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Temporal and Spatial Pattern of Expressway Construction in China from 1999 to 2019 and Its Correlation with Regional Economic Growth

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Abstract: As one of the important factors affecting regional economic development, expressway construction has been a concern of scholars worldwide. China's highway construction is relatively late compared with Western developed countries, but the speed is faster. The construction is in step with China's high-speed economic growth stage. However, there is temporal and spatial heterogeneity in expressway construction and economic development across different regions of the world, which has not been fully documented in the current literature. Using panel data from 1999 to 2019 encompassing expressway construction and regional economic development indicators of 233 prefecture-level cities in China, this paper delves into the dynamics of expressway infrastructure development and its correlation with regional economic growth. Using regression analysis, the study provides the following key insights: (1) As of 2019, expressway density exhibits a spatial pattern characterized by a higher density in major urban clusters and provincial capitals and a lower density in northeastern China and border regions. Between 1999 and 2009, the eastern region witnessed the fastest increase in expressway density, while the central region surpassed the eastern region in density growth during 2009–2019. Over the past two decades, there has been a significant overall increase in expressway growth nationwide, with the distribution of prefecture-level cities experiencing relatively faster growth rates aligning with the principles of the "National Highway Network Planning". (2) Although there has been an overall increase in per capita GDP among prefecture-level cities, there has also been a widening disparity between these cities. Meanwhile, the total GDP of the central and western regions has experienced notable growth, effectively closing the gap with the eastern region. While total GDP demonstrates balanced development, per capita GDP displays a more varied pattern of growth. (3) Expressway density has played a positive role in fostering regional economic growth across the country over the long term. However, its impact has been more pronounced in the western region from 1999 to 2009 and increasingly significant in the eastern and central regions from 2009 to 2019.

Keywords: expressway; regional economy; China; correlation

Citation: Liang, J.; Zong, H. Temporal and Spatial Pattern of Expressway Construction in China from 1999 to 2019 and Its Correlation with Regional Economic Growth. *Land* **2024**, *13*, 2041. https://doi.org/10.3390/land13122041

Academic Editors: Fernando Fonseca, Daniel Rodrigues, Paulo Ribeiro and Antônio Nélson Rodrigues da Silva

Received: 28 October 2024
Revised: 23 November 2024
Accepted: 26 November 2024
Published: 28 November 2024

1. Introduction

Since China embarked on its reform and opening-up journey, the nation has achieved remarkable milestones in highway development. The construction of highway transportation infrastructure has catalyzed regional economic and social advancement, evolving into a widely acknowledged development paradigm. The adage "The path to wealth begins with road construction" has become emblematic of the era's ethos. Although China's exploration of expressway development commenced decades later than that of developed nations, it was in the 1980s that significant strides were taken. By the end of 2022, the length of expressways in China had reached 177,000 km, ranking first in the world.

Traffic conditions are commonly recognized as crucial factors influencing regional economic dynamics, with scholars widely concurring that enhancements in transportation infrastructure can stimulate regional economic expansion to a significant degree [1]. As an integral component of the contemporary transportation network, expressways play a pivotal role in mitigating geographical constraints between regions, influencing the flux of population and goods, among other factors, thereby exerting a multiplier effect on regional economic and industrial development, ultimately reshaping the regional economic landscape [2].

The strategic policy framework of the “National Road Network Planning Document” is both competitive and complementary with other modes of transportation, such as high-speed rail and aviation. In terms of short- and medium-distance transportation, highways and high-speed railways exhibit strong competitiveness. For long-distance transportation, aviation holds a distinct advantage. These various modes of transportation complement each other to form China’s comprehensive transportation network. It is likely that China’s “National Road Network Planning” document will primarily focus on enhancing domestic road traffic connectivity and efficiency, while Europe demonstrates a more pronounced regional integration feature in its approach to road network planning. The changes in China’s road network planning policy reflect an increased emphasis on the development of high-speed rail infrastructure and the modernization of the overall road network.

However, the current focus of research in transportation studies in China predominantly revolves around high-speed rail construction and its associated social and economic impacts, overshadowing investigations into the singular construction of expressways and their influence on regional economic growth [3]. Owing to variations in developmental stages, endowments in resources, and policy orientations, China’s highway construction exhibits significant spatial heterogeneity. The current state of this spatial heterogeneity, along with strategies for efficient utilization and optimization of China’s highway network in the future to foster sustainable regional economic development and mitigate regional disparities, are topics worthy of our attention and in-depth research. Therefore, from the perspective of temporal and spatial patterns of expressway construction, this paper puts the research time period in the rapid development stage of China’s expressway from 1999 to 2019 and studies the temporal and spatial patterns of China’s expressway construction and regional economic growth in prefecture-level cities in order to understand the correlation effect of transportation infrastructure and regional economic development.

2. Literature Review

Currently, scholarly investigations into regional economic growth predominantly center on the disparities in regional economic development [4], the determinants of regional economic growth [5–7], and strategies to address regional economic development challenges [8,9]. The research on the equilibrium of regional economic development is often carried out based on the theory of regional unbalanced growth, the theory of growth poles, and the inverted “U” shape theory. The common indexes and methods for measuring regional economic equilibrium include the Gini coefficient, Thiel index, and coefficient of variation. These theories and methods provide effective support for understanding and guiding the balanced development of a regional economy and help to realize the coordinated and balanced development and common prosperity among regions.

Notably, transportation infrastructure construction and its ramifications on regional economic development have garnered considerable attention among scholars [6,10]. Scholarly investigations spanning various nations such as Spain [11], Greece [12], and Turkey [13] have underscored the spillover effects inherent in transport infrastructure [14]. Infrastructure initiatives including highways, railways, and aviation have demonstrated capabilities to reduce transportation costs [15], enhance efficiency, and expedite the flow and consolidation of economic factors such as population, capital, information, technology, knowledge, and production resources. Consequently, these initiatives foster regional employment growth and exert significant impacts on regional population distribution and industrial spatial structure [16–18]. In addition, transportation infrastructure exhibits spatial heterogeneity with regard to regional development [19,20]. As transportation infrastructure networks mature, polarization and diffusion effects manifest within core and peripheral cities [21–23]. Initially, polarization effects dominate during the nascent stages of transportation infrastructure construction, transitioning into diffusion effects as maturity is attained [24].

