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The Impact of Expressway Development on Industrial Structure in Rugged Terrain: The Case of Sichuan Province, China

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Abstract: The expressway is an important pillar of economic development and has a significant impact on the transformation of regional industrial structure. This study analyzes the optimization of the industrial structure and spatial distribution of three industries using relevant statistical data from Sichuan Province, China. It also assesses the influence of expressways on the change in industrial structures using a difference-in-differences model. The results indicate that regions with well-developed expressway networks generated high-added value for the three industry sectors. The introduction of expressways upgraded the industrial structure of mountainous regions with rich tourism resources, increasing the added value of the tertiary industry and constricting the secondary industry. While aiding the overall development of the regional economy, expressways optimized the industrial structure and guided the transformation of the secondary industry, along with the development of the tertiary industry. Similarly, the private-sector economy also developed rapidly owing to the introduction of expressways. This study would serve as a useful reference for studying the relationship between expressways and regional economic development.

Keywords: expressway; mountainous region; industrial structure; difference-in-differences

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Citation: Su, M.; Guo, M.; Luan, W.; Pian, F. The Impact of Expressway Development on Industrial Structure in Rugged Terrain: The Case of Sichuan Province, China. *Land* **2023**, *12*, 1071. https://doi.org/10.3390/land12051071

Academic Editor: Thomas Panagopoulos

Received: 25 April 2023
Revised: 12 May 2023
Accepted: 13 May 2023
Published: 15 May 2023

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1. Introduction

The development of transportation infrastructure is essential for regional economic development [1,2], and the rapid flow of inter-regional produce increasingly requires the support of high-grade transportation modes. In the past, expressways in China were not well-developed owing to the limitations in technology, capital, and development strategies, especially in areas with specific geographical environments, such as hilly or mountainous terrains (e.g., Sichuan, Yunnan, and Guizhou provinces). With the rapid and high-quality development of the overall economy, specific geographical environments have been exposed as deficient in terms of the swift flow of production factors, which cannot be solved by low-grade roads. This problem leads to uneven regional development and a reduced capacity to partake in economic expansion. Compared with expressways, winding low-grade roads present serious challenges to safety, energy consumption, time efficiency, and environmental protection and ineffectively address the adverse effects resulting from a specific geomorphology. In contrast, expressways substantially ease the adverse effects of these geomorphological factors, compress space-time, and facilitate the flow of production factors, creating conditions for sustainable regional economic development. Recently, China has demonstrated remarkable achievements in economic growth and expressway development (as shown in Figure 1) with top rankings for many indicators globally [3], while many expressways remain under accelerated construction timelines [4]. In this context, numerous questions arise. At a time when expressways continue to advance, how can each region better leverage the market effect? What is the best approach to optimize industrial structure and accelerate development momentum? How can a balance be struck between high-speed and high-quality development? These are all questions worthy of deep consideration.

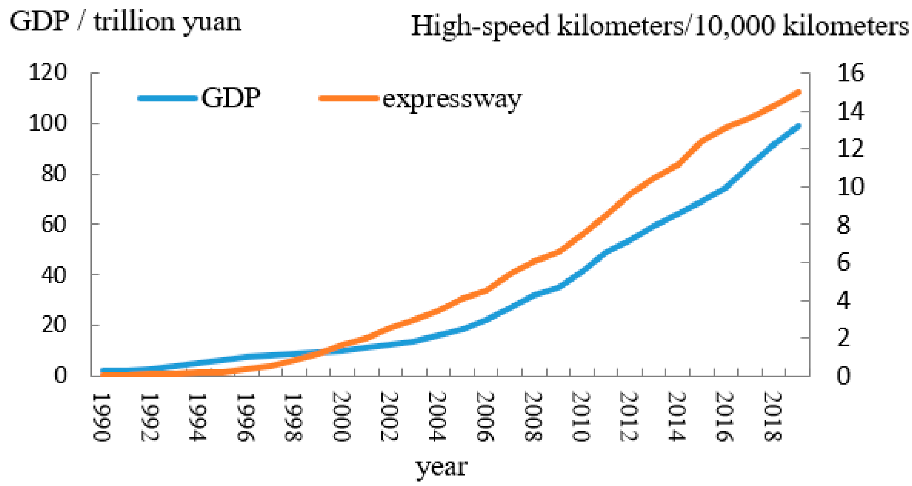


Figure 1. Changes in China's GDP and high-speed kilometers.

Many scholars have studied the impact of transportation development on regional economic growth [5]. Overall, transportation infrastructure is a key catalyst for regional economic growth [6]. Moreover, it makes a significant positive contribution to economic growth [7], and there is a long-term causal relationship between the two [8]. However, Jubiz-Dia et al. proposed that owing to "diminishing marginal propensity to consume" and "constant marginal return on capital", the role of transportation infrastructure in promoting economic growth will only be short-term, not long-term [9]. The interaction between economic growth and infrastructure investments can be described through the use of accessibility indicators [10]. Reachability refers to the difficulty of moving from the starting point to the destination by rail and road transport [11]. Increasing accessibility has a positive impact on the rational use of urban land resources and economic growth as it helps in reshaping the regional spatial structure and facilitating the flow of goods, personnel, and information [12,13]. At present, accessibility indicators are widely used to study the spatial and temporal compression benefits of different transportation systems in different regions, and the spatial convergence effect and economic spillover effect generated by the construction of expressway networks are more obvious [14]. The spatial convergence effect is more evident, especially in special geographic areas, such as those with mountains, hills, and other types of challenging terrains. The impact of an expressway network on regional accessibility was previously analyzed using the Yangtze River Economic Belt as the study area, and the results showed that accessibility of different regions of the Yangtze River Economic Belt significantly improved [15]. Accessibility is significantly better in flat areas than in mountainous areas, and following expressway construction, accessibility within Yunnan and Sichuan Provinces has improved significantly, with a dual-core development pattern emerging [15]. Bian et al. assessed the effects of improving intra-regional road accessibility and found that the spatial effects in terms of reducing road accessibility issues showed strong regional heterogeneity, with cities in southwestern China's rugged terrain being the most vulnerable to reduced road accessibility due to the lack of national expressway routes [16]. In general, for rugged areas without appropriate roads, improving accessibility is critical to increasing regional productivity and expanding potential markets [16].

