sustainability

MDPI

Article

Interaction Effects of R&D Investment, Industrial Structure Rationalization, and Economic Growth in China Based on the PVAR Model

Xiaohua Zhang and Zhixuan Zhang *

School of Economics, Hebei University, Baoding 071000, China
* Correspondence: zhangzhixuan@stumail.hbu.edu.cn; Tel.: +86-173-3642-6220

Abstract: With the deepening of economic globalization, research and development (R&D) activities have become an important link in promoting the optimization of industrial structure and high-quality economic growth. To clarify the interaction between R&D investment, industrial structure rationalization, and regional economic growth, this paper established the panel vector auto-regressive (PVAR) model on the basis of panel data of 30 provinces in China from 2006 to 2018 and analyzed the degree of interaction among the three variables from static and dynamic perspectives. The results showed that R&D investment had a long-term positive effect on regional economic growth, and the relationship between R&D investment intensity and industrial structure rationalization was different in different regions of China. The rationalization of industrial structure had a short-term promoting effect as well as a medium- and long-range inhibiting effect on R&D investment, and in the eastern and western regions, the industrial structure rationalization had a catalytic effect on economic growth. Economic growth would restrain R&D investment in the short term, but in the long term, it would steadily promote the enhancement of R&D investment intensity, showing a "U-shaped" relationship. The results of this study will be helpful to provide differentiated policy supports to broaden the channels of economic transition and promote industrial upgrading.

Keywords: R&D investment; industrial structure rationalization; economic growth; panel vector auto-regressive model

check for updates

Citation: Zhang, X.; Zhang, Z. Interaction Effects of R&D Investment, Industrial Structure Rationalization, and Economic Growth in China Based on the PVAR Model. *Sustainability* **2023**, *15*, 545. https://doi.org/10.3390/su15010545

Academic Editor: Bruce Morley

Received: 6 November 2022
Revised: 22 December 2022
Accepted: 24 December 2022
Published: 28 December 2022

1. Introduction

In the context of digital economy and industry upgrading, the economic development and soft power of a country, depending on the majorization and upgrading of economic structure, and the enhancement of innovation ability become the key factors to promote the sustainable economic development effectively. Activities of research and development (R&D) are an important part of enhancing innovation capacity, which is an index valued by governments around the world. Innovative activities have rapidly developed since the 21st century. Under the Patent Cooperation Treaty (PCT) system, the amount of global international patent filings grew from 100,000 in 2000 to 275,000 in 2020, basically keeping consistent with the growth of GDP, which implies that the world economic recovery is closely connected with technological innovation [1]. Thus, on the premise of the smooth functioning of the economy, using innovation investment to push on the upgrading of industrial structure to achieve sustained growth in the global economy is necessary, now more than ever.

As the largest developing country, the quality of China's scientific research achievements has steadily improved. China has become a major producer of innovative achievements. The R&D investment of China from the entire society reached 2.8 trillion yuan, ranking second in the world, and the number of international patent applications reached 69,640, ranking first in the world, and successfully entering the ranks of innovative countries in 2021. Since the 19th National Congress, China's economic characteristics have undergone profound changes, and the goal of economic construction has shifted from speed to quality, facing a new situation of transforming growth momentum and adjusting economic structure. As the key support for advancing technological progress and knowledge spillover, R&D investment is becoming an important source to stimulate the vitality of the national economy. Increasing the intensity of R&D investment can greatly enhance social productivity, expand marginal output, and promote sustainable economic development. At the same time, GDP is the basic information reflecting a country's overall strength and the key to determining a country's international competitiveness. Many factors directly or indirectly affect GDP, such as the quantity and quality of labor, natural resource endowment, etc. However, the improvement of technological innovation caused by the increase in R&D investment is becoming the fundamental driving force for guiding sustainable economic and social development with the further deepening of technological change. Industrial structure rationalization is a process of rational allocation of production factors, such as natural endowments, human capital, and technological level in the region. Increasing investment in R&D is conducive to the transformation of traditional industries and the rise of new sectors, which provides strong technical support for industrial structure rationalization. In addition, sustainable economic growth is bound to be restricted by the level of the industry; thus, R&D investment and industrial structure are also affected by the size of the economy. Therefore, it is of great significance to clarify the relationship among R&D investment, industrial structure rationalization, and economic growth and to keep the healthy interaction among the three for the construction of scientific and technological, manufacturing, and economic power in China.

The relationship between two of the three variables has been analyzed in previous studies. Scholars have studied R&D investment in many ways. The conclusion on the relationship between R&D investment and economic growth was not consistent due to many differences in the selection of variables and the angle of research. In general, the vast majority of scholars believed that R&D investment could contribute indirectly or directly to economic growth [2,3] or that the effects of R&D investment on economic growth are nonlinear [4]. Some scholars believed that rationalization and upgrading of the industrial structure would lead to alteration in the size of the economy [5]. The optimization of industrial structure was the key factor of economic growth. When the local industrial structure developed in the direction of rationalization and advancement, it could effectively enhance the economic resilience of the region [6]. Previous research has focused more on the one-way effect of R&D investment on economic growth and the influence of industrial structure on economic development. However, few of them have explored the interaction mechanism among R&D investment, industrial structure rationalization, and regional economic growth, and fewer studies have applied empirical methods to integrate all three variables into the same framework for comprehensive analysis. As the economic system is always in the process of change, R&D investment, industrial upgrading, and economic growth present time-varying trends, and the interaction among the three may have a time lag or instability. However, previous studies lack research on the dynamic interaction among the three variables. On the one hand, R&D activities are conducive to the upgrading of the industrial structure, while good R&D conditions require a sound industrial base, and the two interact. At the same time, R&D investment and industrial upgrading are likely to affect economic growth to varying degrees. Sustained economic growth relies on reasonable industrial positioning and effective investment in innovation. On the other hand, sustainable economic growth may also provide adequate funding for R&D activities to a certain extent, shorten the application cycle of new technologies, and provide strong technical support for the optimization of industrial structure.