As one of the important factors affecting regional economic development, expressway construction has attracted wide attention and research in the world. From the perspective of different countries, highway construction in the United States focuses on interstate connections and long-distance transportation, with the early formation of a relatively complete national highway network [25]. The construction of the highway network has driven the economic development of the areas along the route, promoted the formation of new commercial and residential areas, and increased employment opportunities, thus stimulating economic growth [26]. The European motorway network not only connects domestic cities, but also enables regional connectivity through transnational motorways and promotes economic integration within the EU [27–29]. The improvement of the expressway network has reduced the logistics costs of cross-border trade and investment, promoted the free flow of capital and goods, and enhanced the economic vitality of the region [23]. While China's highway development is relatively late, the speed of highway construction is very fast. The rapid expansion of the expressway network is carried out simultaneously with the rapid economic growth and urbanization process [2]. Compared to other modes of transport, highway construction primarily focuses on enhancing intra-regional traffic conditions, thereby expediting urbanization and influencing regional economic structures [30,31]. Highway freight transport constitutes a vital driver of regional economic growth, particularly in less developed cities, where economic development is more sensitive to deficiencies in highway infrastructure [32]. The introduction of new expressways can significantly impact the spatial configuration of urban industries [33,34]. Some scholars have also paid attention to the impact of expressway construction on urban spatial form [35,36] and argued that road traffic links make urban networks have spatial dependence and hierarchical characteristics.

At present, different studies have been carried out around the world on the spillover effect of highways and high-speed rails. However, a spatial heterogeneity analysis of the highway effect and the situation in China have not been fully researched. Therefore, this paper takes 233 prefecture-level cities in China as the object and uses the research period from 1999 to 2019, which represents the stage of rapid development of China's highway construction and regional economy. This paper aims to analyze the temporal and spatial pattern of China's economic development and highway construction in the same period, its spatial heterogeneity, as well as the relationship between highway and regional economic growth.

3. Methodology

3.1. Research Area

Due to the difficulty in obtaining data in some prefecture-level cities, this study finally selects 233 prefecture-level cities, encompassing 4 municipalities directly under the central government, as its research subjects. These cities are distributed across various regions, comprising 82 in the eastern region, 64 in the central region, 54 in the western region, and 33 in the northeast region (Figure 1). In 2019, the total GDP of these regions accounted for 88% of China's total GDP, and the highway mileage accounted for 70%. These regions are involved in the national highway network planning and have a high representation.

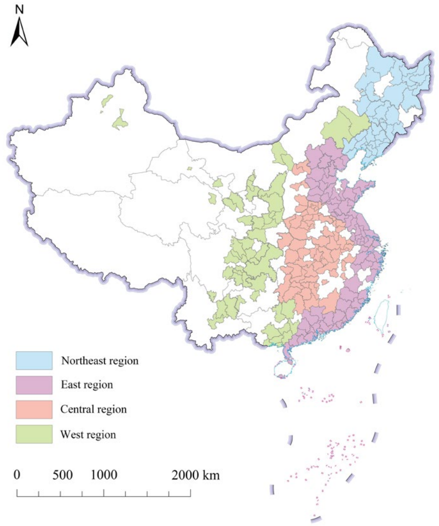


Figure 1. Selected 233 prefecture-level cities in China.

3.2. Data Sources

Taking into account that China's highway construction commenced in the late 1990s and experienced rapid development in the early 21st century, and considering the availability of data, this paper selects three time points: 1999, 2009, and 2019. The research data primarily stem from sources such as the China Urban Statistical Yearbook (2000–2020), China Statistical Yearbook, Statistical Bulletin of National Economic and Social Development, as well as statistical yearbooks from provinces and prefecture-level cities for the relevant years. Expressway mileage data from graded highways in the statistical records constitute the primary dataset. Utilizing ArcGIS software 10.8, the expressway network was vectorized, and subsequent calculations and statistical analyses were conducted. In cases of missing data, interpolation methods were employed to complete the dataset, with reference to comparisons across national traffic atlases from various years.

3.3. Research Methods

This paper conducts an analysis of expressway density and growth rates across 233 prefecture-level cities for the years 1999, 2009, and 2019, aiming to delineate the evolution of expressway construction and development. Subsequently, visualizations of the variation coefficients of GDP and per capita GDP are generated for both the nation as a whole and its four major regions—eastern, central, western, and northeastern—providing insights into changes in economic development within the study area. Finally, leveraging regression modeling, the paper delves into the relationship between China's highway construction and regional economic growth. Thus, the methods and models employed in this study are outlined as follows:

First, the coefficient of variation is employed. This paper primarily employs the coefficient of variation (CV) to gauge the equilibrium of regional economic development. The coefficient of variation is computed using the following formula:

$$CV = \frac{\sqrt{\frac{1}{n}\sum_{i=1}^{n}(y_i - \overline{y})^2}}{\overline{y}} \tag{1}$$

where y_i is the GDP of i prefecture-level cities, $\overline{y}$ is the national GDP, and n represents the number of regions. The coefficients of variation for both GDP and per capita GDP for the four major sectors are calculated similarly.

Second, regression analysis is employed. In this analysis, the natural logarithm of per capita GDP serves as the dependent variable (Y), and the density of highways acts as the core explanatory variable (X1). Additionally, seven control variables are incorporated into the model, namely, the proportion of value-added by the secondary industry in GDP (X2), the proportion of value-added by the tertiary industry in GDP (X3), the number of employees in urban units (X4), science and technology expenditures in local general public budgets (X5), fixed-asset investment (X6), actual utilization of foreign capital (X7), and total retail sales of consumer goods (X8), as shown in detail in Table 1.

Table 1. Statistical table of variables.

Variable Type	Variable Name	Short for Variable	Units
Dependent variable	The natural logarithm of per capita GDP	Y	CNY
Core explanatory variables	The density of highways	X1	m/km^2
Control variables	The proportion of value-added by the secondary industry in GDP	X2	%
	The proportion of value-added by the tertiary industry in GDP	X3	%
	The number of employees in urban units	X4	Ten thousand people
	Science and technology expenditures in local general public budgets	X5	Billion CNY
	Fixed-asset investment	X6	Billion CNY
	Actual utilization of foreign capital	X7	Billion USD
	Total retail sales of consumer goods	X8	Billion CNY

The regression model is formulated as follows:

$$Y = \alpha + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \beta_4 X_4 + \beta_5 X_5 + \beta_6 X_6 + \beta_7 X_7 + \beta_8 X_8 + \varepsilon_i \quad (2)$$

where α is the constant term, ε_i is the random disturbance term, and β_1–β_8 is the regression coefficient of the core explanatory variable and the control variable.

4. Results

4.1. Temporal and Spatial Pattern Analysis of China's Expressway Development

By 2019, the expressway network layout in China exhibited a spatial pattern characterized by "high density in major city clusters and provincial capitals, and low density in northeastern China and border areas". In the initial phase of expressway construction, cities along the eastern coast, particularly those within the Bohai Sea Rim, Yangtze River Delta, and Pearl River Delta city clusters, emerged as focal points for expressway development. The period spanning from 1999 to 2009 marked a phase of rapid expansion in China's expressway infrastructure. During this period, proactive fiscal policies were implemented by the state in response to the Asian financial crisis, which propelled the construction of infrastructure such as expressways. Consequently, expressway density witnessed a significant surge nationwide, with prefecture-level cities along the eastern coast experiencing particularly accelerated growth. This trend manifested as a gradual decline in density from the eastern coastal regions toward the western hinterlands. From 2009 to 2019, with the infrastructure construction focus in the east shifting toward high-speed rail projects, the epicenter of expressway development transitioned from the east to the central and western regions. While the growth rate of expressway density in the east decelerated, the western regions witnessed continued expansion, gradually closing the gap with the east. By 2019, the density of expressways across 233 prefecture-level cities in China exhibited a spatial distribution pattern characterized by "higher density in major city clusters and provincial capitals, and lower density in northeastern and border regions". Despite the overall increase in expressway length, the density of expressways in northeastern China remained relatively subdued (Figure 2).