In addition, the effects of transportation infrastructure, especially expressway construction, vary in different regions and industries [17]. Along with the development of transportation infrastructure, the optimization and upgrading of industrial structures have attracted increasing attention as the proportions of primary, secondary, and tertiary industries within the national economy have been changing [4] and the output value of each industry sector has been increasing [18]. Song et al. found that road infrastructure had the largest positive impact on primary industry, the smallest positive impact on secondary industry, and a medium positive impact on tertiary industry [18]. Within transportation infrastructure, expressways play an important role in influencing the regional industrial structure, and in counties with greater output and higher industrial investment, the construction of expressways has promoted industrial development [17]. Amitabh and Eric found that some industry sectors in the United States either grew because of lower transportation costs or declined owing to the shifts in economic activity [19]. Areas with expressways have been reported to experience significant growth in manufacturing, retail, and services compared to areas without expressways [20]. Existing studies agree that expressways promote regional industry development [17,21] and that an increase in the length of the road network has a strong positive impact on added value, especially in industry sectors that are highly dependent on transportation services [22]. Among such sectors, agriculture is highly dependent on traffic trunk lines, and the introduction of expressways can increase the specialization of agricultural production [23], leading to the development of primary industries. Moreover, secondary industries benefit from improved road transport conditions, especially traditional manufacturing industries, which tend to have a higher weight value [24]. In a study by Ahmed et al. on the impact of roads, railroads, ports, and aviation on industrial output in Pakistan, it was found that roads boosted industrial output in Pakistan and effectively led to the development of secondary industries [25]. In an impact study by Kim et al. of the western coast region of South Korea, it was found that the introduction of expressways attracted new manufacturing industries and contributed to industrial progress [26]. Concomitantly, highway construction can increase the scale dispersion and market concentration ratio of manufacturing enterprises, leading to the development of more companies and outsourcing activities near expressways [27]. Studies on the impact of expressways on the tertiary sector have also drawn positive conclusions. Michaels found significant growth in the retail industry after the establishment of connecting highways by examining the economic changes in approximately 2000 towns in the United States between 1959 and 1975 [28]. Another study in the United States found that expressways had a positive impact on employment in services but a negative impact on manufacturing employment [29]. Concerning China and its different regions, expressways have played a significant role in promoting the tertiary sector in the western region [4]. Overall, roads have had the greatest impact on population distribution and tertiary industry development while having the least impact on manufacturing [17].

While most studies focus on the effects of introducing expressways in terms of regional economic growth, traffic accessibility, and regional industrial structure, the adverse effects of topographic features have been rarely assessed. Therefore, this study analyzes the spatial distribution of output value in relation to primary, secondary, and tertiary sector industries using publicly available data concerning expressway and socio-economic development in Sichuan Province, China, with rugged terrain. Additionally, it assesses the impact of expressway development on changes in the industrial structure using a difference-in-differences (DID) model. This study makes an important contribution to the literature for the following reasons. First, we focused on a specific geomorphological area type where expressways could greatly reduce the adverse effects of geomorphological factors and, thus, play a greater role in economic development. Second, we collected data at the county level and, through extensive screening and collation, obtained data on the introduction of expressways, county industries, per capita gross domestic product (AGDP), population density, number of people employed, total retail sales of consumer goods, total investment in fixed assets, and urbanization rate for 160 counties in Sichuan Province from 2011 to 2019. These data enabled us to examine the impact of expressways on the evolution of industrial structures, including secondary industry, tertiary industry, and industrial structure optimization, in each county unit. We further anticipate that this study will enrich current research through providing additional evidence-based support for the role of expressways in promoting regional industrial development.

The rest of the paper is structured as follows: In Section 2, we review the study area and data processing; Section 3 presents the study methodology; Section 4 presents the results and analysis of the findings; and, finally, Section 5 presents the discussion and conclusions.

2. Study Area and Data Processing

The research area of the study comprised Sichuan Province, China. The landform types of Sichuan Province are complex and include plateau, mountain, plain, etc. From the south to the southeast plain of Sichuan Province, the expressway network connecting the main cities is well developed, and the number of expressways is large. The terrain from north to northwest is rugged, the number of expressways is limited, and expressway construction is difficult to promote, which limits the rapid flow of production and living factors inside and outside the province. Therefore, the importance of expressways is better reflected by studying their impact on the industrial structure in a region of this sort. To this end, we constructed a database containing relevant indicators, including when the expressway was opened, county private secondary industry output value, county private tertiary industry output value, industrial structure optimization, AGDP, population density, number of employed persons, urbanization rate, the proportion of total retail sales of social consumer goods in GDP, and the proportion of total investment in fixed assets of GDP.

The expressway data for each county unit in Sichuan Province were derived from construction process data for each expressway line, which can be extracted from the Baidu Encyclopedia using the expressway number and name. The expressways that were functional in the fourth quarter of a given year were considered to be completed in the following year, as there are vast differences between the years of opening of the expressway in each county unit. Zhang et al. [30] used this method to study the impact of the introduction of high-speed railways on the civil aviation industry.

Relevant socio-economic data were obtained from the Sichuan Statistical Yearbook from 2012 to 2020. We collated data on 160 counties with or without expressways from 2011 to 2019 on parameters, such as county industries, regional per capita GDP, population density, total retail sales of social consumer goods, number of people employed, county population, and total fixed asset investment. A total of 1440 observations were obtained, and some missing data were supplemented and interpolated to eliminate the potential impact of heteroscedasticity. These data include the county's private secondary industry output value, private tertiary industry output value, private industrial structure optimization, regional per capita GDP, population density, number of employed persons, and other data in logarithmic form. Concurrently, considering the multicollinearity of social and economic statistics, the variance inflation factor (VIF) was tested. The test results of all variables showed that the VIF was less than five, which meets the empirical preconditions.

