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Impact of Innovation Capacity on Regional Economic Resilience: Based on Entropy-Tobit Model

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Abstract

In recent years, uncertain events such as financial crisis, trade frictions, and an outbreak of COVID-19 have occurred frequently, which have made economic development face severe tests, so the issue of regional economic resilience has attracted much attention. As the link between industrial structure and economic growth, innovation capacity has an essential impact on economic resilience. Based on measuring the economic resilience of 31 provinces (municipalities and autonomous regions) in China from 2008 to 2019, this study uses the Entropy-Tobit model to analyze the specific role of innovation capacity impact on economic resilience. The findings confirm that the overall level of China's economic resilience has increased annually, with significant regional differences: the Eastern is higher than the Western, and the high-value regions have been shifting from north to south. Innovation capacity is positively correlated with economic resilience, and the magnitude of its effect is influenced by industrial structure with a regional, which means that regions with a higher degree of industrial specialization have a relatively weaker ability of innovation capacity to enhance economic resilience. Thus, to strengthen the ability of Chinese regions to cope with risks, regions need to focus on fostering innovation capabilities, optimizing industrial structures, and building supporting economic systems.

Keywords

Innovation Capacity, Economic Resilience, Industrial Diversification, Industrial Specialization, Entropy-Tobit Model

1. Introduction

1.1. Background

In the past 40 years, even though China's economy has been influenced by a series of endogenous factors and exogenous shocks such as economic system reform and financial crisis, it has always maintained steady growth and shown strong resilience. Xi Jinping, the Chinese President, had repeatedly mentioned in public that "China's economy was resilient, with vast space for domestic demand and a strong industrial base". Even with the domestic and international shocks, the long-term positive fundamentals and the inherent upward trend of the Chinese economy remain unchanged. The key to an economy's success in withstanding the risks of uncertainty is its strong economic resilience, which determined whether an economy "recovers successfully and achieves steady economic growth" after a shock or "goes downhill from there". Innovation, as a medium linking industrial structure and economic growth, radiates to the economic system through inter-industry linkages. It is therefore an important driving force for the stable development and rapid transformation of regional economies. In November 2020, when attending the APEC Business Leaders Dialogue, President Xi Jinping said "China insists on putting innovation as the first driving force to lead development". Therefore, in an environment full of uneven development and uncertain risks, there is an urgent need to conduct a systematic study of China's economic resilience. In other words, this paper, which scientifically explores the impact of innovation capacity on economic resilience, is of great relevance to achieving economic transformation and promoting stable and sustainable high-quality economic development.

1.2. Literature Review

1.2.1. Literature Review of Economic Resilience

Resilience is originally an engineering concept, measuring the ability of a system to maintain its stability and return to its original state after an impact. Holling first introduced it to the study of ecosystems, and gradually applied it to psychology, economics, and other fields. Reggiani introduced the concept of resilience to the field of economics (Reggiani et al., 2002). Then Martin and Sunley proposed the concept of regional economic resilience when they studied the ability of economic systems to resist shocks based on a regional industry perspective (Martin & Sunley, 2007). Evolutionary economists defined this ability, to withstand exogenous shocks and thereby promote economic transformation, as regional economic resilience. The definition of regional economic resilience has not been unified by academia yet owing to the great differences in research perspectives. Based on the divergence of economic system development equilibrium, economic resilience evolves into "engineering resilience", "ecological resilience" and "evolutionary resilience". In the equilibrium perspective, engineering resilience and ecological resilience had the assumptions of system single equilibrium or system multiple equilibria, respectively. In contrast, evolutionary resilience stepped out of the system equilibrium flaw. This perspective assumed that there was a self-adaptive capacity in a system and its development was a non-equilibrium evolutionary process. The regional economy was influenced by multiple factors, leading to complex and variable development, which also presented a non-linear process. Hence, the view of non-equilibrium, complex adaptation, and dynamic evolution was more in line with the changing characteristics of economic systems. The more commonly adopted definition of evolutionary resilience by scholars was defined in terms of four dimensions: resistance, recovery, re-orientation, and renewal (Martin, 2012).

Initially, Chinese scholars translated the term "resilience" as "elasticity" (Hu, 2012; Peng et al., 2015), but it was easily confused with the existing concept of resilience (reflecting the degree of change) in the Chinese concept. However, as research in this area grew so did the recognition of "resilience" (the ability of a system to maintain its stability after a shock and to recover itself to its pre-shock state) (Sun & Sun, 2017; Su, 2015). Currently, Chinese scholars mostly used this concept to investigate social resilience, ecological resilience, and economic resilience. Combining with China's situation, this paper argues that regional economic resilience refers to the resistance against shocks and the recovery from shocks or the transformation to a better development path when the system is disturbed by shocks including economic structure, market structure, policy environment, financial environment, and natural environment. Resistance means the ability of several economic elements in the regional economic system to divide and cooperate in such a way as to ensure the smooth operation of the regional economy in a volatile environment. The defense function of a regional economy is resistance, which depends on the historical development path (including the industrial structure, resource endowment, and institutional arrangement formed in the long-term evolution). Resilience refers to the ability of an economy to return to its pre-disruption development path or a better development path after being damaged by disruptive factors, of which the creative function is a major component.