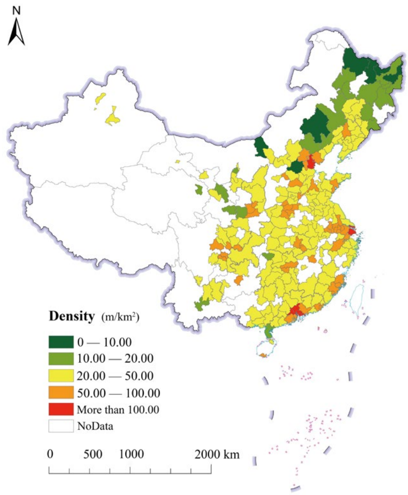


Figure 2. Density of expressways in 233 prefecture-level cities in 2019 (m/km^2).

In the first decade, expressway density experienced the most rapid increase in the eastern region, while in the subsequent decade, the central region surpassed the eastern region in terms of density growth. Expressway density exhibited a continuous rise across the eastern, central, western, and northeastern regions. However, disparities in expressway density among these regions continued to widen. Initially, the total number of highways in each region was divided by the area of each region to compute the average highway density (Table 2). Subsequently, the incremental density and growth rates of expressways were calculated for the four major regions during the periods of 1999–2009 and 2009–2019. Analysis of the results revealed that the eastern region witnessed the largest density increase during 1999–2009, with a notable difference of 20.61 m/km^2. Conversely, from 2009 to 2019, the central region exhibited a density increase of 19.56 m/km^2, surpassing the eastern region's increase of 19.13 m/km^2. In terms of the overall density growth rate, the central region demonstrated the most rapid growth among the four major regions over the past two decades. Examining the disparities in highway density among the four major regions in 1999, 2009, and 2019, it is evident that expressway density within each region continued to rise. The density growth pattern in the initial decade followed the sequence of "East > Central > West > Northeast", while in the subsequent decade, it shifted to "Central > East > West > Northeast". Furthermore, there exists a significant disparity in average expressway density between the northeast and the east, central, and west regions. On a regional scale, it is observed that aside from the east-central region, the gap in highway density between other regions continued to widen, albeit at a gradually decelerating rate. The most substantial disparity predominantly manifests between the eastern and northeastern regions, as well as between the eastern and western regions.

From 1999 to 2019, there has been a significant increase in the overall growth rate of expressways throughout China, with the distribution of prefecture-level cities exhibiting relatively faster growth rates aligning with the radiation pattern outlined in the "National Highway Network Planning". This trend mirrors the developmental stages of China's highway infrastructure. Initially, construction and development efforts were concentrated in the eastern coastal areas; however, as highway construction in these developed coastal regions reached saturation levels, attention shifted towards new infrastructure ventures such as high-speed rail, intercity rail, and subway systems. Consequently, the focus of highway construction gradually transitioned to the central and western regions. The growth trajectory of China's expressway network from 1999 to 2019 is depicted in Figure 3. Prefecture-level cities with accelerated growth rates predominantly exhibit four distinct linear distributions: "Harbin—Beijing", "Beijing—Taipei", "Beijing—Hong Kong and Macao", and "Beijing—Kunming", all of which align with the national highway network planning. Overall, the growth rate of expressway mileage in prefecture-level cities within the central and western regions consistently outpaced that of the eastern coastal areas. This underscores the nation's aim to bolster economic and social development in the central and western regions by enhancing transportation infrastructure. Anticipated deceleration in China's highway expansion is expected to persist due to the gradual refinement of the national highway network and other contributing factors. Furthermore, future increases in highway construction may primarily target the central and western regions, facilitating inter-provincial connectivity and establishing multi-road links between urban agglomerations and prefecture-level city expressways.

Table 2. Statistical table of highway density and gaps in 233 prefecture-level cities (m/km^2).

	Regions	East	Central	West	Northeast
1999 density		5.99	2.30	2.73	1.82
Density increase, 1999–2009		20.61	15.47	9.49	5.62
Density growth rate, 1999–2009		444%	773%	448%	409%
2009 density		26.60	17.77	12.22	7.44
Density increase, 2009–2019		19.13	19.56	15.37	10.26
Density growth rate, 2009–2019		172%	210%	226%	238%
2019 density		45.73	37.33	27.59	17.70
1999 density difference	East	0.00			
	Central	3.69	0.00		
	West	3.27	0.43	0.00	
	Northeast	4.18	0.48	0.91	0.00
2009 density difference	East	0.00			
	Central	8.83	0.00		
	West	14.38	5.55	0.00	
	Northeast	19.17	10.34	4.79	0.00
2019 density difference	East	0.00			
	Central	8.40	0.00		
	West	18.13	9.73	0.00	
	Northeast	28.02	19.62	9.89	0.00

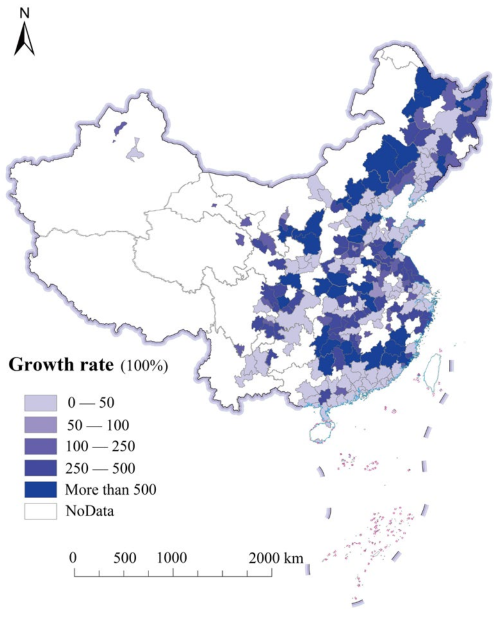
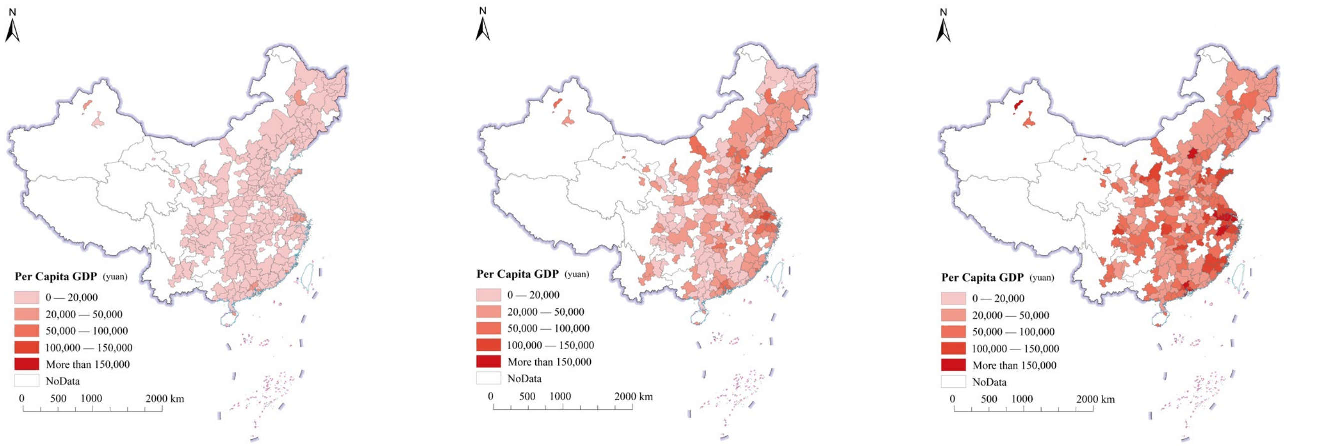