3. Research Methodology

3.1. Industrial Structure Optimization Index

According to modern industrial structure theory, the industrial structure optimization index reflects the degree of regional industrial structure upgrade and industrial service development. It is calculated by using the ratio of the added value of the tertiary industry to the added value of the secondary industry [31], as shown in Equation (1). In this study, the higher the industrial structure optimization index, the stronger the trend of regional industrial structure adjustment, and the more evident the direction of industrial service.

$$\text{IndustryOptimization} = \frac{\text{TertiaryIndustry}}{\text{SecondaryIndustry}} \tag{1}$$

3.2. Difference-in-Differences (DID) Model

The DID method is considered one of the most effective econometric methods for analyzing the effects of policies [32,33]. This method originated from natural science experiments wherein a new policy or institution is considered a "natural experiment" that is exogenous to the economic system, with divisions allocated into "treatment groups" and "control groups". Comparisons are made between the two groups before and after the impact of policies. If the studied intervention event has a certain impact, then changes in the "treatment group" and in the "control group" will show a certain difference after the intervention event takes effect; this difference is used to detect the impact of the particular intervention event between the two groups. The basic idea of the DID method is to construct a DID statistic reflecting the effect of a policy through determining differences in the dependent variable between different groups both before and after the treatment period. The mathematical expression of the idea is shown in Equation (2):

$$Y_{it} = \beta_0 + \beta_1 G_i + \beta_2 T_t + \beta_3 (G_i \times T_t) + \beta X_{it} + \varepsilon_{it}, \quad (2)$$

where Y_{it} is the explanatory variable; G_i is the grouping dummy variable (G_i = 1 if an individual i belongs to the treatment group, and G_i = 0 if an individual i belongs to the control group); T_t is the policy implementation dummy variable (T_t = 0 before policy implementation, and T_t = 1 after policy implementation); the interaction term $G_i \times T_t$ is used to measure the processing effect of the treatment group; and X refers to other explanatory variables.

3.3. Expressway Impact Model

Following the DID method, the county units in which an expressway was in operation were considered as the "treatment group", while the county units in which an expressway had not been introduced were considered as the "control group". The impact models of expressways on secondary and tertiary industries are constructed as follows:

$$\begin{aligned} S_{jt} = \alpha_0 + \alpha_1 Expressway_{jt} + \alpha_2 LNAGDP_{jt} + \alpha_3 PD_{jt} + \alpha_4 LNEmployees_{jt} \\ + \alpha_5 UR_{jt} + \alpha_6 RSCG_{jt} + \alpha_7 FAI_{jt} + \mu_i + \delta Year_t + \varepsilon_{rt} \end{aligned} \quad (3)$$

In Equation (3), S_{jt} is the added value of the secondary industry in t year of region j. In this study, we construct regional secondary industry added value (LNSecondaryIndustry) and private secondary industry added value (LNPrivately_SecondaryIndustry) to measure the change of regional and private secondary industry added value; $Expressway_{jt}$ [equivalent to the interactivity $G_i \times T_t$ in Equation (1)] is a dummy variable for the presence or absence of an expressway service in region j in year t, taking the value of 1 if there is an expressway and 0, otherwise; $AGDP_{jt}$ is the GDP per capita in year t of region j, which reflects the level of economic development of the city within a certain range; PD_{jt} is the population density in year t of region j, an important indicator of the distribution of regional population; $Employees_{jt}$ is the number of employed persons in year t of region j, which reflects the level of labor force and attractiveness of the city to the population; UR_{jt} is the urbanization rate of region j in year t, which is used to reflect the scale degree of urban development; $RSCG_{jt}$ refers to the total retail sales of consumer goods as a share of GDP in year t in region j, an important indicator of retail market movements and economic prosperity in each region; FAI_{jt} is the share of total fixed asset investment in GDP in year t of region j, an important indicator of the sustainability of urban economic growth development and activity of market agents such as enterprises; and μ_i represents individual fixed effects of the region. Year is the year dummy variable that captures the time effects that may exist even without the introduction of expressways; ε_{rt} represents the random disturbance term. Meanwhile, we construct a model of the impact of expressway introduction on the tertiary sector, as follows:

$$\begin{aligned} T_{jt} = \alpha_0 + \alpha_1 Expressway_{jt} + \alpha_2 LNAGDP_{jt} + \alpha_3 PD_{jt} + \alpha_4 LNEmployees_{jt} \\ + \alpha_5 UR_{jt} + \alpha_6 RSCG_{jt} + \alpha_7 FAI_{jt} + \mu_i + \delta Year_t + \varepsilon_{rt} \end{aligned} \quad (4)$$

In Equation (4), T_{jt} is the added value of the tertiary industry in year t of region j. In this study, we construct regional secondary industry value-added (LNTertiaryIndustry) and private tertiary industry value-added (LNPrivately_TertiaryIndustry) to measure regional and private tertiary industry changes. Other explanatory variables are the same as those in Model (3). To analyze the evolution of the optimization of the industrial structure and to further validate the reasonableness of the conclusions, we construct a multi-period DID impact Model (5) to analyze the impact of the expressway on the optimization of the industrial structure:

$$Z_{jt} = \alpha_0 + \alpha_1 Expressway_{jt} + \alpha_2 LNAGDP_{jt} + \alpha_3 PD_{jt} + \alpha_4 LNEmployees_{jt} \\ + \alpha_5 UR_{jt} + \alpha_6 RSCG_{jt} + \alpha_7 FAI_{jt} + \mu_i + \delta Year_t + \varepsilon_{rt} \quad (5)$$

In Equation (5), Z_{jt} is the industrial structure of region j in year t. We construct regional industry structure optimization (LNIndustryOptimization) and private industry structure optimization (LNPrivately_IndustryOptimization) to measure the optimization of regional and private industry structures. Other explanatory variables are the same as those in Model (3). The descriptive statistical results of the variables in the experimental and control groups are shown in Table 1.

Table 1. Summary statistics.