What is the interaction among R&D investment, industrial structure rationalization, and economic growth? Is there an obvious lag period in the interaction? In addition, there are great differences in the technology level and industrial base in different parts of China. Will this result in a difference in the dynamic relationship among the three variables? What are the various characteristics of the three geographical divisions in China respectively? The above issues deserve discussion. The target of the study is to respond to them. Discussing these questions will help to deepen the understanding of the significance of technological innovation, make the orientation of technological innovation consistent with the orientation of industrial adjustment, and provide more specific references for the economic construction of China and other emerging economies around the world. In particular, addressing the above-mentioned issues will contribute to the future sustainable and high-quality economic development of different regions of China. Therefore, this study endeavors to place R&D investment, industrial structure rationalization, and economic growth into the same framework for empirical analysis, selecting a panel vector auto-regressive model (PVAR) to analyze the dynamic impact path of R&D investment, industrial structure rationalization, and regional economic growth. Thirty provinces of China were selected as the study sample, and the total sample was divided into three geographical regions: east, central, and west. The differences among R&D investment, industrial rationalization, and economic growth were discussed in different regions, which will provide theoretical support for the discussion of related issues, the implementation of endocycle–strategy and sustainable economic growth.

The contents of the rest of the study are as below. Part 2 combs the existing literature. Part 3 presents the experiment data and sets the econometric model. Part 4 empirically analyzes the relationship among R&D investment, industrial structure rationalization, and economic growth. Part 5 draws conclusions and puts forward suggestions.

2. Literature Review

2.1. R&D Investment and Industrial Structure Rationalization

Regarding the research on the relationship between R&D investment and industrial structure rationalization, previous research mainly focused on the following two aspects. On the one hand, the R&D input has a one-way driving effect on upgrading of industrial structure. Zhuang and Wang (2020) found that technological innovation has a stimulative significance for the rationalization and advanced development of the industrial structure by constructing a provincial fixed-effect model [7]. Tang and Li (2011) considered Guangdong province as a sample to research the relationship among economic growth, R&D innovation, industry coordination, and corresponding mechanisms of action [8]. They found that R&D input was a key factor affecting the industrial structure and promoting industrial transformation and upgrading, while there were differences in the effect among different industrial sectors. They also proposed that R&D investment could effectively contribute to the optimization and upgrading of the whole industrial structure by enhancing technological innovation capacity [9]. At the same time, increasing the intensity of R&D investment helps China occupy a favorable position in the process of global industrial chain remodeling and greatly enhances the competitiveness of Chinese products and export trade development. However, this effect has a time lag, and only over time will this be reflected in boosting exports of Chinese products [10]. On the other hand, Wang et al. (2019) constructed simultaneous equation models from the national and regional levels, respectively. The results showed that industrial structure rationalization had a forced mechanism on the intensity of R&D input, under the pressure of energy conservation and emission reduction. It is necessary to further improve the R&D investment level [11]. By comparing multiple countries, foreign scholars such as Cohen (1989) [12] and Lorweth (2005) [13] have found that the inconsistency of industrial structure level was an important factor contributing to the difference in the intensity of R&D input.

2.2. R&D Investment and Economic Growth

With the rise of the fourth technological revolution, R&D investment has become a common concern in economics and management, and technological R&D is widely recognized as a key production factor. From a theoretical perspective, on the basis of the Cobb–Douglas production function, Lucas (1988) argued that the level of science and technology and human capital had a significant impact on national economic output [14];

therefore, R&D investment would affect economic growth through output acceleration mechanisms. Recent theoretical developments have moved towards integrating knowledge accumulation into macroeconomic frameworks, thus linking knowledge spillovers to economic growth [15]. From the perspective of empirical studies, Xu (2012) demonstrated that R&D investment contributed to economic growth by examining the regression relationship between R&D input and technological innovation on national income, but this influence mechanism relied on the introduction and diffusion of technological innovation [16]. Zhang (2014) used an improved Cobb–Douglas production function model to evaluate the elasticity coefficient of R&D investment in Chinese industrial enterprises and found that there was a significant disparity compared with the developed Western countries, although R&D investment in industrial enterprises in China had contributed to economic growth [17], while the huge shock to corporate performance had a considerable passive impact on R&D input and output during the international financial crisis, and the effect of R&D investment on economic growth was heterogeneous in different regions of China [18]. In addition, Wan et al. (2014) [19] found that the driving force of R&D capital input on regional economic growth is very limited, and the policy effect of R&D investment was not apparent until 2 to 5 years later [20]. Wu et al. (2021) considered listed enterprises in Shanghai and Shenzhen as samples and found that excessively high economic growth targets inhibited the growth of corporate R&D investment, and both the industrialization orientation of the industrial structure and increase in corporate financial leverage hurt the growth of R&D investment [21].

2.3. Industrial Structure Rationalization and Economic Growth

The research on the connection between industrial structure rationalization and economic growth focuses mainly on two main aspects. On the one hand, the previous studies explored the influence mechanism of industrial structure rationalization on economic growth as well as conducted relevant empirical tests, and most scholars [22–24] have come to a uniform conclusion that industrial structure rationalization could promote economic growth in the region. Zhang et al. (2019) found that industrial structure rationalization had a significant promoting effect on regional economic growth, but the relationship between the two was influenced by spatial and temporal factors, and there were differences in this effect in different periods and regions [25]. However, some scholars had different opinions; Li et al. (2019) studied the transmission effect of industrial restructuring on economic growth and concluded that industrial structure rationalization had a strong inhibitory effect on economic development [26], which was especially significant in the central and western regions of China, and lower industrial structure rationalization was detrimental to regional economic development [27]. On the other hand, scholars have explored the synergistic relationship between both industrial structure rationalization and economic growth. Wang (2014) thought that the process of industrial structure rationalization contributed more significantly to economic growth and that economic growth provided a resource guarantee for the softening and upgrading of industrial structures [28].

In general, the bilateral research on R&D investment, industrial structure rationalization, and economic growth has been relatively mature in academic circles. This paper attempts to extend the previous research by combining the three into the same system to explore the dynamic synergistic relationship and mechanism among R&D investment, industrial structure rationalization, and economic growth.

3. Methodology and Data

3.1. Data Sources

On the basis of the availability of data, this study selected the panel data of R&D investment, industrial structure rationalization, and economic growth of 30 provinces in China from 2006 to 2018 as data samples. The data sources are the *China Statistical Yearbook*, the *China Science and Technology Counting Statistical Yearbook*, and the statistical yearbooks and bulletins of each province, city, and autonomous region. Due to the large time span of the data, to avoid the interference of heteroskedasticity on the analysis results, the GDP per capita should be logarithmically processed before conducting empirical tests.