Figure 3. Growth rate of expressways in 233 prefecture-level cities during 1999–2019 (100%).

4.2. Analysis of Regional Economic Development Patterns

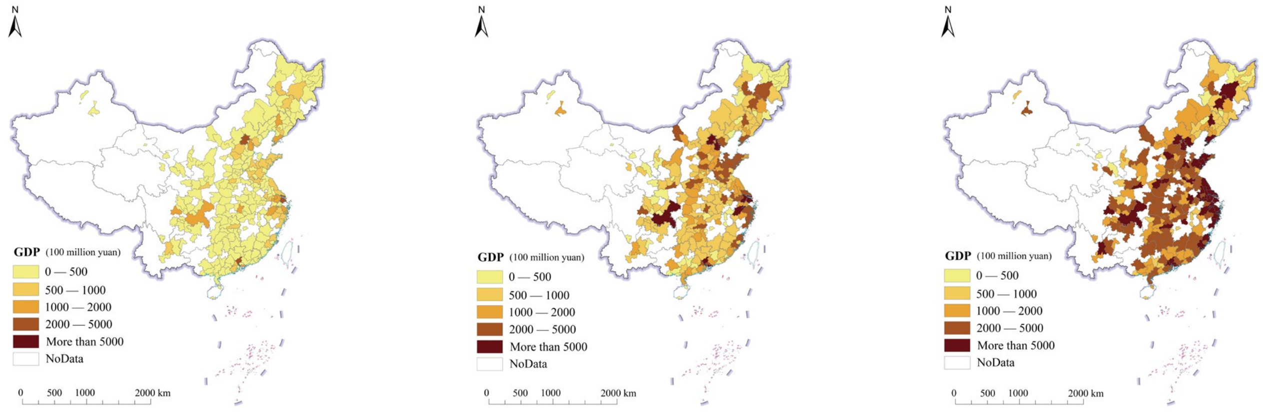
The per capita GDP of prefecture-level cities has experienced a notable increase; however, disparities among these cities have also widened. As depicted in Figure 4, the per capita GDP of 233 prefecture-level cities has displayed a certain degree of growth over time, albeit with significant variations. From 1999 to 2009, prefecture-level cities witnessing faster per capita GDP growth were predominantly concentrated in the eastern coastal areas, particularly within the Bohai Sea, Yangtze River Delta, and Pearl River Delta regions, exhibiting a discernible pattern of concentrated and widespread distribution. Subsequently, during the period from 2009 to 2019, although the overall per capita GDP of prefecture-level cities exhibited significant growth, those led by the Yangtze River Delta and Pearl River Delta city clusters maintained a higher per capita GDP compared to most other prefecture-level cities, resulting in a considerable disparity. Concurrently, provincial capitals in central and western China, such as Chengdu in Sichuan Province, Zhengzhou in Henan Province, Changsha in Hunan Province, and Wuhan in Hubei Province, along with some surrounding prefecture-level cities, have also experienced rapid economic growth. This underscores the government's efforts to stimulate regional economic development by bolstering policy support and advancing infrastructure development, thereby fostering coordinated regional development. However, economic growth in Northeast China appears relatively subdued, with the "Revitalization of the Old Industrial Base in Northeast China" initiative yielding unsatisfactory results. Currently, the region is confronted with the challenges of population and economic contraction.



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

Figure 4. Distribution of per capita GDP in 233 prefecture-level cities from 1999 to 2019 (CNY): (**a**) Per capita GDP distribution in 1999; (**b**) Per capita GDP distribution in 2009; (**c**) Per capita GDP distribution in 2019.

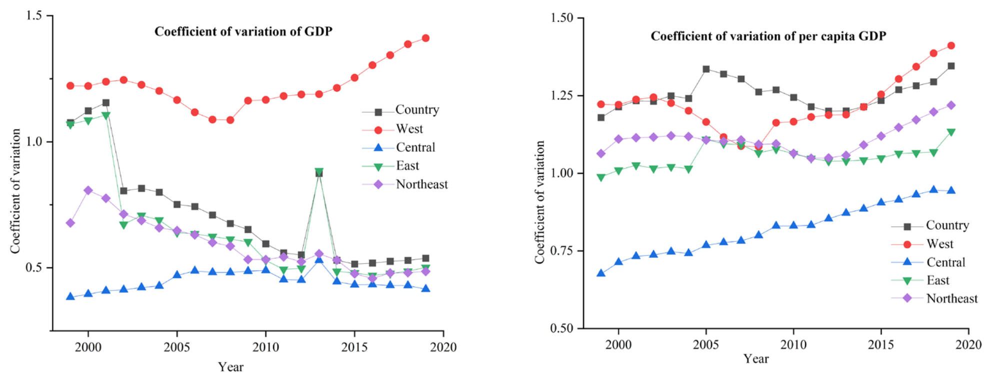
The total GDP of the central and western regions has increased, with active efforts to catch up with the eastern regions. As illustrated in Figure 5, the economy of the eastern region experienced rapid growth during the period of 1999–2009, with the total GDP of prefecture-level cities in the eastern coastal region significantly surpassing that of the central and western regions. However, municipalities and provincial capitals such as Chongqing, Chengdu, Xi'an, and Changsha in the central and western regions remained at the forefront, alongside prefecture-level cities in the eastern coastal regions. With the strategic implementation of western region development and the ascent of the central region, prefecture-level cities in the central and western regions have encountered new opportunities for economic advancement. The total GDP of these cities has continued to rise, actively narrowing the gap with those in the eastern region. Nevertheless, the GDP of prefecture-level cities in the eastern coastal areas and provincial capitals in the central and western regions still significantly surpasses that of other prefecture-level cities, while the GDP growth of cities in the northeast remains relatively sluggish.