The measurement of economic resilience is an important element in the field of economic resilience research. The available kinds of literature provide two methods of measurement. One is a unidimensional indicator measure, such as using the regional sensitivity index as an evaluation indicator of regional economic resilience (Xu & Wang, 2017; Guo & Xu, 2019). The methodology takes the rate of change in regional GDP or employment during periods of economic volatility as the core variable measured to calculate a sensitivity index, in which a higher sensitivity means a lower regional economic resilience. Some scholars also choose the core variables affected by shocks as weights directly to avoid the errors caused by the selection of indicators. Both Davies (2011) and Brakman et al. (2015) directly selected unemployment numbers and GDP indicators to measure the economic resilience of European countries. Bing Zeng (2018) also referred to this approach, using the GDP growth rate to evaluate the provincial economic resilience in China. However, since there were no major ups and downs in production or employment in the process of China's economic development, it is somewhat unreasonable to use gross product or employment share as weights to assess regional economic resilience. Another measure is multidimensional indicators. This approach takes mostly reference from Briguglio's system of indicators (Briguglio et al., 2006). Martin et al. (2016) developed a framework for analyzing economic resilience that included industrial structure, labor, financial, and institutional factors. Chinese scholars also selected specific indicators to assess regional economic resilience on this basis (Tan et al., 2020). Although the multidimensional indicators system has not yet been uniformly recognized, and the conclusions can vary greatly depending on the selection of indicators, this method is more scientific and applicable in comparison. Therefore, this paper selects classical influencing factors from previous empirical studies as the evaluation indicators of economic resilience and then selects a more objective method to calculate it.

1.2.2. Literature Review of the Relationship between Innovation and Economic Resilience

As noted above, economic resilience is dependent on the historical development path of the region. Different regions exhibit different capabilities when dealing with external shocks. Regions with stronger resilience can quickly adjust to the dilemma, innovate new development paths and realize the upgrade of industrial structure. The structure and layout of industries vary greatly between different provinces in China, so the economy of different regions is affected by different factors, for example, the economy of the Sichuan region was affected by a major natural disaster, and the old industrial zone in Northeast China was influenced by industrial decline and resource depletion, etc. Resource-based regions have a single industrial structure, and their economic development mainly relies on resources such as coal coking and petrochemicals. Such areas have a high degree of specialization in industrial structure, but insufficient diversification. Once faced with external shocks, the old growth model can hardly withstand them. The reason for this is the limitation of technological innovation. It has been revealed that factors such as industrial structure, knowledge base, and labor skills are related to economic resilience (Martin et al., 2015). Even more, some studies directly pointed out that regions with high innovation capacity were more resistant to external risks (Bristow & Healy, 2017). In the studies of China's situation, scholars considered that the main factors influencing economic resilience were industrial structure, institutional environment, social capital, and cultural factors (Sun & Sun, 2017). Recently, some Chinese scholars have argued that there is a non-linear relationship between industrial structure and economic resilience, in which innovation may play an important role. Such practices fall into two categories, one using innovation as a threshold (Guo & Xu, 2019) and the other as a mediator (Xu & Deng, 2020).

The role of innovation in economic resilience is twofold: on the one hand, it has a radiating effect on economic efficiency and technological linkages through specialized or diversified industrial structures, and on the other hand, it depends on innovation in renewing and reconfiguring long-term development paths.

Specifically, innovation has a continuous endowment effect, which means that it has a lasting impact on the industrial structure. The essence of whether the industrial structure should develop towards specialization or diversification is considering both economic efficiency and innovation capacity. Regional systems enhance economic efficiency through innovation, thus equipping themselves for economic growth when exposed to external shocks. The economy should not only recover its original development model by adapting its internal industrial and technological structure but also create new paths of development through innovation.

In summary, the analysis shows that innovation does have an important impact on economic resilience, but the extent and direction of the impact have been unknown. Much has also been written exploring the relationship between economic resilience and innovation, but the shortcoming of the existing approach was the use of a single indicator to measure economic resilience. In addition, existing studies in China are mostly literature reviews and measures of economic resilience, which need to be supplemented by a large number of empirical tests about the actual situation. Therefore, this paper takes 31 provinces (municipalities and autonomous regions) in China as the research object and used the comprehensive evaluation index system method, entropy value method, Tobit Regression Model, and Fixed-effect Regression Model to conduct research. The article focuses on measuring the current state of China's regional economic resilience and analyzing how the innovation capacity of each region affects economic resilience. Finally, we make appropriate recommendations in response to the conclusions drawn to improve the overall level of economic resilience.

2. Methodology

2.1. Economic Resilience Evaluation Indicator

In this paper, we define economic resilience as resistance and recovery. Based on the description of the two capabilities above, the resistance is evaluated with indicators selected from three dimensions-economic growth, industrial structure, and labor force. The evaluation of regional recovery capacity contains both self-organizing capacity and innovative transformation capacity. The former is reflected by investment and consumption, while the latter is expressed by the degree of infrastructure, research, and education, which together constitute the recovery power of the region after impacts. Following the three principles of scientificity, comparability, and accessibility and combining the practices and results of existing studies, we select a total of 13 evaluation indicators from seven benchmark levels to establish a comprehensive evaluation index system, as shown in Table 1.

Firstly, economic resilience is shown as resistance.

The level of economic growth best reflects the regional economic development trend over time. GDP is the optimal indicator of macroeconomic conditions.

Table 1. Regional economic resilience evaluation index system.

Target Layer	Guideline Layer	Base layer	Indicator layer	Sign	Weight
Regional Economic Resilience	Resistance	Economic Growth	GDP per capita	+	0.1371
			Foreign trade dependency (%)	−	0.0334
		Industry Structure	Urbanization rate (%)	+	0.0476
			Tertiary sector share (%)	+	0.1251
			Secondary industry share (%)	−	0.1280
		Workforce	Urban unemployment rate (%)	−	0.0883
	Recovery	Investment	Fixed asset investment per capita	+	0.0955
			FDI share of GDP (%)	−	0.0242
		Consumption	Total retail sales of social consumer goods as a percentage (%)	+	0.0575
		Infrastructure	Share of telecom business (%)	+	0.0748
		Research Education	R&D investment intensity (%)	+	0.0770
			Rate of college students per 100,000 people (%)	+	0.0870
			Average years of education (years)	+	0.0244

Experience shows that regions with more stable GDP growth are more resilient to shocks, so GDP per capita is used as a specific indicator in this paper, which is a positive indicator. Foreign trade dependence reflects the degree of economic dependence on international trade, which is often measured by the proportion of total import and export trade to GDP. The higher the foreign trade dependence, the more dependent the economic development is on export trade. It has been studied that there is a significant negative correlation between foreign trade and economic resilience (Xu & Wang, 2017). The volatility and uncertainty of the international environment are highly likely to affect the stability of the regional economy, so the indicator is negative.