In the study, the 30 selected provinces are divided into three regions according to the National Bureau of Statistics of China (http://www.stats.gov.cn/tjzs/cjwtjd/201308/t20130829_74318.html, accessed on 25 August 2022)—the east, the central, and the west—which are analyzed separately. Eleven coastal provinces, such as Hainan Province and Guangdong Province, are listed as the eastern region; eight provinces, such as Henan Province and Hubei Province are listed as the central region; ten provinces, such as Xinjiang Province and Yunnan Province are listed as the western region. The three regions mentioned above were used as representatives to examine different regional heterogeneity separately. The specific geographical distribution of China is shown in Figure 1.

Figure 1. The map of the geographical distribution in China. The blue, green, and pink areas represent the eastern, central, and western regions, respectively. Figure source: manually created by the author.

3.2. Variable Descriptions

In the paper, three variables are involved: R&D investment, industrial structure rationalization, and economic growth.

R&D input (RD): RD represents the intensity of R&D input. The ratio of R&D spending to GDP in each province of China used in this paper is according to the research of Liu et al. [29].

Industrial structure rationalization (UIS): from the dimension of rationalization of industrial structure, this paper observes the state of industrial coordination in various provinces and cities in China. Regarding the measurement of industrial structure rationalization, academics usually use structural deviation indicators to measure it according to the following formula [30,31]:

$$K = \sum_{\mathrm{j}=1}^{\mathrm{n}} \left| \frac{P_{\mathrm{j}}/P}{L_{\mathrm{j}}/L} - 1 \right| = \sum_{\mathrm{j}=1}^{\mathrm{n}} \left| \frac{P_{\mathrm{j}}/L_{\mathrm{j}}}{P/L} - 1 \right| \tag{1}$$

P is sector output, L is labor input, j is industry, and n is sector quantity. The greater the K value, the more irrational the economic operation and the lower the level of the industrial structure.

Since factors such as capital and labor are not fairly and adequately mobile in practice and economic imbalances are common in social development [32,33], K is generally not equal to 0. Gan et al. (2009) [34] proposed that the index of structural deviation did not subdivide the contribution of different industries to economic development, while the Theil Index better measures the rationality of industrial structure. The Theil Index has a negative correlation with industrial structure rationalization. This study uses this method to calculate the index of industrial structure rationalization. According to the general measure of the Thiel Index, n in Equation (2) represents the primary, secondary, and tertiary industries. The formula is as Equation (2):

$$TI = \sum_{\mathrm{j}=1}^{\mathrm{n}} \left(\frac{P_{\mathrm{j}}}{P} \right) \times \ln \left(\frac{P_j}{L_j} / \frac{P}{L} \right), n = 3 \tag{2}$$

Economic growth (GDP): In previous studies, the size of GDP was selected mostly to measure regional economic growth. This paper, referring to the general practice, adopted the logarithm of the per capita GDP of each province (per capita GDP) as the proxy variable of regional economic growth.

3.3. Panel Vector Auto-Regressive Model

The PVAR model has the advantages of both panel data and vector self-regression model, considering the endogenous problems and lag periods of variables to study the interaction among variables. In this paper, to understand the interaction and effect of the three more accurately, the PVAR model is used to study the evolutionary characteristics of R&D investment, industrial structure rationalization, and regional economic development in 30 provinces of China. The model allows for better observation of multi-dimensional data, but since the model itself contains temporal and individual fixed effects, the dynamic interaction among variables was analyzed using the generalized moment estimation (GMM) method. The specific model is set as Equation (3):

$$Y_{it} = \alpha_0 + \sum_{j=1}^{n} \alpha_j Y_{i,t-j} + \delta_i + \eta_t + \varepsilon_{it} \tag{3}$$

Expand Y_{it} to obtain Equation (4):

$$Y_{it} = \begin{pmatrix} RD_{\mathrm{it}} \\ UIS_{\mathrm{it}} \\ \ln GDP_{\mathrm{it}} \end{pmatrix} \tag{4}$$

In Equations (3) and (4), Y_{it} is a column vector of 1×3 order, which means the vector consisted of the i-th province in the t-th year, containing three endogenous variables: R&D investment (RD), industrial structure rationalization (UIS), and regional economic growth (lnGDP). The index i = (1, 2, . . ., 30) denotes 30 provinces. The index t ranges from 2006 to 2018. j is the lag order. α_0 is the intercept; α_{j} is a parameter matrix with a lag of j order; δ_i and η_t are individual and temporal fixed effects, respectively [35]; and ε_{it} is a random perturbation term.

4. Empirical Analysis

Before regression, the PVAR model should conduct a smoothing test and lag order selection on the selected data to prevent the phenomenon of estimation bias and ensure the accuracy of the model. Then, the systematic GMM is applied to estimate the regression results among R&D investment, industrial structure rationalization, and economic development variables. Secondly, the Granger causality test is used to examine the relationship among variables, and the dynamic effect of single variable shock on other variables is also investigated by observing the impulse-response curve. Finally, the variance decomposition is applied to measure the contribution of unit shocks to the endogenous variables.

4.1. Smoothing Test and Optimal Lag Order Selection

4.1.1. Smoothing Test

To avoid spurious regression in model estimation and to ensure that there is no significant bias in experimental results, we adopt four different tests, namely IPS, LLC, Fisher-ADF, and Fisher-PP, to check the smoothness of the variables, such as R&D investment. The results are shown in Table 1. The above three variables are integration sequences of the same order, which are suitable for constructing PVAR models. At the national level and in the central and east regions, all three variables can reject the original hypothesis with at least a 10% confidence level, proving that the unit roots do not exist. Similarly, in the West region, dUIS and dlnGDP pass all three tests except ADF test. dRD passes two tests except for ADF and LLC. Generally speaking, as long as the variables pass the two tests, the indexes can be considered smooth. Thus, it can be judged that each sequence is smooth and the PVAR model can be established.

Table 1. Smoothing test.