Control	N	Mean	Sd.	Min.	Max.
IndustryOptimization	504	1.514	1.829	0.129	14.185
SecondaryIndustry	504	39.638	19.419	4.386	85.677
TertiaryIndustry	504	34.866	12.245	10.801	75.128
Privately_IndustryOptimization	504	0.96	0.956	0.099	5.48
LNPrivately_SecondaryIndustry	504	10.705	1.635	7.139	13.834
LNPrivately_TertiaryIndustry	504	10.284	1.183	8.026	13.896
AGDP	504	25,138.28	19,076.407	5670	124,312
PopulationDensity	504	128.342	336.921	3.255	2298.802
Employees	504	10.283	8.771	1.49	47.7
SocialConsumptionProportion	504	31.514	11.189	5.489	70.505
FixedAssetsInvestmentProportion	504	1.424	1.323	0.167	23.619
UrbanizationRate	504	29.146	17.083	4.587	99.1
Treaded					
IndustryOptimization	936	0.754	0.752	0.158	16.636
SecondaryIndustry	936	50.7	11.775	5.192	82.406
TertiaryIndustry	936	32.62	10.277	13.012	86.384
Privately_IndustryOptimization	936	0.585	0.428	0.133	7.412
LNPrivately_SecondaryIndustry	936	13.101	0.810	9.074	15.087
LNPrivately_TertiaryIndustry	936	12.406	0.903	8.907	14.897
AGDP	936	36,789.091	18,238.644	9379	121,034
PopulationDensity	936	473.243	388.182	8.812	3431.39
Employees	936	34.672	18.408	0	95.86
SocialConsumptionProportion	936	39.497	12.730	9.891	122.445
FixedAssetsInvestmentProportion	936	0.915	0.385	0.225	3.633
UrbanizationRate	936	41.598	16.043	7.729	99.41

4. Analysis of Results

4.1. Spatial Distribution

To observe the spatial distribution of secondary industry output value, tertiary industry output value, and industrial structure optimization in each county unit more intuitively, we constructed a spatial distribution map using industrial output value data and expressway network data in Sichuan Province in 2019 (shown in Figures 2 and 3).

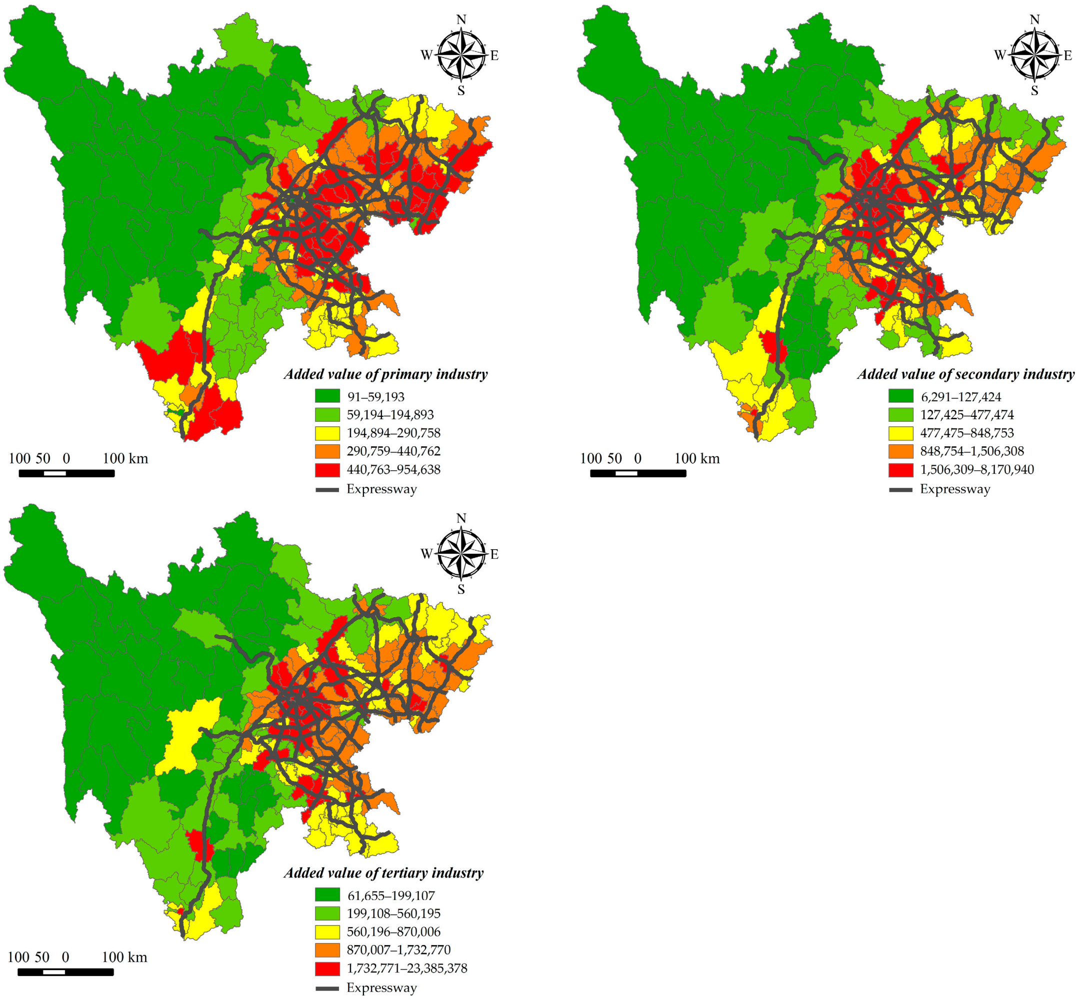


Figure 2. Spatial distribution of three industries in Sichuan Province in 2019.

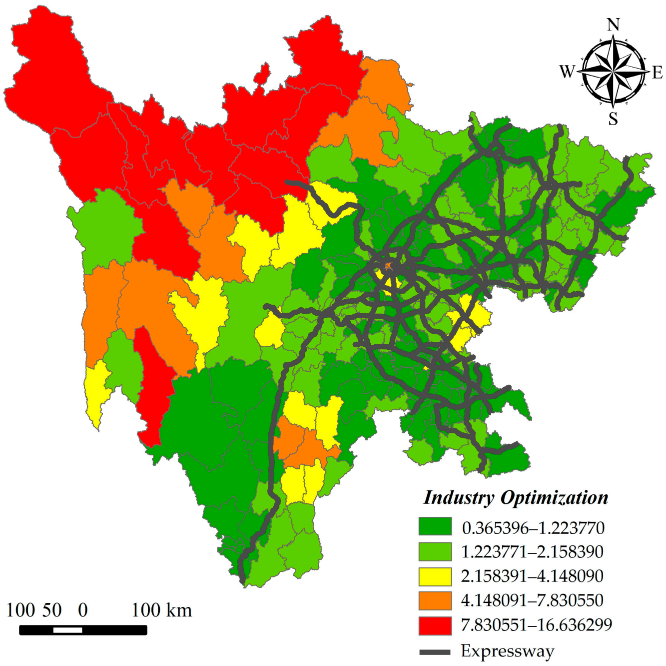


Figure 3. Spatial distribution of industrial structure optimization in 2019.