The industrial structure is the basis of the development of an economy, whose rationality contributes to the stability of the economy. The level of urbanization reflects the level of industrial agglomeration in a region as a positive indicator. The internal ratio of the three industries reflects the level of regional industrial structure. The proportion of tertiary industry to GDP can reflect the degree of optimization of industrial structure, while a large proportion of secondary industry tends to lead to a monolithic industrial structure, which can make regional development fall into a locked and path-dependent situation, so the two are in opposite directions.

The increase in the number of unemployed is not conducive to economic stability. The unemployment rate, reflecting the state of the labor force and most indicative of the stability of the regional economy, is a negative indicator.

Secondly, economic resilience is shown as recovery.

An economic system needs internal absorption and adjustment after impacts. Investment and consumption are best able to achieve internal restructuring and production arrangement of the economy. Considering domestic and foreign investment changes, the regional investment status is measured by the amount of fixed asset investment per capita and the share of FDI in GDP. The former is a positive indicator, and the latter is a negative indicator because of its high susceptibility to external economic influences. Experience shows that the higher the level of consumption in a region, the better its ability to absorb shocks on its own. Consumption capacity is measured by total retail sales of consumer goods as a share of GDP, which is a positive indicator.

Having a better infrastructure is a favorable prerequisite for innovative activity. Extensive coverage of telecommunication infrastructure greatly facilitates innovation exchange and sharing. Therefore, the level of infrastructure is measured by the share of telecommunication business revenue in GDP, which is positive.

As potential driving forces of regional economic development, the level of technology and education determines the level of regional innovation development, and both are positive indicators.

2.2. Economic Resilience Evaluation Methodology

Previous studies adopt the subjective assignment method or objective assignment method to set weights for each indicator of the comprehensive evaluation system, and the target values were derived by weighted average. To avoid the influence of man-made factors and improve the objectivity and rationality of the economic resilience evaluation results, this paper selects the entropy value method to set the weights of the 13 indicators. In order not to eliminate the time trend of the final composite index which makes the results more reasonable, we introduce the time variable to improve the entropy method. Referring to the previous practice (Yang & Sun, 2015; Fang & Ma, 2019), our improved method is shown below.

Firstly, setting the meaning of each sign. Where, a refers to the year; m refers to the cross-sectional unit, i.e., province (municipality directly under the central government or autonomous region); *n* refers to the total number of indicators; $x_{\tau,i,j}$ means the *j*-th indicator value of the *i*-th province in the τ-year. To eliminate the influence of the dimension and the size of indicators, and to make the different indicators comparable, $x_{\tau,i,j}$ is calculated by the "minimum-maximum normalization" method. The indicator is calculated using a positive normalized formula if it is positively correlated with the system growth, and vice versa, using a negative normalized formula.

Positive normalization formula is as follows:

$$x^*_{\tau,i,j} = \frac{x_{\tau,i,j} - X_{\min}}{X_{\max} - X_{\min}};$$

Negative normalization formula is as follows:

$$x^*_{\tau,i,j} = \frac{X_{\max} - x_{\tau,i,j}}{X_{\max} - X_{\min}}.$$

Next, the indicator weights are calculated and the procedure is shown in Equations (1)-(4).

$$p_{\tau,i,j} = \frac{x^*_{\tau,i,j}}{\sum_\tau \sum_i x^*_{\tau,i,j}} \tag{1}$$

Equation (1) $p_{\tau,i,j}$ refers to the contribution of the *j*-th indicator in the province *i*, and $x^*_{\tau,i,j}$ is the standardized observation value.

$$E_j = -K \sum_\tau \sum_i p_{\tau,i,j} \ln p_{\tau,i,j}, K = \frac{1}{lnam} \tag{2}$$

Equation (2) calculates the entropy value of the *j*-th indicator.

$$e_j = 1 - E_j \tag{3}$$

In Equation (3), e_j is the information utility value of the *j*-th indicator.

$$w_j = \frac{e_j}{\sum_j^n e_j} \tag{4}$$

The final weights are calculated by Equation (4), i.e., w_j refers to the weight of the j-th indicator.

$$Z_{\tau,i} = \sum_{j=1}^n w_j \times x^*_{\tau,i,j} \tag{5}$$

Combined with the previous processing results, Equation (5) finally calculates the target value. $Z_{\tau,i}$ refers to the regional economic resilience level index; $x^*_{\tau,i,j}$ is the standardized observation; w_j is the result of the weight calculated by Equation (4).

2.3. Indicator Determination

2.3.1. Explanatory Variables

Regional innovation capacity is the core explanatory variable of the proposed model in this paper. Previous studies in China have mostly measured regional innovation capacity in terms of R&D investment or the number of patents, which are rather limited and could not comprehensively reflect the level of regional innovation. Since 1999, China's Ministry of Science and Technology (MOST) has been comprehensively measuring the innovation capability value in five aspects: knowledge creation, knowledge acquisition, enterprise innovation, innovation environment, and innovation performance every year, which are authoritative and scientific. Therefore, this paper adopts the comprehensive value of innovation capacity from the *Regional Innovation Capacity Evaluation Report* issued by the Ministry of Science and Technology as the innovation capacity evaluation index of each province (municipality directly under the Central Government or autonomous region).

