post-holiday movement of people in the island’s tourism economic circle was the slowest in terms of relative recovery. Therefore, in the process of coping with the impact of the pandemic, Hainan Island can propose corresponding industrial structure adjustment measures to improve the diversification of regional industrial structure.

(2) The COVID-19 outbreak led to a weakening of the strength of city or county interaction network connection within Hainan Island, but with the dissipation of the pandemic, the network connectivity gradually increased. Overall, the level of economic resilience of cities and counties on Hainan Island has improved, and the resilience level of cities (counties) within two economic circles of Haikou and Sanya tends to be more coordinated. Appropriate regional unified planning such as transportation accessibility could be considered to promote the regional coordination level in economic circles.

(3) Under the impact of the pandemic, population movement in cities or counties within the Dazhoush-Yangpu Port Economic Circle contributed to improve regional economic resilience but had a negative effect in the Central Ecological Conservation Area. So, as for ecologically prioritized areas within island, in the highest protected areas, the government may consider piloting some protection policies, such as an ecological relocation policy [60] and, in other protected areas, could improve regional economic resilience through digital transformation of the tourism industry to reduce offline interactions during acute phases of public health emergencies [61].

(4) There is a local spatial autocorrelation between economic resilience and population mobility, showing sporadic scattered distributions of the H-H, H-L, and L-L types. For the above-mentioned regions with spatial aggregation, cooperation with adjacent sectors could be strengthened, and an interconnected mechanism for early warning of risks could be established.
This study still has some limitations. For example, the economic resilience is affected by a combination of many factors, the current selection of control variables is not a unified standard that can be followed. Based on the limited accessibility of research data and other practical dilemmas, the research model needs to be further optimized. Future research will focus on the following points: Using questionnaire survey and interview data related to tourists’ own factors to refining the results, such as analyzing whether the pandemic has an impact on people’s willingness to travel and the gap between the actual travel, and the long-term impact of economic resilience remains to be tracked. In addition, the intermediate mechanism of population mobility’s impact on economic resilience is need to be discussed in depth.

Author Contributions: Conceptualization, X.F. and W.L.; methodology, X.F.; software, X.F.; validation, X.F. and W.L.; formal analysis, X.F.; investigation, X.F. and W.L.; resources, X.F. and W.L.; data curation, X.F.; writing—original draft, X.F. and W.L.; writing—review and editing, X.F. and W.L.; visualization, X.F.; supervision, X.F. and W.L.; project administration, X.F. and W.L.; funding acquisition, W.L. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by the 2023 Special Fund for High-quality Development Theme Research of the Guangdong Planning Office of Philosophy and Social Science, grant number GD23WTD03-20.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: The data used to support the findings of this study are available from the corresponding author upon request.

Acknowledgments: We appreciate the productive suggestions from editors and anonymous reviewers and would like to give our thanks to them.

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

References


Disclaimer/Publisher’s Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of MDPI and/or the editor(s). MDPI and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.