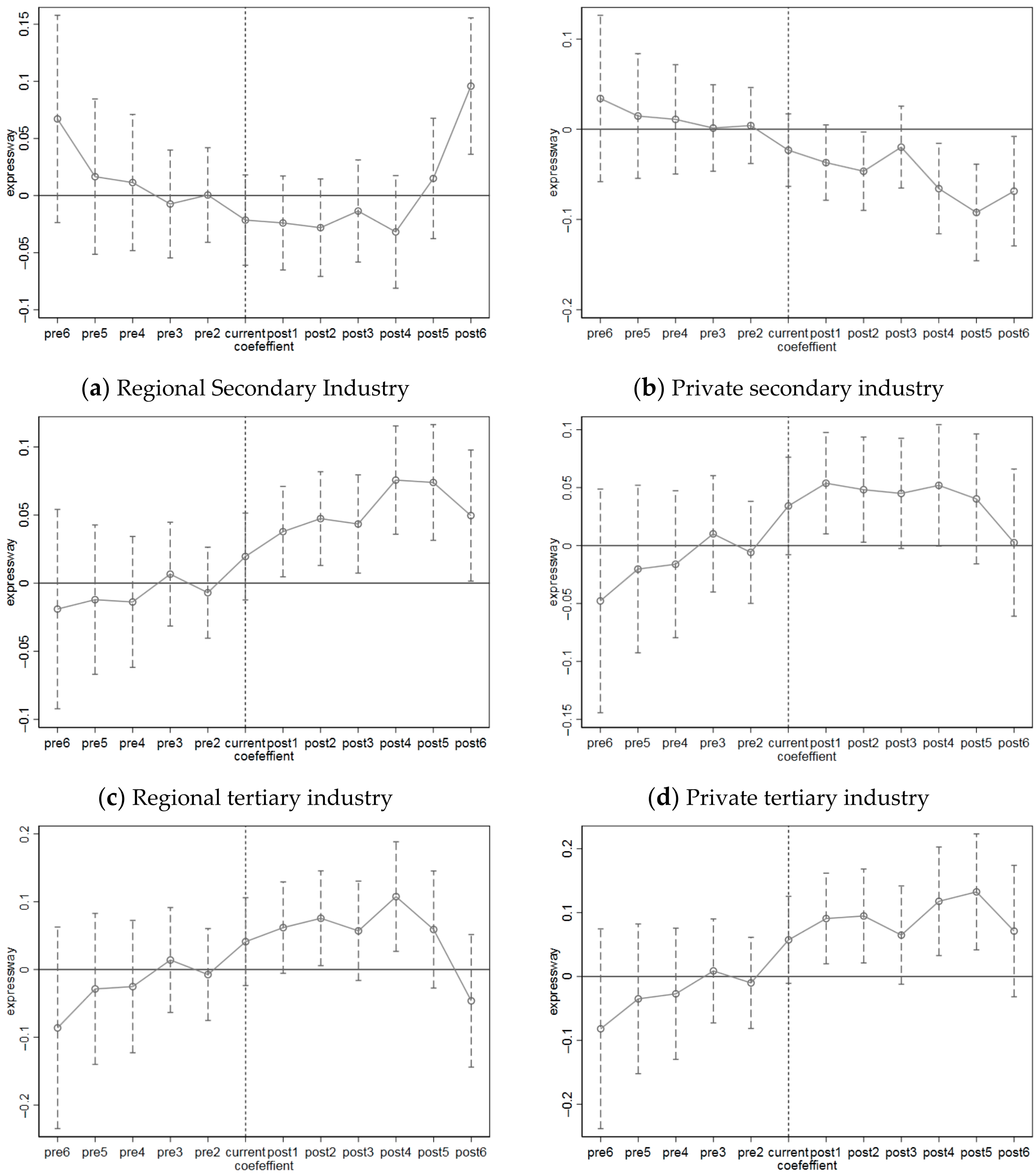
From the distribution of the added value of the three industries, it is evident (as shown in Figure 2) that the added value of the three industries is relatively higher in the county-level administrative units with developed expressway road networks. Additionally, the density distribution of the added value of the three industries shows a radial decreasing distribution rule with the opening line of expressway road networks as the center, and the farther from the expressway connection, the lower the added value of the primary, secondary, and tertiary industries. From the topography perspective, the terrain characteristics of "plain-mountain-plateau" in Sichuan Province from southeast to northwest are also closely related to the spatial distribution of three industrial output values and the density characteristics of expressway areas. Specifically, the dependence of the primary industry on expressways was more evident in agriculture, forestry, animal husbandry, and fishery production. The perishable characteristics of products in primary industries require faster transportation, thus affecting their distribution based on their industrial location, which is limited by traffic conditions. Simultaneously, a high population and stable consumption base in these areas also promoted the development of primary industry. Secondary industry was distributed around the provincial capital cities with high densities of expressway networks and areas accessible by expressways. The input of raw materials and output of finished products, characteristic of this type of industry, necessitates the support of transportation services. In Sichuan, with its mountainous terrain, expressways likely promoted the steady development of this type of industry. Moreover, in Sichuan, which has a highly developed tourism sector, the rapid growth of tertiary industry is also inextricably linked to the development of expressways, as they allow the effective utilization of tourism resources and promote the development of service industries.

From the perspective of the spatial distribution of industrial structure optimization (as shown in Figure 3), most regions without expressways have relatively high industrial structure optimization indices. Although the degree of industrial structure optimization is higher in these regions owing to their poor socio-economic development, the industrial structure development is only beginning there, and the added value of secondary industry is especially low. As a result, the tertiary industry accounts for a higher proportion in these regions. On the contrary, the degree of industrial structure optimization in areas with a high density of expressway networks is relatively low, as these areas have a relatively better degree of economic and social development, a higher level of industrialization, and have entered or are about to enter a stage of industrialization-led transformation. Therefore, the value-added of the secondary industry is higher than the output value of the tertiary industry. The above-mentioned industrial distribution shows that the secondary industry has higher requirements for the transportation service industry. Although the development of tertiary industries is also dependent on expressways, the layout of secondary industries is particularly influenced by the ready availability of transportation.