2.3.2. Control Variables

The industrial structure firstly shows the characteristics of specialization and diversification. The regional industrial structure is an essential factor in economic resilience. Based on different theories of externalities, industry specialization and diversification have different mechanisms of impact on economic resilience. Marshall-Arrow-Romer's (MAR) externality theory, which focuses on innovation by firms of the same type within an industry, argues that specialization clusters are more likely to be innovative. Jacobs' externality theory supports a diverse industrial structure, arguing that competition between industries leading to knowledge spillovers would promote innovation, with a greater focus on innovation between industries. To differ from the value indicators above, this paper chooses the relative specialization and relative diversification indexes of industries to represent the regional industrial structure characteristics. The calculation is as follows.

Relative Specialization Index:

$$SP_i = \max_q \left(s_{iq} / s_q \right) \tag{6}$$

Relative Diversity Index:

$$DIV_i = 1 \Big/ \sum_q \left| s_{iq} - s_q \right| \tag{7}$$

where i refers to the region and q refers to the industry; s_{iq} refers to the share of employment in industry q of the province i to the total number of employees; s_q refers to the share of total employment in industry q to the total employment in all regions.

Government finance can ensure the proper functioning of the state machinery and contribute to the improvement of the economic environment. In other words, government finance is the expenditure on public welfare infrastructure construction with great external economic benefits, which can help regions to improve their capacity to prevent and resist external impacts. Therefore, this paper selects government fiscal expenditure as a share of GDP to measure the level of government finance, which is included in the model as a control variable.

The essence of finance is to achieve optimal allocation of funds. An effective financial system allocates funds appropriately and promotes the upgrading of industries, which plays an important role in economic stability. This paper uses the ratio of deposit and loan balances of financial institutions at year-end to indicate the level of financial development, which is the fourth control variable.

Consumption can best enable the internal restructuring and production arrangement of the economy. Regions with large market scales can instinctively pull business investment and development to achieve industrial transformation based on the local market. The larger a regional market is, then the greater its potential to absorb external impacts. To a certain extent, the scale of the population can reflect the market scale. Therefore, this paper expresses the market scale potential in terms of population density (the number of people on each square kilometer).

The construction of facilities is the foundation of economic development, especially the construction of public transportation, which concerns the circulation and communication of the economy as well as being crucial to economic stability. It also means that well-developed transportation can enhance the resilience of the regional economy. As a result, this paper also includes the level of transportation infrastructure as a control variable in the model, expressed by the number of road miles. See Table 2 for details.

2.4. Model Setup and Data Sources

2.4.1. Model Setting

The Tobit model is mainly used for regression analysis of models containing restricted dependent variables. The economic resilience index measured by the entropy method is between 0 and 1, which has the characteristic of being cut and is precisely suitable for this model. The mathematical model is constructed by

Table 2. Variable description.

Variable Type	Variable Name	Sign	Definition or Description
Dependent Variable	Economic Resilience	RES	Combined Score of Regional Resistance and Recovery Measured by Entropy Method
Independent Variable	Innovation Capability	INN	Comprehensive Value of Regional Innovation Capacity
Control Variable	Industry Specialization	SP	Relative Specialization Index by Province
	Industry Diversification	DIV	Relative Diversity Index by Province
	Government Financial Expenditures	GOV	Government Fiscal Expenditures as a Percentage of GDP
	Financial Development Level	FINAN	Ratio of Deposit and Loan Balances of Financial Institutions at Year-end
	Market Scale Potential	MARKET	Population Density
	Transportation Infrastructure	INFRA	Number of Highways Miles

referring to Xu and Zhang (2019), with economic resilience as the explanatory variable and innovation capacity as the explanatory variable. The panel regression model is shown below.

$$\begin{cases} \text{res}_{it}^{*} = \upsilon_i + \beta_1 \text{inn}_{it} + \beta X + \varepsilon_{it} \\ \text{if } \text{res}_{it}^{*} > 0, \text{res}_{it} = \text{res}_{it}^{*} \\ \text{if } \text{res}_{it}^{*} \le 0, \text{res}_{it} = 0 \end{cases} \tag{8}$$

where υ_i refers to the constant term, β refers to the coefficient, and ε_{it} refers to the random disturbance term. res refers to economic resilience, which was the explanatory variable, and inn refers to innovation capacity, which is the core explanatory variable of the model. X is the set of control variables, including industry specialization (SP), industry diversification index (DIV), government fiscal expenditure (GOV), financial development level (FINAN), market scale potential (MARKET), and transportation infrastructure (INFRA). To eliminate possible multicollinearity and heteroskedasticity among the variables, this paper takes the innovation capacity and market scale potential as logarithms and expresses them as Lninn and Lnmarket, respectively. The refined Tobit model is shown below.

$$\begin{aligned} \text{res}_{it} = {} & \upsilon_i + \beta_1 \text{Lninn}_{it} + \beta_2 \text{SP}_{it} + \beta_3 \text{DIV}_{it} + \beta_4 \text{GOV}_{it} + \beta_5 \text{FINAN}_{it} \\ & + \beta_6 \text{Lnmarket}_{it} + \beta_7 \text{INFRA}_{it} + \varepsilon_{it} \end{aligned} \tag{9}$$

2.4.2. Data Sources and Industry Segmentation

The data in this paper are mainly derived from the *2009-2020 China Statistical Yearbook*, *the Provincial Statistical Yearbooks*, and *the Statistical Bulletin*. The data are divided into provincial administrative units, including municipalities directly under the Central Government and autonomous regions, with a total of 31 provinces. A small number of missing data are filled in by interpolation method and average growth rate according to data characteristics.