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

Figure 5. GDP distribution of 233 prefecture-level cities in China from 1999 to 2019 (100 million CNY): (**a**) GDP distribution in 1999; (**b**) GDP distribution in 2009; (**c**) GDP distribution in 2019.

Total GDP exhibits balanced development, while per capita GDP is evolving in a more varied manner. This study employs the coefficient of variation method to gauge changes in regional GDP and per capita GDP (Figure 6). Apart from the western region, the trend of GDP and per capita GDP variation coefficients across the nation and other regions is "contrary", reflecting the "contradiction" inherent in the regional economic development process. From the standpoint of total GDP, with the exception of prefecture-level cities in the west, the overall trend at the national level and within the other three major regions indicates a diminishing discrepancy and an increasing equilibrium. However, a closer examination of per capita GDP reveals a widening disparity among prefecture-level cities within each region, leading to a decrease in equilibrium. Conversely, both the GDP and per capita GDP coefficients of prefecture-level cities in the western region exhibit a similar trajectory, initially decreasing from 2002 to 2008, followed by an increase post 2008. This fluctuation underscores the oscillation in economic development equilibrium among prefecture-level cities, initially strengthening and subsequently weakening. This change can be attributed to the state's encouragement of the western region's development and construction, yielding some success in narrowing economic disparities among prefecture-level cities in the west. However, as economic development progresses, varying levels of resource endowment, transportation infrastructure, and policy support affect different prefecture-level cities, resulting in divergent economic development statuses and opportunities. Consequently, the coefficient of variation within the western region has steadily risen, leading to a more pronounced imbalance in regional economic development.



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

Figure 6. Coefficient of variation of GDP (**a**) and coefficient of variation of per capita GDP (**b**) from 1999 to 2019.

4.3. Expressway Construction and Regional Economic Development Analysis

4.3.1. Construction of the Model

Through the aforementioned analysis, a noticeable correspondence emerges between the economic trajectories of the eastern, central, western, and northeastern regions and the evolution of expressway infrastructure. Prefecture-level cities exhibiting a denser distribution of expressways tend to demonstrate stronger economic development, while those with a sparser network of expressways manifest relatively weaker economic performance. Thus, it can be inferred that a certain relationship exists between the construction of expressways and regional economic growth. Building upon this observation, the present study employs spatial panel data and constructs an econometric model to scrutinize the intricate nexus between expressway development and regional economic advancement.

Because the focus of this paper is on the connection between highway construction and regional economic development, the density of highways is selected as the core explanatory variable. Many factors affect regional economic disparities. Industrial structure, labor resources, scientific and technological innovation, investment, consumption, and exports are generally recognized by scholars as important factors affecting regional economic development, and these relevant indicators are used frequently. Therefore, considering the availability of data, this paper ultimately selects the proportion of value-added by the secondary industry in GDP, the proportion value-added by the tertiary industry in GDP, the number of employees in urban units, science and technology expenditures in local general public budgets, fixed-asset investment, actual utilization of foreign capital, and total retail sales of consumer goods as the control variables.

In this paper, eight explanatory variables are selected. Considering the multicollinearity problem that may exist between the variables, in order to improve the calculation accuracy of the model and make the results more convincing, the multicollinearity test is carried out first. The variance inflation factor (VIF) is used in this paper, and the specific calculation results are as follows (Table 3):

Table 3. VIF test results.

Variable	VIF	1/VIF
X8	8.830	0.113
X5	4.220	0.237
X6	3.960	0.253
X7	3.390	0.295
X4	2.580	0.387
X1	1.820	0.548
X3	1.590	0.629
X2	1.000	0.997

Based on the variance inflation factor (VIF) test outcomes, it is observed that the VIF values for all eight explanatory variables are below the critical threshold of 10. From a statistical standpoint, this indicates the absence of significant multicollinearity issues among the independent variables, thereby minimizing potential distortion in parameter estimation results.

4.3.2. Analysis Results

In this paper, Stata MP 16 was employed to conduct regression analysis on panel data spanning 1999, 2009, and 2019, covering the entire country as well as its eastern, central, western, and northeastern regions. Notably, the fixed effects model was preferred over the random effects model, and the regression outcomes are detailed in Table 4. According to the findings, the regression coefficient of expressway density surpassed the significance threshold of 1% both nationally and within the eastern, central, western, and northeastern regions, exhibiting a positive correlation with regional per capita GDP. This suggests that expressway construction effectively stimulated regional economic development from 1999 to 2019.

Expressways, characterized by safety, efficiency, low transportation costs, short travel times, and extensive service coverage, provide conducive conditions for intercity transportation, facilitating the swift and convenient movement of goods. The construction and expansion of expressway networks serve to diminish temporal and spatial distances between regions, hasten the flow of population and commodities, expedite the circulation between production and consumption, and foster the efficient allocation of regional resources.

Table 4. Regression results from 1999 to 2019.

Time		Country	East	Central	West	Northeast
1999–2019	X1	0.0241 ***	0.00543 ***	0.0204 ***	0.0334 ***	0.0547 ***
		(0.00190)	(0.00154)	(0.00271)	(0.00584)	(0.0105)
	X2	0.000404	0.0656 ***	0.0704 ***	0.0667 ***	0.000109
		(0.000356)	(0.00484)	(0.00670)	(0.00967)	(0.000350)
	X3	0.0350 ***	0.0938 ***	0.0810 ***	0.0750 ***	−0.00698
		(0.00446)	(0.00535)	(0.00740)	(0.0138)	(0.0117)
	X4	−0.00273 ***	−0.000426	−0.00762 ***	−0.00285	−0.000689
		(0.000812)	(0.000640)	(0.00184)	(0.00289)	(0.00299)
	X5	−0.00662 ***	−0.00511 ***	0.0135 **	0.0144	−0.0181
		(0.00158)	(0.00107)	(0.00455)	(0.0261)	(0.0308)
	X6	−0.00305	0.00271	−0.00751	−0.0195	−0.0153
		(0.00385)	(0.00322)	(0.00629)	(0.0150)	(0.0140)
	X7	0.0000947	0.000138 **	−0.000349 *	−0.0000237	0.0000894
		(0.0000609)	(0.0000432)	(0.000159)	(0.000280)	(0.000175)
	X8	0.000165 ***	0.000116 ***	0.000279 ***	0.000152	0.000373 *
		(0.0000306)	(0.0000237)	(0.0000732)	(0.000127)	(0.000146)
	_cons	7.978 ***	2.936 ***	3.153 ***	3.244 ***	9.362 ***
		(0.168)	(0.383)	(0.516)	(0.840)	(0.436)
	N	699	246	192	162	99
	R^2	0.709	0.900	0.922	0.795	0.634
	adj. R^2	0.556	0.844	0.876	0.669	0.382

Note: Significance levels: *~p < 0.1, **~p <0.05, ***~p < 0.01.