4.2. Analysis of the Regression Results of the Expressway Impact Model

4.2.1. Parallel Trend Test

The assumption that the treatment and control groups should show the same trend before policy variables are introduced is a key prerequisite in ensuring the validity of DID estimation. To test that time-staggered expressway opening is an effective exogenous shock to regional industrial structure and to verify the appropriateness of the DID model, a parallel trend test was conducted in this study. Using the data from 2011 to 2019 of each county as the sample, the dummy variables of each time point and the interaction terms of the dummy variables of the expressway opening treatment and control groups were added to the regression. The regression trend plots of the value-added of secondary industry, value-added of tertiary industry, and industrial structure optimization in the model were conducted respectively, with results shown in Figure 4.



(**a**) Regional Secondary Industry (**b**) Private secondary industry

(**c**) Regional tertiary industry (**d**) Private tertiary industry

(**e**) Regional industrial structure optimization (**f**) Private industrial structure optimization

Figure 4. Regional and private secondary industry, tertiary industry, and industrial structure optimization parallel trend test.

The results of the parallel trend test showed that before the introduction of expressways, the coefficients for the interaction terms were not significant. Additionally, the value-added of secondary and tertiary industries and industrial structure optimization in the treatment and experimental groups of regional and private sectors roughly maintained the same growth trend. However, after the introduction of expressways, the growth trends of the value-added of secondary industry and tertiary industries, as well as industrial structure optimization in the treatment and control groups of regional and private sectors changed significantly. Therefore, this study meets the prerequisites of the parallel trend hypothesis and can use the DID model to analyze the impact of expressways on the secondary industries, d tertiary industries, and industrial structure optimization.

4.2.2. Analysis of Regression Results

To avoid heteroskedasticity among individuals in the panel data, we ran a "fixed effects model + robust standard error" regression on the constructed expressway impact model to statistically assess the impact of expressways on the evolution of industrial structure from a developmental and statistical perspective.

Table 2 presents the regression results of Model (3) and shows the impact of the introduction of expressways on the secondary industry's added value in both the regional and private economy. The results show that the introduction of expressways significantly reduced the value-added of the secondary sector. Without the inclusion of control variables, the introduction of expressways resulted in a 0.05% decrease in the secondary industry's value-added in the private economy and is significant at the 10% level. However, the effect in the region is not significant, which indicates that the secondary industry adds more value to the private economy, which is more affected by the expressway. With the inclusion of control variables, regional GDP per capita, population density, and the proportion of total fixed asset investment to GDP have significant positive effects on the value-added of the secondary industry in the region and private economy. This indicates that with the socio-economic growth of the region, the higher the proportion of population density and total fixed asset investment, the faster the growth rate of the secondary industry. The urbanization rate has a certain negative effect on the value-added of the secondary industry, and the proportion of total retail sales of social consumer goods to GDP has a non-significant effect on the value-added of the secondary industry. Both the region as a whole and the private economy show similar impact results, indicating that with the expansion of urban construction land, urban commercial activities increase and squeeze the development of the secondary industry. Overall, with this data, it can be concluded that the introduction of expressways reduces the value-added of the secondary industry in the region.

Table 3 presents the regression results of Model (4) and shows the impact of the introduction of expressways on the added value of the tertiary industry in the regional and private economy. Without the inclusion of control variables, the introduction of expressways increased the value-added of the tertiary industry in the region by approximately 0.04%, and the value-added of the tertiary industry in the private economy increased by 0.05%, both changes being significant at the 5% level. This finding indicates that the introduction of expressways promoted the development of the tertiary industry. With the inclusion of control variables, the effects of regional GDP per capita and population density on the value-added of both regional and private economy tertiary industry are significantly positive. This result indicates that the higher the level of urban economic development and the greater the concentration of the population, the faster the growth rate of tertiary industry. The proportion of total retail sales of social consumer goods to GDP has a certain positive effect on the value-added of regional tertiary industries, and the proportion of total retail sales of social consumer goods to GDP does not have a significant effect on the value-added of tertiary industries in the private economy, which indicates that the proportion of total retail sales of social consumer goods contributes more to the development of regional tertiary industries. Overall, the introduction of expressways influenced the regional industrial structure and promoted the rapid development of the tertiary industry.

Table 4 presents the regression results of Model (5) and shows the impact of expressways on the optimization of the industrial structure in the regional and private economies. The results show that although there is a slight difference in the magnitude of the impact coefficient of industrial structure optimization in the regional and private economies, the opening of expressways promotes industrial structure optimization in the regional and private economies, and that there is a positive and significant impact effect. Without the inclusion of control variables, the opening of expressways increased regional industrial structure optimization by approximately 0.08% and was significant at the 5% level; similarly, industrial structure optimization in the private economy was up by 0.1% and was significant at the 1% level. The opening of expressways promotes the upgradation of regional industrial structure optimization and has a greater impact on industrial structure optimization in the private economy, indicating that the development of industrial structure optimization in the private economy is more dependent on expressway traffic. With the inclusion of control variables, there is a significant negative effect of GDP per capita and population density on industrial structure optimization, both from the regional and private economy perspectives. This finding is consistent with the regression results shown in Tables 2 and 3, which indicate that the growth of regional GDP per capita and population density is dominated by secondary industry. In addition, the coefficient of the influence of the secondary industry is greater than that of the tertiary industry, leading to a decrease in the index of industrial structure optimization. This factor is also evident in the private economy, and the change is more obvious. The number of employed persons and the proportion of total retail sales of social consumer goods to GDP have a positive effect while the urbanization rate does not have a significant effect on industrial structure optimization. These data indicate that the regional employment population and the proportion of total retail sales of social consumer goods to GDP are numerically greater in regions with higher industrial structure optimization. The impact of the total fixed asset investment as a proportion of GDP is not significant on regional industrial structure optimization while industrial structure optimization in the private economy shows some significant negative effects. These effects indicate that compared to the region as a whole, the proportion of total investment in fixed assets reduces the optimization of the industrial structure in the private economy. Thus, the introduction of expressways drives the optimization of industrial structure and promotes the growth of regional and private economies.

Table 2. Regression results of secondary industry data.