The more detailed the industry division level is, the more accurate the industry indicators can be measured. Therefore, when calculating the relative specialization and relative diversification indices of industries, we divide industries into 19 sub-categories of sectors according to *China's statistical Yearbook*. That is, Agriculture, Forestry, Animal Husbandry and Fisheries, Mining, Manufacturing, Electricity, Gas and Water Production and Supply, Construction, Finance, Real Estate, Leasing and Business Services, Transportation, Warehousing and Post Office, Information Transmission, Computer Services and Software, Wholesale and Retail, Accommodation and Catering, Residential Services and Other Services, Culture, Sports and Entertainment, Scientific Research, Technical Services and Qualification Exploration, Water Environment and Public Facilities Management, Education, Health, Social Security and Social Welfare, and Public Administration and Social Organizations. Based on this, we compile relevant employment data to calculate the relative specialization and relative specialization indices.

3. Analysis of Measurement Results

3.1. Descriptive Characteristics of Regional Economic Resilience

3.1.1. Descriptive Statistics

Based on the improved entropy method, we use Python to measure the comprehensive economic resilience scores of 31 provinces in China from 2008 to 2019. The results are first analyzed at the descriptive statistics level, and the results are shown in Table 3. According to the minimum (MIN), median (MED), and average (AVE) values, China's regional economic resilience generally shows an upward trend. The mean economic resilience is 0.3758 in 2008 and 0.4198 in 2019, up 0.044; the median economic resilience is 0.3333 in 2008 and 0.4001 in 2019, an increase of 0.0668; and the minimum economic resilience is 0.2589 in 2008 and 0.3113 in 2019, a rise of 0.0524. Comparing the mean and median levels, the mean is constantly greater than the median, indicating that regions with poor regional economic resilience still exist widely in China. The difference between the maximum and minimum values is large, with the largest difference between the maximum values of regional economic resilience reaching 0.5914 in 2010, but this gap is constantly narrowing until the maximum gap narrows to 0.4513 in 2019. The data characteristics show that the minimum value has been increasing and the maximum value has been maintained at a high level of resilience. Although there are large gaps in resilience between regions, the low resilience areas are gradually improving and the overall picture is positive.

3.1.2. Fluctuation Characteristics

This paper also evaluates the magnitude of fluctuations in economic resilience in each province by calculating the variance of economic resilience in the sample region. If the variance is larger, it indicates that the economic resilience of the region is changing more. Referring to the approach of Shizhong Tian et al. (2020), the article defines regions with economic resilience variance in the range of 0 - 0.0008 as the smooth fluctuation type, 0.0008 - 0.0012 as the continuous fluctuation type, and over 0.0012 as the jump fluctuation type. The fluctuation types of each region are shown in Table 4. The result shows that the regions with smooth fluctuations are mostly located in the eastern region, which is generally more resilient and has a more stable economic resilience. Continuous

Table 3. Descriptive statistics of economic resilience.

Year	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
MIN	0.2589	0.2471	0.2424	0.2419	0.2447	0.2568	0.2718	0.2796	0.2862	0.3112	0.3006	0.3113
MAX	0.8346	0.8203	0.8338	0.8271	0.8122	0.8043	0.7993	0.8037	0.7992	0.7829	0.7612	0.7626
Delta	0.5757	0.5732	0.5914	0.5852	0.5675	0.5475	0.5275	0.5241	0.5130	0.4717	0.4606	0.4513
MED	0.3333	0.3399	0.3313	0.3438	0.3498	0.3566	0.3624	0.3733	0.3761	0.3735	0.3727	0.4001
AVE	0.3758	0.3677	0.3671	0.3784	0.3762	0.3882	0.3890	0.3924	0.3993	0.4042	0.4058	0.4198

Table 4. Types of economic resilience fluctuations.

Smooth Type ($0 \le S_k^2 < 0.0008$)	Continuous Type ($0.0008 \le S_k^2 < 0.0012$)	Jump Type ($0.0012 \le S_k^2$)
Guangdong, Fujian, Jilin, Shanghai, Beijing, Hebei, Shandong, Tianjin, Shaanxi, Ningxia, Xinjiang, Inner Mongolia	Jiangsu, Jiangxi, Tibet, Heilongjiang, Hainan, Guizhou, Zhejiang, Shanxi, Sichuan, Hubei, Gansu, Yunnan	Guangxi, Hunan, Henan, Anhui, Liaoning, Chongqing, Qinghai

fluctuation type areas are mostly located in the central and western regions, and their economic resilience is unstable. Jump volatility type regions have more fluctuations in economic resilience. For regions with poor economic resilience, if we can promote economic structural transformation and industrial restructuring, then there is a gradual trend for the better.

3.2. Spatial and Temporal Evolution Characteristics

3.2.1. Temporal Evolution Characteristics

On a temporal level, the overall economic resilience shows a rising chronological feature year by year. Based on the geographical location and the level of economic development, China is divided into three regions: East, Central, and West. Figure 1 shows that the eastern region has the strongest economic resilience, far exceeding the national average; the central and western regions are flat as well as below the national average. The economic resilience of the eastern region was worst rated in the two years of 2008 and 2009 by the economic crisis, then gradually rose in 2010. However, in the past two years, there has been a smaller decline again. The eastern region has a favorable economic foundation and robust economic development strength, therefore it has a stronger ability to resist and recover in the face of external impacts. Both the central and western regions show an upward fluctuation trend. Due to their geographical location and economic development patterns, the two regions experience less change in economic resilience. It also means that they need a longer time to complete their economic transformation so as to cope with external risks. In general, the economic resilience of all regions is gradually increasing. The eastern region has high economic resilience and potential for economic development; the central and western regions are limited by natural location factors and economic development patterns, thus showing a lack of economic resilience.

3.2.2. Spatial Evolutionary Characteristics

Based on the results of economic toughness measurement, we plot the spatial evolution of economic resilience of 31 provinces in China for four years (2008, 2012, 2016, and 2019) by Python, and the results are shown in Figure 2.