In addition, according to the calculation results of the model, it can be seen that the proportion of value-added by the tertiary industry in GDP in the country, eastern, central, and western regions has passed the significance level test of 1% and has a positive impact on regional economic growth. The proportion of value-added by the tertiary industry in GDP reflects the industrial economic structure of a region. The development of the tertiary industry not only enhances the degree of modernization. It also promotes economic growth, employment, and regional economic vitality; improves the economic structure; and promotes industrial upgrading and innovation. The transformation and upgrading of regional industrial structure have important impacts on the sustainable development of the regional economy.

Second, this paper conducts a comparative analysis of the national, eastern, central, western, and northeastern regions during two periods: from 1999 to 2009 and from 2009 to 2019 (Tables 5 and 6). In the initial decade, the influence of expressway density on the economy achieved statistical significance at the 1% level in the entire country and the western region and at the 10% level in the northeastern and central regions. However, its impact on the economic development of the eastern region was not statistically significant during this period. Factors such as investment and consumption played a more dominant role in driving economic growth in the east.

From 1999 to 2009, the total retail sales of consumer goods had a significant positive effect on the economic growth of the eastern region in Table 5. The total retail sales of consumer goods is an important index of the national economy, which directly reflects the living standard of residents, the purchasing power of consumer goods, social productivity, and monetary flow. It can be seen that the strong consumption power of eastern residents has played a virtuous cycle that promotes regional economic growth and development.

Table 5. Regression results from 1999 to 2009.

Time		Country	East	Central	West	Northeast
1999–2009	X1	0.0112 ***	0.00287	0.0112 *	0.0378 ***	0.0409 *
		(0.00248)	(0.00196)	(0.00512)	(0.0105)	(0.0192)
	X2	0.0664 ***	0.0575 ***	0.0692 ***	0.0709 ***	0.0507 **
		(0.00534)	(0.00549)	(0.0113)	(0.0142)	(0.0170)
	X3	0.0454 ***	0.0657 ***	0.0699 ***	0.0255	0.000903
		(0.00812)	(0.00779)	(0.0135)	(0.0218)	(0.0296)
	X4	−0.00246 **	−0.00115	−0.0104 ***	−0.00612	0.00373
		(0.000941)	(0.000746)	(0.00243)	(0.00422)	(0.00531)
	X5	−0.0106	−0.0103 *	−0.00187	0.221	−0.143
		(0.00545)	(0.00405)	(0.0615)	(0.184)	(0.244)
	X6	−0.0222 *	−0.00677	−0.00107	−0.0726	0.00553
		(0.00929)	(0.00716)	(0.0281)	(0.0620)	(0.0753)
	X7	0.000329	0.000198	−0.000617	0.00337 *	0.000850
		(0.000246)	(0.000185)	(0.000544)	(0.00142)	(0.00190)
	X8	0.000468 **	0.000488 ***	0.000906 **	−0.00133	0.000579
		(0.000143)	(0.000122)	(0.000302)	(0.000802)	(0.000758)
	_cons	4.475 ***	4.291 ***	3.661 ***	4.548 ***	6.479 ***
		(0.443)	(0.415)	(0.810)	(1.187)	(1.471)
	N	466	164	128	108	66
	R^2	0.774	0.912	0.901	0.744	0.739
	adj. R^2	0.533	0.805	0.775	0.404	0.321

Note: Significance levels: *~$p < 0.1$, **~$p < 0.05$, ***~$p < 0.01$.

Table 6. Regression results from 2009 to 2019.

Time		Country	East	Central	West	Northeast
2009–2019	X1	0.0141 ***	0.00759 ***	0.0111 ***	0.0119	0.00415
		(0.00241)	(0.00208)	(0.00223)	(0.00963)	(0.00810)
	X2	0.0000231	0.0992 ***	0.0693 ***	0.103 **	0.0000287
		(0.000264)	(0.0140)	(0.00767)	(0.0295)	(0.000180)
	X3	0.0263 ***	0.121 ***	0.0934 ***	0.133 ***	0.00887
		(0.00387)	(0.0136)	(0.00772)	(0.0357)	(0.00814)
	X4	−0.00108	−0.000992	0.000136	−0.000710	−0.0145
		(0.00110)	(0.00108)	(0.00200)	(0.00451)	(0.00882)
	X5	−0.00232	−0.00147	0.00861 *	0.00444	0.0177
		(0.00129)	(0.000906)	(0.00340)	(0.0350)	(0.0654)
	X6	0.000154	0.000947	−0.00317	−0.00112	−0.00595
		(0.00313)	(0.00304)	(0.00476)	(0.0197)	(0.0183)
	X7	0.0000652	0.0000873 *	−0.000176	−0.000256	0.000177
		(0.0000493)	(0.0000398)	(0.000119)	(0.000332)	(0.000121)
	X8	0.0000961 ***	0.0000435 *	0.0000738	0.000195	0.0000629
		(0.0000245)	(0.0000212)	(0.0000507)	(0.000153)	(0.000174)
	_cons	8.849 ***	0.360	2.924 ***	−0.254	10.25 ***
		(0.143)	(1.217)	(0.624)	(2.614)	(0.470)
	N	466	164	128	108	66
	R^2	0.686	0.877	0.946	0.678	0.576
	adj. R^2	0.350	0.729	0.878	0.251	−0.101

Note: Significance levels: *~$p < 0.1$, **~$p < 0.05$, ***~$p < 0.01$.

In the subsequent decade, expressway density began to exert a significant impact on the national, eastern, and central economies (Table 6). The progressive expansion of the expressway network enhanced accessibility within urban agglomerations like the Yangtze River Delta and Pearl River Delta, facilitating effective connectivity among previously disparate cities and enterprises, thereby fostering a robust economic network system. Furthermore, with the development of new infrastructure such as high-speed rail, spatial and temporal distances between regions have further diminished, leading to enhanced accessibility in the western region and notably benefiting prefecture-level cities in the west. Therefore, the impact of other factors such as high-speed rail on the regional economy may lead to a less significant economic impact of expressways in the western and northeast regions from 2009 to 2019.

5. Conclusions and Discussion

Based on spatial panel data covering 233 prefecture-level cities in China from 1999 to 2019, this paper examines the spatial and temporal evolution of highway construction and economic development in China. Empirical analysis is conducted using an econometric regression model. The key findings are as follows:

(1) As of 2019, expressway density exhibits a spatial pattern characterized by higher density in major urban clusters and provincial capitals and lower density in northeastern China and border regions. Over the past two decades, there has been a significant increase in the overall growth rate of expressways throughout China, with the distribution of prefecture-level cities exhibiting relatively faster growth rates aligning with the radiation pattern outlined in the "National Highway Network Planning". Between 1999 and 2009, the eastern region witnessed the fastest increase in expressway density, while the central region and west region surpassed the eastern region both in density increase and growth rate during 2009–2019.