Variables	LNSecondaryIndustry	LNPrivately_ SecondaryIndustry	LNSecondaryIndustry	LNPrivately_ SecondaryIndustry
	Coef.	Coef.	Coef.	Coef.
expressway	−0.042 (−1.56)	−0.053 * (−1.71)	−0.028 * (−1.75)	−0.032 * (−1.68)
LNAGDP			1.417 *** (15.44)	1.555 *** (13.27)
LNPopulationDensity			1.123 *** (6.57)	1.239 *** (7.04)
LNEmployees			−0.177 *** (−3.50)	−0.275 *** (−3.83)
SocialConsumptionProportion			−0.001 (−0.68)	−0.002 (−1.42)
FixedAssetsInvestmentProportion			0.017 * (1.75)	0.015 * (1.86)
UrbanizationRate			−0.002 * (−1.69)	−0.003 ** (−2.43)
2012.Year	0.174 *** (19.98)	0.184 *** (23.00)	−0.012 (−0.85)	−0.019 (−1.14)
2013.Year	0.284 *** (18.05)	0.329 *** (20.09)	−0.014 (−0.47)	0.016 (0.47)
2014.Year	0.368 *** (16.48)	0.429 *** (18.14)	−0.037 (−1.00)	0.002 (0.05)
2015.Year	0.396 *** (15.64)	0.468 *** (17.78)	−0.088 ** (−2.05)	−0.043 (−0.84)

Table 2. *Cont.*

Variables	LNSecondaryIndustry	LNPrivately_ SecondaryIndustry	LNSecondaryIndustry	LNPrivately_ SecondaryIndustry
	Coef.	**Coef.**	**Coef.**	**Coef.**
2016.Year	0.447 *** (14.57)	0.535 *** (15.74)	−0.138 *** (−2.75)	−0.085 (−1.38)
2017.Year	0.471 *** (13.44)	0.532 *** (13.84)	−0.241 *** (−3.98)	−0.225 *** (−2.99)
multirow2* 2018.Year	0.543 *** (14.23)	0.618 *** (14.52)	−0.272 *** (−4.00)	−0.253 *** (−3.01)
2019.Year	0.385 *** (9.43)	0.559 *** (12.46)	−0.640 *** (−8.87)	−0.543 *** (−5.43)
_cons	12.408 *** (838.21)	11.879 *** (770.31)	−6.627 *** (−4.46)	−8.768 *** (−4.98)
N	1440	1440	1439	1439
R2	0.425	0.491	0.676	0.738

t statistics in parentheses. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

Table 3. Regression results for tertiary industry data.

Variables	LNTertiaryIndustry	LNPrivately_ TertiaryIndustry	LNTertiaryIndustry	LNPrivately_ TertiaryIndustry
	Coef.	**Coef.**	**Coef.**	**Coef.**
expressway	0.038 ** (2.39)	0.046 ** (2.23)	0.036 ** (2.19)	0.047 ** (2.17)
LNAGDP			0.602 *** (10.10)	0.592 *** (7.66)
LNPopulationDensity			0.584 *** (5.07)	0.560 *** (4.21)
LNEmployees			0.031 (0.62)	0.092 (1.21)
SocialConsumptionProportion			0.003 *** (2.68)	0.002 (1.35)
FixedAssetsInvestmentProportion			−0.001 (−0.21)	−0.006 (−1.05)
UrbanizationRate			0.001 (0.70)	0.000 (0.28)
2012.Year	0.118 *** (46.59)	0.127 *** (34.06)	0.034 *** (3.99)	0.043 *** (3.82)
2013.Year	0.229 *** (45.19)	0.235 *** (33.77)	0.074 *** (3.56)	0.087 *** (3.66)
2014.Year	0.341 *** (42.25)	0.347 *** (28.05)	0.128 *** (4.90)	0.144 *** (4.65)
2015.Year	0.451 *** (45.37)	0.453 *** (31.78)	0.195 *** (6.43)	0.210 *** (5.86)
2016.Year	0.588 *** (41.70)	0.578 *** (28.64)	0.282 *** (7.64)	0.286 *** (6.65)
2017.Year	0.814 *** (41.49)	0.799 *** (32.08)	0.449 *** (10.12)	0.451 *** (8.52)

Table 3. *Cont.*

Variables	LNTertiaryIndustry	LNPrivately_ TertiaryIndustry	LNTertiaryIndustry	LNPrivately_ TertiaryIndustry
	Coef.	Coef.	Coef.	Coef.
2018.Year	0.917 *** (44.42)	0.902 *** (34.51)	0.508 *** (10.40)	0.511 *** (8.87)
2019.Year	1.282 *** (66.24)	1.389 *** (52.47)	0.785 *** (14.03)	0.913 *** (13.74)
_cons	11.879 *** (1865.17)	11.107 *** (1344.47)	2.834 *** (2.86)	2.142 * (1.79)
N R2	1440 0.925	1440 0.894	1439 0.937	1439 0.905

t statistics in parentheses. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Table 4. Regression results of industrial structure optimization data.

Variables	LNIndustryOptimization	LNPrivately_ IndustryOptimization	LNIndustryOptimization	LNPrivately_ IndustryOptimization
	Coef.	Coef.	Coef.	Coef.
expressway	0.080 ** (2.49)	0.100 *** (2.65)	0.064 ** (2.25)	0.079 ** (2.35)
LNAGDP			−0.815 *** (−6.28)	−0.962 *** (−6.17)
LNPopulationDensity			−0.539 ** (−2.43)	−0.679 *** (−2.89)
LNEmployees			0.208 *** (2.70)	0.366 *** (3.43)
SocialConsumptionProportion			0.003 * (1.83)	0.003 * (1.70)
FixedAssetsInvestmentProportion			−0.018 (−1.62)	−0.020 * (−1.69)
UrbanizationRate			0.003 (1.35)	0.003 (1.57)
2012.Year	−0.056 *** (−6.40)	−0.058 *** (−6.94)	0.046 ** (2.37)	0.062 *** (2.75)
2013.Year	−0.055 *** (−3.52)	−0.093 *** (−5.35)	0.087 ** (2.08)	0.072 (1.54)
2014.Year	−0.027 (−1.15)	−0.082 *** (−3.04)	0.165 *** (3.14)	0.142 ** (2.36)
2015.Year	0.055 ** (2.10)	−0.015 (−0.53)	0.283 *** (4.66)	0.253 *** (3.62)
2016.Year	0.140 *** (4.22)	0.043 (1.17)	0.419 *** (5.83)	0.372 *** (4.47)
2017.Year	0.344 *** (7.98)	0.267 *** (5.39)	0.690 *** (7.89)	0.676 *** (6.52)
2018.Year	0.373 *** (7.97)	0.283 *** (5.26)	0.780 *** (7.98)	0.764 *** (6.62)
2019.Year	0.897 *** (21.28)	0.830 *** (17.38)	1.425 *** (13.51)	1.456 *** (10.86)
_cons	−0.529 *** (−32.76)	−0.773 *** (−44.64)	9.461 *** (4.68)	10.910 *** (4.59)
N R2	1440 0.653	1440 0.603	1439 0.690	1439 0.659

t statistics in parentheses. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

5. Discussion and Conclusions

Based on relevant socio-economic data concerning expressways in 160 counties in Sichuan Province between 2011 and 2019, this study determined the effects of introducing expressways on the industrial structure in mountainous areas using the DID approach.