The figure shows that the spatial distribution of China's economic resilience is characterized by a block distribution. Judging from the geographical location, the regions with higher level of economic resilience are mostly distributed in the

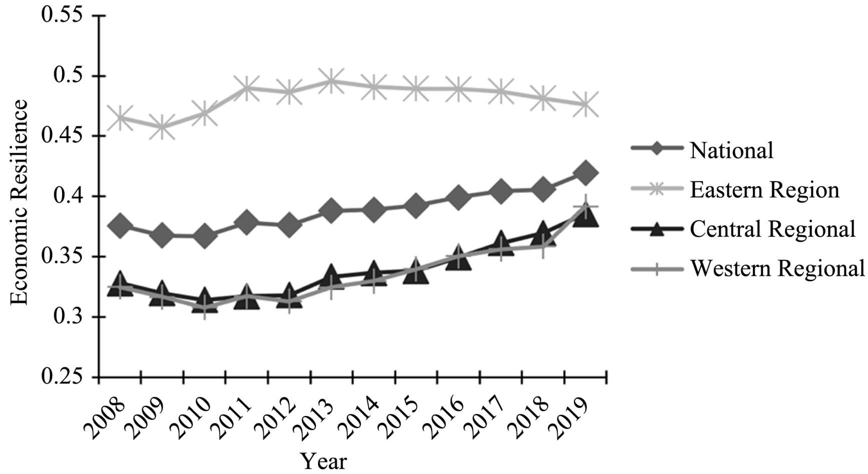

Figure 1. Comparison of the economic resilience of the three regions.

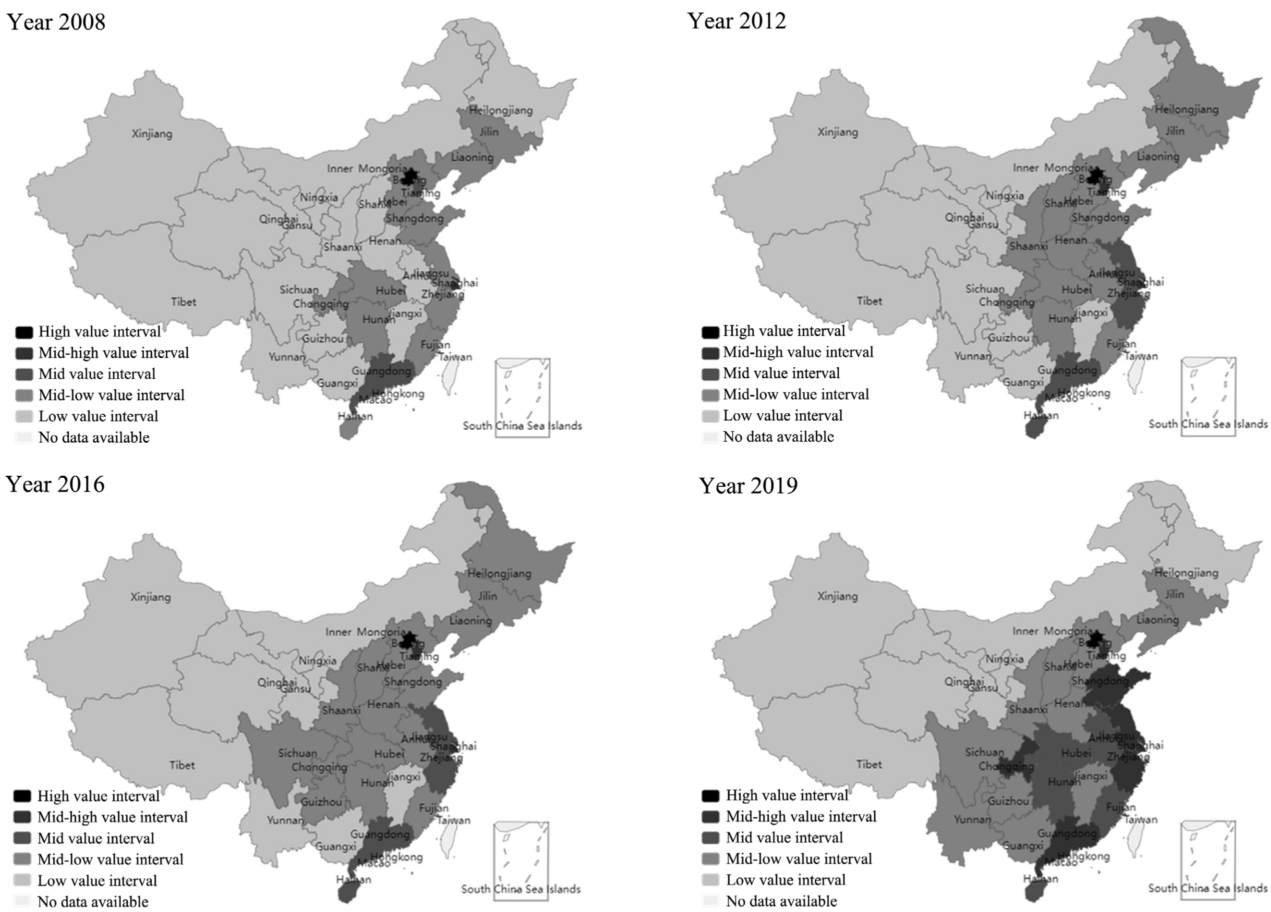

Figure 2. Spatial distribution of economic resilience.