Sample	Variable	IPS	LLC	Fisher-ADF	Fisher-PP	Result
China overall	dRD	−6.5311 ***	−7.7752 ***	−3.1915***	−7.7710 ***	Smooth
	dUIS	−6.7590 ***	−6.1031 ***	−1.5910 *	−6.5105 ***	Smooth
	dlnGDP	−6.9418 ***	−7.5667 ***	−2.1881 **	−7.1407 ***	Smooth
Eastern	dRD	−4.7501 ***	−9.6029 ***	−5.8417 ***	−6.9707 ***	Smooth
	dUIS	−3.9438 ***	−5.0118 ***	−2.2734 **	−3.3852 ***	Smooth
	dlnGDP	−4.7800 ***	−3.8517 ***	−1.6285 *	−6.0932 ***	Smooth
Central	dRD	−3.5492 ***	−5.6058 ***	−2.9155 ***	−4.0796 ***	Smooth
	dUIS	−3.6615 ***	−5.3571 ***	−3.7693 ***	−2.7850 ***	Smooth
	dlnGDP	−3.6458 ***	−6.0534 ***	−2.5322 ***	−3.4406 ***	Smooth
Western	dRD	−3.8110 ***	−0.1927	0.8997	−5.3175 ***	Smooth
	dUIS	−4.1087 ***	−3.1382 ***	−0.1678	−4.9782 ***	Smooth
	dlnGDP	−3.7966 ***	−1.8677 **	0.2489	−3.8472 ***	Smooth

Note: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$. d indicates first-order difference. Table source: created by the author.

4.1.2. Optimal Lag Order

The consistent moment model selection criteria proposed by Andrews and Lu (2001) [36] specifically include three information criteria, Bayesian Information Criterion (BIC), Akuchi Information Criterion (AIC) [37], and Hannan−Quinn Information Criterion (HQIC), which are widely used to determine the lag order of this model. Table 2 shows that under all samples, the lag order where the minimum value under different criteria is located is first order. After attempting to divide samples into the east region, central region, and cest region, it proves that the optimal lag order is also first order. Therefore, the lag order of the model is set to first order.

Table 2. Optimal lag order determination.

Hysteresis Period	BIC	AIC	HQIC
1	−168.2505 *	−32.7718 *	−87.8125 *
2	−126.2951	−17.9122	−61.9447
3	−103.8203	−22.5331	−55.5575
4	−78.5258	−24.3344	−46.3507
5	−30.7891	−3.6934	−14.7015

Note: * denotes the optimal lag order under the three criteria. Table source: created by the author.

4.2. GMM Estimation

After determining the optimal lag order and conducting the unit root test, GMM is used to estimate R&D investment, industrial structure rationalization, and economic growth. The specific parameters are shown in Table 3.

Table 3. Estimation results of GMM.

Dependent Variable	Sample	Independent Variable		
		L1.dRD	L1.dUIS	L1.dlnGDP
dRD	China overall	0.1366 (0.1159)	0.0010 (0.0008)	0.0021 (0.0013)
	Eastern	0.3414 * (0.1886)	0.0006 (0.0051)	0.0038 (0.0026)
	Central	−0.0146 (0.1687)	−0.0006 (0.0013)	0.0036 * (0.0019)
	Western	−0.2191 (0.1570)	0.0012 ** (0.0006)	−0.0023 (0.0021)
dUIS	China overall	5.9749 (6.9993)	0.0564 (0.0855)	0.2266 ** (0.1155)
	Eastern	1.2463 (4.5883)	0.0414 (0.1299)	0.0765 (0.0923)
	Central	25.8029 ** (10.8292)	0.2246 (0.2736)	0.2435 (0.1534)
	Western	−2.5413 (23.1501)	0.0150 (0.0793)	0.2907 (0.2705)
dlnGDP	China overall	15.3776 *** (5.3871)	−0.0397 (0.0385)	0.7706 *** (0.0545)
	Eastern	11.4053 (7.9913)	−0.1590 (0.1329)	0.6299 *** (0.0869)
	Central	19.4246 ** (8.3695)	0.0218 (0.0610)	0.7796 *** (0.0915)
	Western	21.0401 *** (7.7376)	−0.0348 (0.0423)	0.8958 *** (0.1090)

Note: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$. d indicates first-order difference; L1. indicates that the variable lags one phase. The numbers in parentheses are the t-test values for the generalized moment estimates. Table source: created by the author.

The above results show that when R&D investment (dRD) is the dependent variable, the effect of R&D investment with one period lag on itself is not significant in the national, central, and western regions, while the effect on the eastern region is significant at the 10% level, which proves that the R&D input in the east coastal region is stronger and the utilization rate of technology transformation is higher, which also reflects that the intensity of R&D input in the last period in different regions has different impacts on the current R&D. Industrial structure rationalization with one period lag has a suppressive effect on R&D input in the western region, but the effect is not significant in the eastern region; meanwhile, the development of industrial structure rationalization increases the R&D input intensity in the central region. In the central region, the economic growth of lag order 1 has a notable positive impact on R&D investment.

When industrial structure rationalization (dUIS) is the dependent variable, the effect of R&D investment with one period lag on the level of industrial structure in the current period has obvious regional heterogeneity. Since industrial structure rationalization is a negative indicator, for the western region, the first-order lag of dRD is negative, indicating that R&D input promotes industrial structure upgrading in West China, while the crowding-out effect of R&D investment with one period lag in the central region on industrial rationalization is significant at the 5% level. Nationwide, the economic development level of lag order 1 has a negative effect on industrial structure upgrading in the current period, but this effect is not obvious at the sub-regional level.

When economic growth (dlnGDP) is selected as the dependent variable, the lagged first-order coefficients of dlnGDP are all positive and significant at the 1% level, indicating that economic growth of lag order 1 has a notable promoting effect on itself. The coefficients of industrial structure rationalization in both the eastern and western regions are negative; thus, the industrial structure rationalization in the lagged one period promotes economic growth. However, in the central region, likely because development of industrial structure rationalization increases economic fluctuations, which is not conducive to the smooth operation of the regional economy. In the central and western regions, the positive effect of R&D input with a one-period lag on the current economic growth is significant at least at the 5% level, while there is no significant effect in the eastern region.