Areas with high added value industry sectors were found to substantially overlap with the expressway network. Expressways facilitated the flow of resource elements between regions with the goal of promoting regional production and trade activities. This flow of resources was especially important for surrounding areas of economically developed regions and provincial capitals with dense expressway lines, where the added value of the three industry types was relatively high and showed a spatial distribution with the expressway network routes as the center of a decreasing radial pattern from near to far. For Sichuan Province, the added value of the three industries from southeast to northwest China and the "dense-sparse" density distribution pattern of the expressway network are consistent with the topographic characteristics of "plain-mountain-plateau". Therefore, it is imperative to give full play to the advantages of constructing expressway traffic trunk lines that can "build bridges through mountains" and the leading role of expressways in the upgrading of industrial structure in the regional economy, thus accelerating regional economic radiation from point to surface and crisscross.

The introduction of expressways resulted in the secondary industry experiencing a reduction in value-added, and those in the private economy were more affected by expressway traffic. The negative result regarding the number of people employed within the industry, as well as the flow to the tertiary industry of labor, indirectly indicates that the county areas connected by expressways are in the transformation stage of industrialization. The improvement of regional economic development level, inter-regional population aggregation and flow, and the strengthening of regional infrastructure construction depend on the improvement of transportation conditions which has driven the development of the secondary industry to a certain extent. The promotion of the private economy has an inherent objective necessity for optimizing the allocation of market resources. On one hand, the government should lead the private economy in industrial transformation and upgradation in several ways: by creating and enforcing positive industrial development and guiding transition policies based on the industrial and economic conditions and the secondary industry's decline in added value; increase investment in science and technology innovation based on local conditions; and further, improve the quality of industrial development based on the advantages of the regional secondary industry resources. These measures will guide the evolution of the secondary industry to an advanced stage. On the other hand, it is imperative to continue to build high-quality transportation infrastructure, give play to the leading role of highway infrastructure in the economic development of Sichuan Province in China, and enhance the momentum of secondary industry development.

The introduction of expressways has accelerated the development of the tertiary industry, which has increased its added value. The evolution pattern of industrialization is the development of the primary industry to secondary industry and tertiary industry. For a long time, resource allocation has focused on industrialization development in areas with low urbanization levels and low output value of the tertiary industry. However, the mountainous terrain and special topography of Sichuan Province make it a resourceful tourism destination, especially the "northwest" rugged zone, which possesses great industrial development potential. The introduction of expressways has resulted in the rapid development of regional tourism and other service industries. In this regard, the government should focus on solving the issues surrounding insufficient regional connectivity, developing expressways and other traffic arteries, increasing the density of road network traffic arteries, accelerating infrastructure construction and capital investment, and supporting the development of leading tertiary industries. These actions could create new opportunities for regional economic development and industrial structure upgrades.

The introduction of expressways has accelerated the optimization and upgradation of the Sichuan Province's industrial sector; that is, expressways have led to the transformation of the secondary industry and the development of the tertiary industry. The industrial structure of China's private economy presents a "three, two, and one" pattern in which the development of the tertiary industry has exceeded that of the secondary industry. From the perspective of impact effect, the opening of expressways has enhanced the optimization of the industrial structure in the private economy to a higher degree relative to the changes in the optimization of the regional industrial structure. From the perspective of the focus on influence, although the main driving force of regional economic growth in Sichuan Province has shifted from the secondary industry to the tertiary industry, the secondary industry still dominates the industrial structure. On the whole, the development of the tertiary industry has compressed the proportion of the added value of the secondary industry. With the development of the social economy, the simple industrial structure has been replaced by a more complex one; therefore, in the context of the current "new normal" in China's economic development, county areas should optimize their industrial structure by taking full advantage of the different industrial development characteristics of secondary and tertiary industries. They should also attempt reasonable development of these industries to realize the transformation and upgradation of the overall industrial structure.

This study focused on changes in industry sector structures following the introduction of expressways in a mountainous region in China. Based on expressway opening data and socio-economic data for counties in Sichuan Province from 2011 to 2019, this study used a DID model and an expressway impact model to perform the analysis of the value-added of secondary and tertiary industries and optimization of the industrial structure of regional and private economy before and after the opening of expressways. The COVID-19 pandemic and its aftermath had an impact on industries such as the tourism industry and the civil aviation passenger transport industry [34]. The impact of COVID-19 on industry sectors in counties (either with or without expressways) remains unknown because the data from 2020 onwards are not available. However, the dataset contains socio-economic statistics for the last decade. Therefore, our study has strong universality and credibility. The analysis of expressways affecting industrial structure optimization in special geographic areas can provide reference values for developing industrial policies and optimizing resource allocation efficiency in less developed areas and even in developing countries, thus, providing sustainable economic development.

Author Contributions: Conceptualization, M.S., W.L. and F.P.; methodology, M.S. and F.P.; software, not applicable; validation, M.S. and M.G.; formal analysis, M.S. and M.G.; investigation, M.S. and M.G.; resources, M.S.; data curation, M.S. and M.G.; writing—original draft, M.G.; writing—review & editing, W.L. and F.P.; visualization, M.S.; supervision, M.S.; project administration, M.S.; funding acquisition, M.S. All authors have read and agreed to the published version of the manuscript.

Funding: This research has received funding from the Key Project of the National Natural Science Foundation (Grant No. 42030409).

Data Availability Statement: Not applicable.

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

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