eastern coastal areas, while the economic resilience level in the northwest inland areas is poor. For example, Beijing, Tianjin, and Shanghai have maintained high levels of economic resilience due to their superior geographic locations and dense transportation networks. Under their influence, neighboring regions also show spatial clustering. However, economic resilience has been at a lower value level in Xinjiang, Qinghai, Yunnan, and other regions due to rugged terrain and poor transportation infrastructure. The eastern Bohai Rim, Yangtze River Delta and Pearl River Delta economic segments have significantly better economic resilience, and such regions have high resilience spillover effects. In the central and western regions, high resilience regions (e.g. Chongqing, Hubei, etc.) radiate to low resilience regions, generating high and low spillover effects to other regions. In terms of the north-south location, the medium-high economic resilience zone shows a trend of gradual shift from north to south during the decade from 2009 to 2019. This is due to the decline of industries and depletion of resources in old industrial bases in the Northeast, where the economy is facing many issues such as lack of power or pattern fixation. With the development of digitalization and intelligence, the traditional economy is rapidly transforming into a digital and intelligent economy. Following the introduction of the "13th Five-Year National Informatization Plan" and other documents, 5G, Artificial Intelligence, Blockchain, Cloud Computing, Big Data and other emerging technologies have become an important driving force for China's high-quality economic development. Such industries are mostly clustered in the southern region, where new development dynamics make the regional economy more stable. In vertical comparison, the number of regions where economic resilience is in the low value zone is greatly reduced, and in medium value zone is increased, indicating that the overall level of economic resilience in China has improved.

4. Analysis of Results

4.1. Regression Results Analysis

In this paper, we use stata15.1 software to conduct a linear Tobit model regression on sample data from 31 provinces in China after conducting the overall regression and then regressing each of the three regions. The regression results are shown in **Table 5**.

Firstly, the overall regression is performed on the sample data. The results show that the estimated coefficient of innovation capacity is significantly positive at the 1% level, indicating that innovation capacity has a significantly positive effect on regional economic resilience. Then, group regressions are performed. The ranking of the influence of innovation capacity on economic resilience, in descending order, is the Eastern, Western, and Central regions. Among them, the estimated coefficient of innovation capacity in the Western region is closest to the coefficient in the national model. The reason for this is mainly the fact that the top five regions in terms of innovation capacity (Beijing, Jiangsu, Guangdong, Shanghai, and Zhejiang) are all located in the eastern region with a healthy economic base. The central region, on the other hand, is mostly province with a high degree of specialization where path dependence leads to the lack of innovation mechanisms.

Table 5. Regression results of factors influencing economic resilience.

Explanatory variables	National	Eastern Region	Central Region	Western Region
Lninn	0.05698*** (2.71)	0.09950*** (3.40)	0.01752* (1.47)	0.05222* (2.05)
SP	0.00569*** (3.27)	0.00578* (1.70)	−0.00376 (−1.12)	0.00018 (0.06)
DIV	0.00547* (1.95)	0.01276*** (3.27)	0.00862** (2.23)	−0.02470*** (−3.31)
GOV	−0.03796 (−0.66)	0.18594 (1.11)	−0.05460 (−0.42)	0.03980 (0.48)
FINAN	0.00560** (2.43)	0.00492** (2.18)	−0.13503*** (−4.48)	0.01285 (1.21)
Lnmarket	0.04393** (2.38)	0.06394* (1.65)	−0.02476 (−1.38)	0.01285 (0.71)
INFRA	0.25907*** (5.36)	0.06149 (0.64)	0.16447** (2.32)	0.11452 (0.89)
_cons	−1.37208 (−5.51)	−0.68262 (−1.39)	−0.26447 (−0.69)	−0.42266 (−0.80)
Wald chi2	72.79	39.57	76.35	25.94
LR test	328.18***	185.85***	60.49***	22.58***
rho	0.97032	0.94937	0.78475	0.60985
N	372	132	120	120

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$, z-statistic in parentheses.

The estimated coefficients of the industrial structure specialization and diversification indices both pass the significance level test with a positive effect. Specialization of industrial structure is more conducive to externalities, which then effectively improves economic efficiency. In other words, a shared pool of resources is more conducive to the aggregation of industrial innovation in the region. However, if industry specialization is too high, then a high correlation of knowledge stocks among industries can easily lead to a lock-in of the economy. The lack of innovation mechanisms makes it difficult to find new development paths for regional economic development, thus the industry is prone to enter a decline phase once it encounters external shocks. In the Central region subgroup model, the coefficient of specialization is negative (although it does not pass the significance test), indicating that a highly specialized industrial structure has a negative effect on economic resilience. Especially in regions such as Shanxi, Heilongjiang, and Jilin, where the relative specialization index of the industrial structure is very high, the negative impact of path dependence on economic growth resulting from the traditional development model has been so severe that new development paths must be found through innovation. Diversified industrial structure plays the role of "shock absorbers" in the economic system. Jacobs' externality theory suggests that a diversified industrial structure promotes knowledge and technology spillovers between different industries, and it is in such a structure that innovation capabilities are manifested in the formation of industrial chains and networks within and between regions through backward and forward industrial linkages, thereby dispersing external impacts. However, the lack of technological linkages leads to weaker inter-industry linkage effects, making it difficult to achieve scale effects in industrially diversified regions. The effect of industrial diversification on economic resilience is significantly negative in the Western subgroup, which may be caused by inefficient innovation and low industry scales.

Descriptions of the other control variables are given below. The impact of the level of government fiscal spending on economic resilience is negative. Although government fiscal spending can help regional enterprise development, infrastructure construction, and employment expansion, it may make regional production development extremely dependent on policies, in the long run, weakening its innovation and development capacity, which is not conducive to coping with external crises. Both the level of financial development and the market scale potential pass the 5% significance level test with positive effects on the economic stability of the region. After a shock to the economic system, the system needs to be absorbed and adjusted internally. Internal economic restructuring and production arrangements can best be achieved through investment and consumption. Better financial development and a larger market scale mean that the region has more potential to recover the economy through its investment and internal consumption. The last one, transportation infrastructure is significantly positive at the 1% level. Good transportation facilities contribute to inter-regional economic exchange and economic efficiency, thus helping to resist external risks.