4.3. Granger Causality Test

The Granger causality test is used to investigate the causal relationship among R&D investment, industrial structure rationalization, and economic growth, and the data obtained are shown in Table 4. From the national overall, with R&D investment as the dependent variable, industrial structure rationalization and economic growth are Granger causes at 5% significant level. With industrial structure rationalization as the dependent variable, economic growth is a Granger cause at the 5% significant level. With economic growth as the dependent variable, R&D investment is the Granger reason at 1% significant level. The above results indicate that there is a mutual driving effect between R&D investment and economic growth, while economic growth unilaterally affects industrial structure rationalization.

Table 4. Full sample Granger causality test.

H_0: The Former Is Not the Granger Reason for the Latter	Chi-Square ≥ F Value	DOF	*p*-Value	Result
dUIS → dRD	1.578	1	0.209	accept
dlnGDP → dRD	2.537	1	0.111	accept
ALL → dRD	7.456 **	2	0.024	reject
dRD → dUIS	0.729	1	0.393	accept
dlnGDP → dUIS	3.846 **	1	0.050	reject
ALL → dUIS	7.235 **	2	0.027	reject
dRD → dlnGDP	8.148 ***	1	0.004	reject
dUIS → dlnGDP	1.063	1	0.302	accept
ALL → dlnGDP	10.245 ***	2	0.006	reject

Note: *** $p < 0.01$, ** $p < 0.05$. DOF is the degree of freedom. Table source: created by the author.

4.4. Impulse-Response Analysis

To achieve the reliability of the experimental results, the steady of the model should be tested before further analysis. According to Figure 2, it can be seen that the dynamic concomitant matrix characteristic roots are all less than 1 (located within the unit circle). Thus, it can be considered that the PVAR model established in this study is stable. The study can be continued.

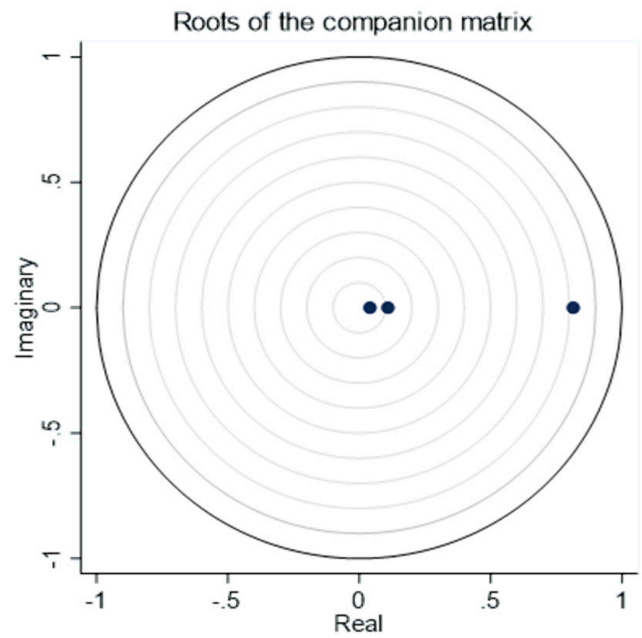

Figure 2. Model stability testing.

To deepen the study of the dynamic interaction among R&D investment, industrial structure rationalization, and economic growth, impulse-response analysis can be used to examine the change in the time path of other variables following a shock to one of the individual variables. The impulse-response function is a mechanism that measures the dynamic impact of a variable on an orthogonal shock to another variable. A standard deviation shock is given to R&D investment, industrial structure rationalization, and economic growth in the base period, and the duration of the shock is 10 periods; here, 200 simulations are conducted using the Monte Carlo method to obtain the impulse-response images of each variable shock in the period 0–10. The results are shown in Figure 3, where the red line is the impulse-response curve and the outer green and blue lines are the 5% and 95% confidence interval lines, respectively.

4.4.1. The Impulse-Response Results for China Overall

Figure 3 shows the impulse-response function among R&D investment itself, industrial structure rationalization, and economic growth for the whole sample. From the figure, it can be seen that current R&D investment inhibits the rationalization of industrial structure, but this effect then gradually diminishes, and in the long run, R&D input has a positive effect on regional economic growth. Considering the impulse-response of industrial structure rationalization on R&D input and the estimated parameters of GMM, it is concluded that industrial structure rationalization increases the intensity of R&D investment only in the current period. In addition, the crowding-out effect of industrial structure rationalization on economic growth reaches its maximum in the current period and decreases over time. Economic growth has a transient inhibitory effect on the growth of R&D investment, but it greatly promotes the increase of R&D investment intensity in the long run.