(2) The total GDP of the central and western regions has experienced notable growth, effectively closing the gap with the eastern region. Meanwhile, there has been an overall increase in per capita GDP among prefecture-level cities. There has also been a widening disparity between these cities. While total GDP demonstrates balanced development, per capita GDP displays a more varied pattern of growth.

(3) Expressway density has played a positive role in fostering regional economic growth across the country during the past two decades. However, its impact has been more pronounced in the western region from 1999 to 2009 and increasingly significant in the eastern and central regions from 2009 to 2019.

China's highway construction is first concentrated in the eastern coastal developed areas, followed by the core cities of provinces, showing obvious spatial characteristics of hierarchy and priority distribution. The eastern coastal area, as the leading area of economic development, takes the lead in realizing the dense coverage of expressways by virtue of its strong economic foundation and strong traffic demand, thus further consolidating the regional economic advantages and accelerating the urbanization process. On this basis, the construction of expressways in the core cities of each province has been promoted rapidly, which has realized the efficient connection within the province and promoted the flow of resources and economic integration within the region. In contrast, highway construction in other countries is mostly reflected in balanced development or focused on specific economic corridors.

The studies conducted in this paper, as well as by other scholars, have demonstrated the growth effect of transportation infrastructure on regional economic development. However, different modes of transportation have varying impacts on regional economic growth and spatial patterns [3,32,37]. This study suggests that expressways have a positive impact on regional economic development. This finding aligns with research on countries and regions such as Spain [33], Turkey [13], and China's Yangtze River Delta region [34]. Expressways drive employment growth, reduce transportation costs, and stimulate regional economic development by attracting investment and promoting consumption [16].

Meanwhile, the effect of expressway construction on regional economic growth varies markedly across different periods and different regions. From 1999 to 2009, expressways played a significant role in promoting economic growth in western China, while impact of highways on the eastern and central regions was more prominent in the period from 2009 to 2019. The reasons for this spatial heterogeneity can primarily be attributed to two factors. First, the lag effect of infrastructure construction is a key factor. This phenomenon indicates that the economic benefits of such projects typically manifest gradually, often materializing several years post completion. Subsequent studies can be further explored. Second, the network effect resulting from expressway construction is another pivotal factor. Research indicates that the positive economic impacts of expressways are predominantly concentrated in the core areas directly linked by the network. Conversely, peripheral regions may encounter adverse effects as a consequence of expressway development [23,38]. Main arterial expressways primarily serve to connect key cities, expanding their accessibility, positively impacting regional agriculture, construction, and retail industries [18]. Conversely, secondary expressways primarily cater to intra-regional transportation needs, focusing on enhancing intra-regional connectivity and convenience, thereby strengthening the relationship between regional socioeconomic development and land use [17]. With the gradual improvement of the expressway network, inter-regional connectivity has been strengthened, and resource flow and market integration have been optimized. They exert a profound and distinctive influence on the economic growth trajectories of various regions at distinct developmental stages.

In conclusion, the influence of expressways on regional economies is multifaceted, exhibiting both temporal and spatial dimensions. In future construction and development process, first, it is necessary to optimize the layout of expressways and strengthen the construction of main transport corridors and key nodes in the expressways network in China. Second, the transport capacity of expressways in various regions and its wider economic effects should be included in the future research. Also, the integration of expressway planning and construction with urban development strategies is crucial. This approach will not only facilitate the adjustment and optimization of urban industrial layouts but also enhance the efficiency of resource allocation, thereby fostering balanced regional economic development. Furthermore, it is essential to enhance the connectivity between expressways and other transportation modes. This will promote a seamless and synergistic development of various transportation systems. For instance, the integration of high-speed rail, expressways, urban roads, and river transport should be pursued to create a comprehensive transportation ecosystem. Such an integrated system will not only bolster the overall transportation infrastructure but also significantly improve the efficiency of transport, thereby facilitating the smooth circulation of economic production factors. In the future, we can further analyze the broader effects brought by highway construction, such as regional economic effects, regional economic disparities, urbanization development, and highway construction investment. Second, to strengthen the empirical and comparative study of cases, it is important to carry out comparative research from different scales and spaces in multiple regions, deepen the understanding and discussion of expressway and regional economic development, assess regional traffic demand and development trend, and promote sustainable development.

Author Contributions: Conceptualization, H.Z. and J.L.; Methodology, H.Z.; Software, J.L.; Writing—original draft preparation, J.L.; Writing—review and editing, H.Z. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by the National Natural Science Foundation of China (grant number: 42071209) and Major Project funds for Dual-City Economic Circle in Chengdu Chongqing Region from Chongqing Federation of Social Science Associations (grant number: 2023ZDSC01).

Data Availability Statement: Data are contained within the article.

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

References

1. Cattaneo, M.; Malighetti, P.; Percoco, M. The impact of intercontinental air accessibility on local economies: Evidence from the de-hubbing of malpensa airport. *Transp. Policy* **2018**, *61*, 96–105. [CrossRef]
2. Xu, H.T.; Nakajima, K. Highways and industrial development in the peripheral regions of China. *Pap. Reg. Sci.* **2017**, *96*, 325–356. [CrossRef]