4.2. Robustness Testing

To ensure that the model is robust, this paper uses both substitution methods and variables for testing. The first approach replaces the Tobit model with a Fixed Effects model. The Hausman test is first performed with a p-value of 0.000 and the Fixed Effects model is selected. The results show that the direction and magnitude of the estimated coefficients of innovation capacity in the Fixed Effects Model are consistent with the results in the Tobit Model and pass the significance test. As for the control variables, the magnitudes and directions are also largely consistent with the results of the Tobit model, and all pass the significance test except for the market scale potential. The second method is the variable substitution method-replacing the ratio of financial institutions' year-end deposit and loan balances with the ratio of financial institutions' year-end deposit and loan balances to GDP. The regression results are consistent with the original regression results, which pass the significance test. Therefore, the above empirical analysis is considered to be robust without the problem of pseudo-regression (**Table 6**).

Table 6. Robustness testing results.

Explanatory variables	FE-Model	Variable Substitution
Lninn	0.05474** (2.57)	0.06038*** (2.84)
SP	0.00603*** (3.38)	0.00549*** (3.14)
DIV	0.00668** (2.39)	0.00570** (2.01)
GOV	−0.15269*** (−2.81)	−0.06619 (−1.09)
FINAN	0.00612*** (2.66)	0.00348** (2.27)
Lnmarket	0.02565 (0.42)	0.03807** (2.18)
INFRA	0.38369*** (8.81)	0.22799*** (4.54)
_cons	−1.87089*** (−6.30)	−1.19065*** (−4.66)
Hausman test	0.0000	-
LR test	-	263.45***

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$, the FE model has t-statistics in parentheses and Z-statistics in others.

5. Conclusions and Recommendations

This paper defines economic resilience in terms of both resistance and resilience and measures the economic resilience level of 31 Chinese provinces from 2008 to 2019 using the integrated indicator system method, based on which the Tobit model is applied to analyze the impact of innovation capacity on economic resilience in combination with regional economic structural characteristics. The conclusions are as follows. 1) China's economic resilience has obvious spatial and temporal evolution characteristics. In the terms of time evolution trend, the overall level of economic resilience has been increasing. The northern region shows the development trend of first high and then low, and the mid-high value of the economic resilience area shifts from north to south. From the perspective of spatial evolution trends, China's economic resilience varies greatly among the Eastern, Central, and Western regions, of which the Eastern region is considerably higher than the Central and Western regions. The Eastern region shows obvious spatial agglomeration, where highly resilient regions have certain spillover effects on neighboring regions; the Central and Western regions are subject to the radiation effects of regions with higher resilience, but the overall economic resilience level is poor. 2) Innovation capacity has a significant positive effect on economic resilience. Regions with greater innovation capacity have relatively better levels of economic resilience. However, there are obvious regional differences in the effects of innovation capability on economic resilience, that is, innovation capability has the greatest impact on economic resilience in the Eastern region and the least impact on the Central region. Regional industrial structure specialization hurts economic resilience, which also has a relatively small effect on innovation capacity on economic resilience. In other words, regions with poorer levels of industrial diversification are also relatively less resilient economically. 3) The level of government fiscal spending harms economic resilience, while the level of financial development, market scale potential, and transportation infrastructure are all positively related to economic resilience. More government fiscal spending, on the contrary, is not conducive to economic resilience, but better financial development, market scale, and transportation infrastructure can all enhance the region's ability to withstand external risks as well as maintain economic stability.

The outbreak of COVID-19 in early 2020 has seriously affected the smooth operation of the economy, with the persistent impacts already having a serious negative effect on it. While the governments adopt various temporary policies to stimulate the economy, they also need to enhance regional economic resilience in the context of long-term development. Combining the above findings, this paper puts forward the following policy recommendations. 1) Enhancing regional innovation capacity and focusing on the positive effect of innovation on economic development. The governments should control the orientation of science and technology policies to effectively improve the efficiency of innovation in emerging industries and high-quality industries. 2) Promoting the rationalization of industrial structure, and the future regional development model should be more inclined to diversification. The diffusion and penetration of different knowledge technologies inside and outside the industry contribute to the positive interaction between productive service and manufacturing industries which can facilitate innovation development. A diversified industrial structure can help the region effectively disperse economic risks and reposition its development model. Therefore, the region should change the unreasonable industrial structure in the past, and promote the development of the service industry, so that the regional industry tends to be more diversified. 3) Improving other aspects of economic system construction, such as strengthening financial and infrastructure development. In addition to the construction of an innovative environment and the rationalization of industrial structure, the construction of economic development system also involves the enhancement of other supporting facilities like financial services and infrastructure. As we know, labor movements, product flows, and knowledge and technology spillovers all depend on well-developed transportation and communication networks. If such infrastructure can be improved, it will improve the efficiency of inter-regional linkages. The government should improve lending regulations and guidelines for financial institutions through policies, to make their operations more standardized and efficient. Fiscal spending ought to be used to support infrastructure development in remote areas to enhance the potential for economic development in low resilience regions.

Of course, there are certain limitations of this paper. For example, in terms of data, the missing data are filled by interpolation method or average method, and the abnormal data that cannot be filled are eliminated, which may make the empirical results have some errors with the actual situation. There are fewer studies on economic resilience, and most of the relevant theories come from other cross-disciplines, and the understanding of the intrinsic role may not be deepened systematically enough. The external environment facing economic development is variable. External conflicts also have multiple types, such as energy crises, natural disasters, economic crises, health emergencies, etc. As conflicts affect the economy at different levels, economic resilience will show different responses. Therefore, future research can also study in depth how a specific conflict affects economic resilience in a practical way, and portray the response mechanism of economic resilience from various aspects.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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