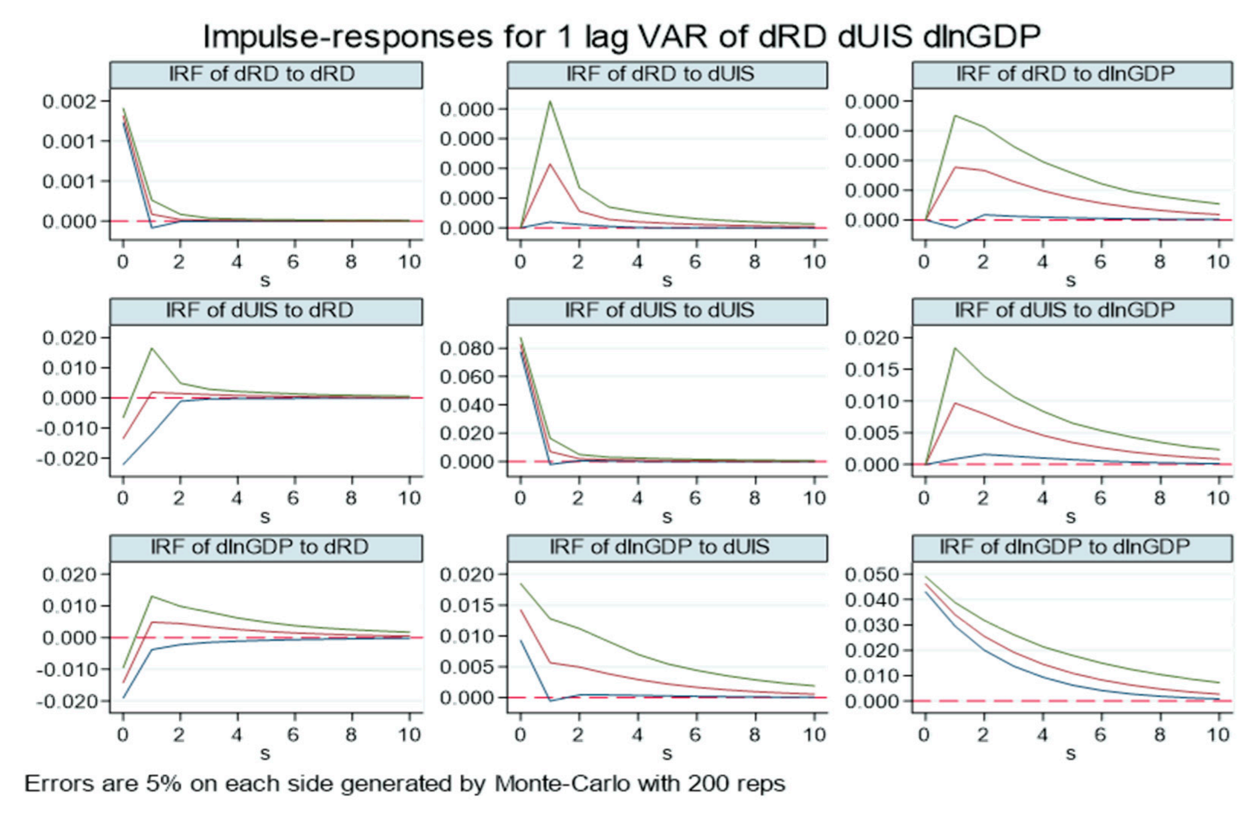

Figure 3. Impulse-response results for China overall. Notes: The lateral axis denotes the number of lag periods (years), the red line in the middle represents the impulse response function curve, and the outer green and blue lines are the 5% and 95% confidence interval lines, respectively. Same chart below.

4.4.2. Impulse-Response Results in the Eastern Region

As can be seen from Figure 4, R&D investment has a continuously positive impact on regional economic growth in East China. R&D input is negative in the current period when facing the impact of industrial structure rationalization, and gradually rises and converges to zero, indicating that current industrial structure rationalization plays a transient role in promoting R&D investment growth, while the long-term effect is not significant. Economic growth first inhibits and then promotes R&D input, and in the long run, the promotion effect tends to be stable. Moreover, the effect of economic growth on industrial structure rationalization in the east region is unstable and can greatly inhibit the industrial structure rationalization in the short run. Economic growth has a positive impact in the face of its own shocks and then weakens to near 0. In other words, economic growth has a self-reinforcing effect on itself and has potential economic inertia, but this effect will gradually decrease with the increase of time. The conclusion conforms to most research results and the Cobb–Douglas production function. In the east region, with the development of big data, artificial intelligence (AI), and new information technology, businesses are motivated to invest more in R&D to meet market changes. This will be conducive to improving the conversion rate of innovation results, promoting the specialization of the division of labor in the market, increasing the input–output ratio of factors of production, increasing the value added of the products produced while reducing energy consumption, and ultimately increasing labor productivity and economic efficiency [38].

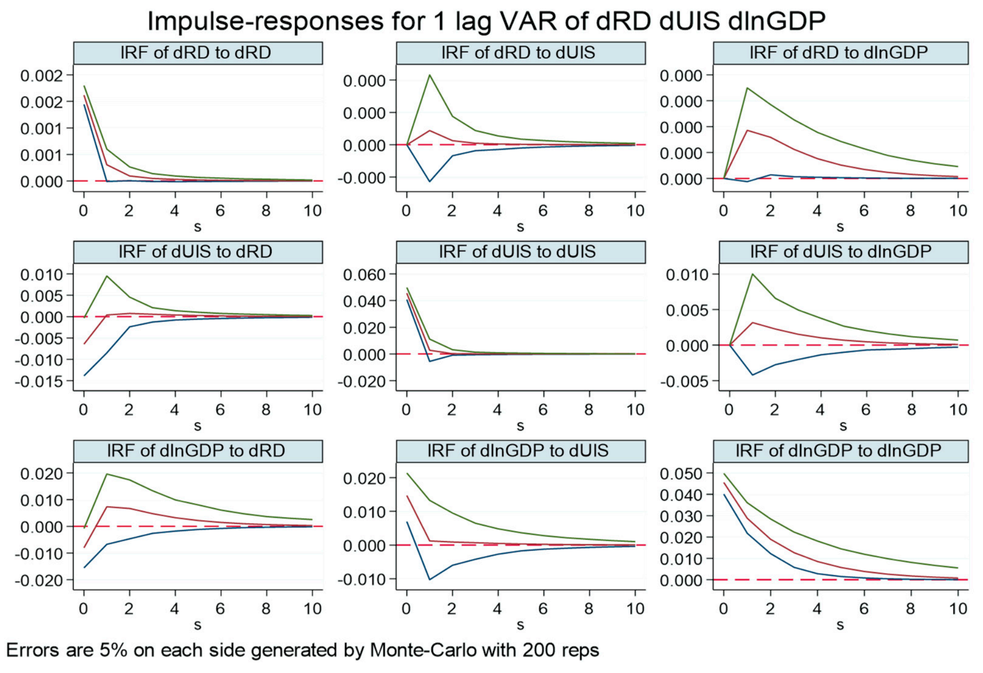

Figure 4. Eastern region impulse-response results.

4.4.3. Impulse-Response Results in the Central Region

Figure 5 shows the impulse-response results in the central region of China. As can be seen from the figure, R&D investment in the central region has a continuously positive impact on economic growth. The promotion effect of industrial structure rationalization on R&D investment is not continuous and only drives the intensity of R&D input to increase in future phase 1, with a response intensity of approximately 0.02. Over time, the motiving force of economic growth in the central region on R&D investment increases continuously, while its own promotion effect continues to weaken. In recent years, industrial upgrading in central provinces has effectively promoted the upgrading of consumption and expanded the domestic and foreign markets. To gain greater market share, companies must invest more in technological research and development to attract consumers through technological innovation. In addition, industrial upgrading will also facilitate the flow of capital, technology, knowledge, and other factors of production, which can raise the productivity of the industrial sector. To support long-term and stable regional economic growth, the government must invest more in new and strategic industries and high-tech industries.