3. Cascetta, E.; Cartenì, A.; Henke, I.; Pagliara, F. Economic growth, transport accessibility and regional equity impacts of high-speed railways in Italy: Ten years ex post evaluation and future perspectives. *Transp. Res. Part A-Policy Pract.* **2020**, *139*, 412–428. [CrossRef] [PubMed]
4. Yilmaz, S.; Haynes, K.E.; Dine, M. Geographic and network neighbors: Spillover effects of telecommunications infrastructure. *J. Reg. Sci.* **2002**, *42*, 339–360. [CrossRef]
5. Xu, M.; Grant-Muller, S.; Gao, Z. Evolution and assessment of economic regulatory policies for expressway infrastructure in China. *Transp. Policy* **2015**, *41*, 42–49. [CrossRef]
6. Banerjee, A.; Duflo, E.; Qian, N. On the road: Access to transportation infrastructure and economic growth in China. *J. Dev. Econ.* **2020**, *145*, 36. [CrossRef]
7. Iacus, S.M.; Natale, F.; Santamaria, C.; Spyratos, S.; Vespe, M. Estimating and projecting air passenger traffic during the COVID-19 coronavirus outbreak and its socio-economic impact. *Saf. Sci.* **2020**, *129*, 11. [CrossRef]
8. Yen, B.T.H.; Mulley, C.; Zhang, M. Equity in financing public transport infrastructure: Evaluating funding options. *Transp. Policy* **2020**, *95*, 68–77. [CrossRef]
9. Zhou, X.X.; Cai, Z.M.; Tan, K.H.; Zhang, L.L.; Du, J.T.; Song, M.L. Technological innovation and structural change for economic development in China as an emerging market. *Technol. Forecast. Soc. Chang.* **2021**, *167*, 10. [CrossRef]
10. Zhao, J.; Guo, D.; Wang, J.; Yang, Z.; Zhang, H. Examining the Association of Economic Development with Intercity Multimodal Transport Demand in China: A Focus on Spatial Autoregressive Analysis. *ISPRS Int. J. Geo-Inf.* **2018**, *7*, 56. [CrossRef]
11. Álvarez, I.C.; Barbero, J.; Zofío, J.L. A spatial autoregressive panel model to analyze road network spillovers on production. *Transp. Res. Part A Policy Pract.* **2016**, *93*, 83–92. [CrossRef]
12. Marinos, T.; Belegri-Roboli, A.; Michaelides, P.G.; Konstantakis, K.N. The spatial spillover effect of transport infrastructures in the Greek economy (2000–2013): A panel data analysis. *Res. Transp. Econ.* **2022**, *94*, 101179. [CrossRef]
13. Piskin, M.; Hewings, G.J.D.; Hannum, C.M. Synergy effects of highway investments on the Turkish economy: An application of an integrated transport network with a multiregional CGE model. *Transp. Policy* **2020**, *95*, 78–92. [CrossRef]
14. Feder, C. Decentralization and spillovers: A new role for transportation infrastructure. *Econ. Transp.* **2018**, *13*, 36–47. [CrossRef]
15. Ahlfeldt, G.M.; Feddersen, A. From periphery to core: Measuring agglomeration effects using high-speed rail. *J. Econ. Geogr.* **2018**, *18*, 355–390. [CrossRef]
16. Chakrabarti, S. Can highway development promote employment growth in India? *Transp. Policy* **2018**, *69*, 1–9. [CrossRef]
17. Hu, X.; Wu, C.; Wang, J.; Qiu, R. Identification of spatial variation in road network and its driving patterns: Economy and population. *Reg. Sci. Urban Econ.* **2018**, *71*, 37–45. [CrossRef]
18. Chen, Z.H.; Li, Y.; Wang, P. Transportation accessibility and regional growth in the Greater Bay Area of China. *Transp. Res. Part D-Transp. Environ.* **2020**, *86*, 21. [CrossRef]
19. Wang, Y.; Hao, C.; Liu, D. The spatial and temporal dimensions of the interdependence between the airline industry and the Chinese economy. *J. Transp. Geogr.* **2019**, *74*, 201–210. [CrossRef]
20. Tong, T.; Yu, T.E. Transportation and economic growth in China: A heterogeneous panel cointegration and causality analysis. *J. Transp. Geogr.* **2018**, *73*, 120–130. [CrossRef]
21. Diao, M. Does growth follow the rail? The potential impact of high-speed rail on the economic geography of China. *Transp. Res. Part A Policy Pract.* **2018**, *113*, 279–290. [CrossRef]
22. Liang, Y.; Zhou, K.; Li, X.; Zhou, Z.; Sun, W.; Zeng, J. Effectiveness of high-speed railway on regional economic growth for less developed areas. *J. Transp. Geogr.* **2020**, *82*, 102621. [CrossRef]
23. Faber, B. Trade Integration, Market Size, and Industrialization: Evidence from China's National Trunk Highway System. *Rev. Econ. Stud.* **2014**, *81*, 1046–1070. [CrossRef]
24. Wang, C.; Lim, M.K.; Zhang, X.Y.; Zhao, L.F.; Lee, P.T.W. Railway and road infrastructure in the Belt and Road Initiative countries: Estimating the impact of transport infrastructure on economic growth. *Transp. Res. Part A-Policy Pract.* **2020**, *134*, 288–307. [CrossRef]
25. Buckwalter, D.W. Road-building and network efficiency in poly-centric Pittsburgh 1980–2010. *Appl. Geogr.* **2013**, *41*, 158–167. [CrossRef]
26. Janssen, M.A.; Anderies, J.M.; Baeza, A.; Breetz, H.L.; Jasinski, T.; Shin, H.C.; Vallury, S. Highways as coupled infrastructure systems: An integrated approach to address sustainability challenges. *Sustain. Resilient Infrastruct.* **2019**, *7*, 100–111. [CrossRef]
27. Garcia-López, M.-À. All roads lead to Rome . . . and to sprawl? Evidence from European cities. *Reg. Sci. Urban Econ.* **2019**, *79*, 103467. [CrossRef]
28. Müller, K.; Steinmeier, C.; Küchler, M. Urban growth along motorways in Switzerland. *Landsc. Urban Plan.* **2010**, *98*, 3–12. [CrossRef]
29. Rocha, B.T.; Melo, P.C.; Afonso, N.; de Abreu e Silva, J. The local impacts of building a large motorway network: Urban growth, suburbanisation, and agglomeration. *Econ. Transp.* **2023**, *34*, 100302. [CrossRef]
30. Liu, W.; Cao, Y.; Wu, W.; Guo, J. Spatial impact analysis of trans-Yangtze highway fixed links: A case study of the Yangtze River Delta, China. *J. Transp. Geogr.* **2020**, *88*, 102822. [CrossRef]
31. Li, B.; Gao, S.; Liang, Y.L.; Kang, Y.H.; Prestby, T.; Gao, Y.Q.; Xiao, R.M. Estimation of Regional Economic Development Indicator from Transportation Network Analytics. *Sci. Rep.* **2020**, *10*, 15. [CrossRef] [PubMed]

32. Bian, F.; Yeh, A.G.O. Spatial-economic impact of missing national highway links on China's regional economy. *Transp. Res. Part D-Transp. Environ.* **2020**, *84*, 13. [CrossRef]
33. Holl, A. Manufacturing location and impacts of road transport infrastructure: Empirical evidence from Spain. *Reg. Sci. Urban Econ.* **2004**, *34*, 341–363. [CrossRef]
34. Zhang, X.L.; Hu, Y.Q.; Lin, Y.R. The influence of highway on local economy: Evidence from China's Yangtze River Delta region. *J. Transp. Geogr.* **2020**, *82*, 16. [CrossRef]
35. Baum-Snow, N.; Brandt, L.; Henderson, J.V.; Turner, M.A.; Zhang, Q. Roads, Railroads, and Decentralization of Chinese Cities. *Rev. Econ. Stat.* **2017**, *99*, 435–448. [CrossRef]
36. Chen, W.; Liu, W.; Ke, W.; Wang, N. Understanding spatial structures and organizational patterns of city networks in China: A highway passenger flow perspective. *J. Geogr. Sci.* **2018**, *28*, 477–494. [CrossRef]
37. Zhang, A.M.; Wan, Y.L.; Yang, H.J. Impacts of high-speed rail on airlines, airports and regional economies: A survey of recent research. *Transp. Policy* **2019**, *81*, A1–A19. [CrossRef]
38. Elburz, Z.; Nijkamp, P.; Pels, E. Public infrastructure and regional growth: Lessons from meta-analysis. *J. Transp. Geogr.* **2017**, *58*, 1–8. [CrossRef]