4.4.4. Impulse-Response Results in the Western Region

According to Figure 6, R&D investment in the western region is more influenced by itself, and there is a significant self-reinforcing effect; the effect on the rationalization of industrial structure is negative in the first period, positive in the second period, and then tends to 0 over time, indicating that there is a lag in the promotion effect of R&D input on industrial structure upgrading. In West China, the economic base is weak, and the government neglects technological innovation and investment in enterprise R&D. Therefore, it is difficult to promote the optimization of industrial structure in the short term. However, over time, according to the law of diminishing returns to scale on capital [39], the capital allocation efficiency of the backward region in the west will grow faster than that of the eastern region, and its late-mover advantage will begin to appear. When economic growth has a shock on R&D investment, its positive effect comes to a head in the first period and then gradually decreases and converges to a steady level in the second period, indicating that economic growth in the western region is also favorable to the increase of R&D investment; when economic growth has a shock on itself, its effect is the largest in the initial period, and then tends to weaken in general and eventually tends to 0 gradually. In the context of western development, the government scientifically sets economic growth targets and effectively restrains the short-term preference in government investment, injects more resources into long-term R&D projects, and strengthens the endogenous motivation of enterprises to carry out research and development activities.

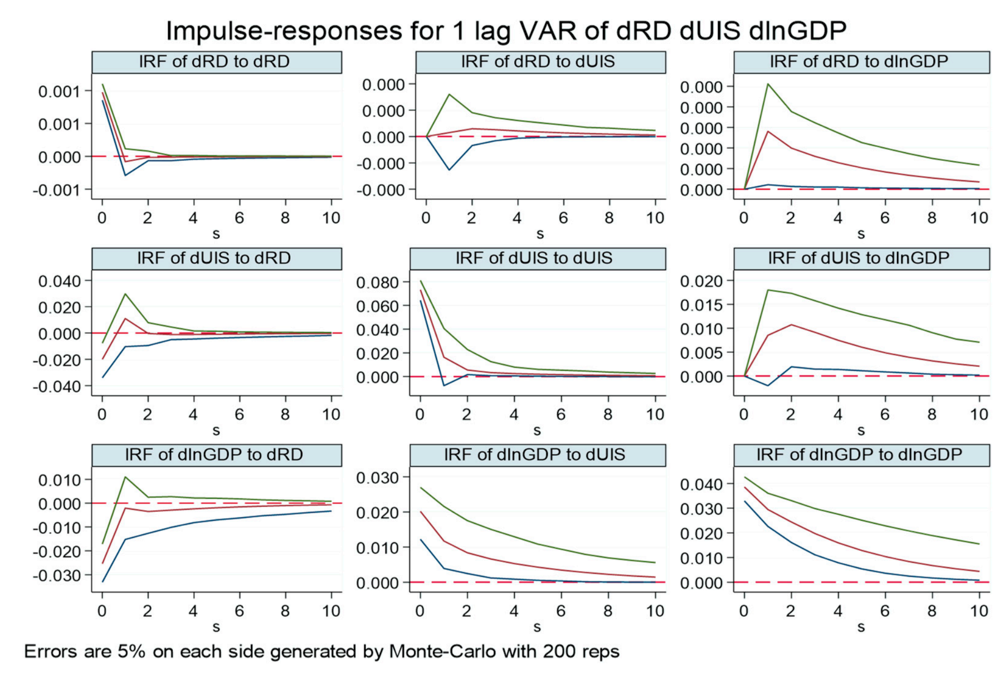

Figure 5. Central region impulse response results.

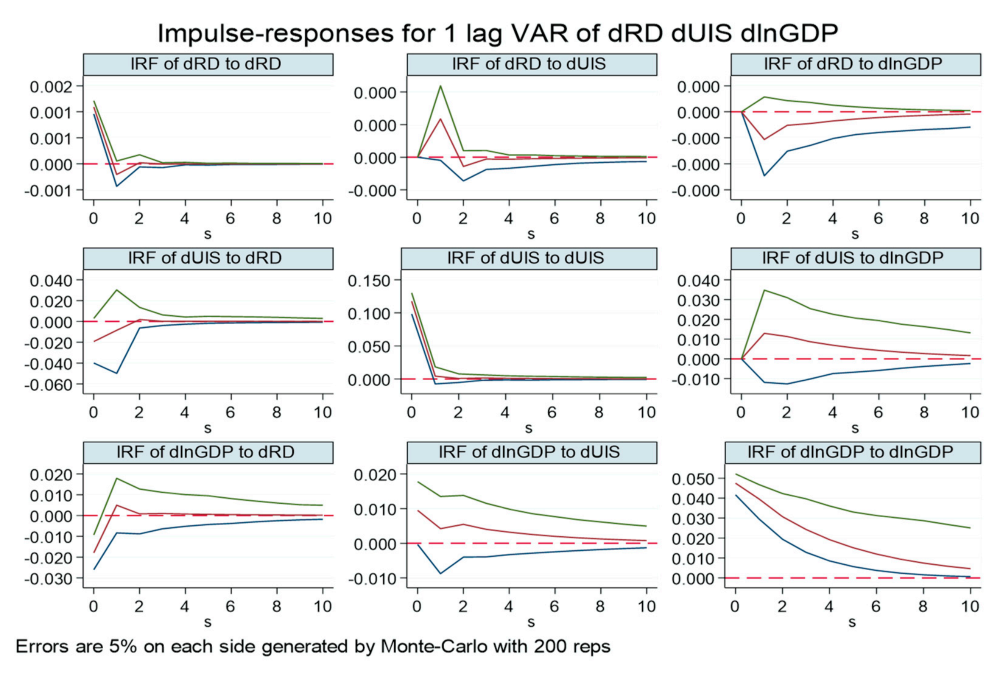

Figure 6. Western region impulse response results.

4.5. Variance Decomposition Analysis

To analyze the interaction and trend among R&D investment, industrial structure rationalization, and economic growth of each region in each period, this study further performs variance decomposition experiments on the regression model to analyze the contribution of each variable to the shocks caused by other variables. The results of the decomposition of variance in periods 5, 10, and 20 to analyze the specific degree of interaction among the three variables are shown in Tables 5 and 6.

Table 5. Variance decomposition.

Variable	Period	China Overall			Eastern Region		
		dRD	**dUIS**	**dlnGDP**	**dRD**	**dUIS**	**dlnGDP**
dRD	5	0.955	0.015	0.029	0.939	0.006	0.053
	10	0.947	0.016	0.036	0.933	0.006	0.059
	20	0.946	0.016	0.037	0.933	0.006	0.060
dUIS	5	0.023	0.933	0.043	0.003	0.982	0.014
	10	0.023	0.924	0.052	0.004	0.980	0.015
	20	0.023	0.922	0.053	0.004	0.980	0.015
dlnGDP	5	0.049	0.077	0.872	0.086	0.066	0.847
	10	0.048	0.077	0.873	0.093	0.065	0.841
	20	0.048	0.077	0.873	0.093	0.065	0.841

Table source: created by the author.

Table 6. Variance decomposition.

Variable	Period	Central Region			Western Region		
		dRD	**dUIS**	**dlnGDP**	**dRD**	**dUIS**	**dlnGDP**
dRD	5	0.940	0.011	0.048	0.954	0.018	0.027
	10	0.921	0.016	0.061	0.948	0.018	0.033
	20	0.916	0.018	0.064	0.947	0.018	0.034
dUIS	5	0.079	0.846	0.074	0.048	0.911	0.040
	10	0.076	0.818	0.105	0.048	0.900	0.051
	20	0.075	0.810	0.113	0.047	0.898	0.053
dlnGDP	5	0.116	0.253	0.629	0.039	0.023	0.936
	10	0.100	0.258	0.641	0.033	0.024	0.942
	20	0.096	0.259	0.644	0.032	0.024	0.943

Table source: created by the author.

Overall, the variance explanation of R&D investment by itself is high and remains above 90%, still at 91.6% in period 20, followed by the degree of economic growth and industrial structure rationalization. The variance decomposition results of R&D investment by regions are similar to the overall one. At lag 20 periods, the contribution of variance of R&D investment itself is 93.3% in East China, 91.6% in Central China, and 94.7% in West China.

By observing the variance decomposition results of industrial rationalization, it is found that the steady state— the contribution rate of industrial structure rationalization to itself—achieved after a lag of 20 periods is as high as 92.2%, and the contribution of R&D investment and economic growth to industrial structure rationalization is 2.3% and 5.3%, respectively. Compared with the western region, the impact of R&D input and economic growth on industrial restructuring is smaller in the eastern region, and the contribution of these two variables to industrial structure rationalization is only 0.4% and 1.5%, respectively, in the 20th period, which means that the extrusion effect of R&D input and economic growth on industrial structure rationalization is weaker in East China.

The variance contribution of economic growth of the full sample originates mainly from itself, which is 87.3% at a lag of 20 periods, and the variance contribution of R&D investment and industrial structure rationalization reach 4.8% and 7.7%, respectively. Comparing the variance decomposition of the economic growth of the sample from different regions, it is found that the variance contribution rate of R&D investment to economic growth is higher in the east and central, while the economic growth in the west region is not significantly influenced by R&D investment. In addition, the contribution of industrial structure rationalization to economic growth is 6.5% in the eastern region and less than 3% in the central and west.

5. Conclusions and Policy Recommendations

This paper discusses the dynamic action mechanism and areal characteristics among R&D investment, industrial structure rationalization, and economic growth by using the PVAR model. The results show that: (1) During the study period, China's overall R&D investment intensity and total economic volume increased year by year, but the central and west provinces lagged far behind the eastern coastal provinces, and the level of industrial structure rationalization in all regions need to be improved. (2) Increasing R&D investment intensity in each province can effectively promote regional economic growth, while there is regional heterogeneity in the relationship between R&D investment intensity and industrial structure optimization. Specifically, increasing R&D investment is beneficial to industrial structure rationalization in the western region, while in the central provinces, R&D investment has an inhibitory effect on industrial structure rationalization in the short run. However, this effect will fade away in the long term. (3) On a national scale, industrial restructuring is only beneficial to increase R&D investment in the current period. At this stage, the rationalization of China's industries weakens the intensity of R&D investment and improves the economic level. (4) Economic growth has a suppressive effect on R&D input in the short run, but it will steadily promote the improvement of R&D input intensity in the long run, showing a "U-shaped" relationship. In addition, on a national level, the economic growth of lag order 1 has an extrusion effect on the industrial restructuring in the current period, but this effect is not obvious at the sub-regional level.

Based on the above findings, it is better for China to increase the intensity of R&D input, promote the rationalization of industrial structure and economic growth, and achieve positive interaction among the three, which will help China to build into a modern and powerful country with world-class competitiveness. Specifically, the following policy proposals are put forward.

Firstly, the eastern region should precisely grasp the direction of science and technology development and continually increase the investment in R&D funds to give full play to its technological innovation advantages. To cause economic development to promote long-term input in science and technology innovation and iron out the "U" shaped relationship between the two, the national finance should provide sufficient financial support for quality R&D projects that meet market demand, to provide a strong technical guarantee for economic growth and promote economic expansion and development quality improvement. In addition, to further strengthen the role of economic growth in empowering R&D input intensity, we should actively promote the transformation of the economic development mode and deepen the implementation of innovation-driven development strategy. Local governments should prudently set scientific medium- and long-term economic growth targets to realize the transformation of local development from efficiency-oriented to quality-oriented to ensure the sustainable development of all sectors of the national economy.

Secondly, the central region should increase the investment in enterprise R&D, support the accumulation of knowledge and transformation of innovation results, draw on the development experience of the developed eastern region, and continuously improve the supporting facilities for the innovation industry. To truly play the role of industrial structure optimization to promote economic growth, local governments should continue to drive the integrated development of strategic emerging industries and traditional industries, enhance the rationalization of industrial structure, and strive to get rid of the reliance on the rough and resource-based development path. At the same time, central provinces and cities should expeditiously formulate and improve policies for the introduction of talents in line with the actual local situation, encourage science and innovation enterprises to cooperate deeply with local universities and research institutes, strengthen the interaction and connection among R&D subjects, promote the collaborative development of industry–university–research, shorten the application cycle of scientific and technological inventions to the market, and better play the role of R&D innovation in the rationalization adjustment of industries.

Thirdly, as the R&D base in the western region is generally weak, we should rely on policies such as "construction of innovative provinces" to create innovation highlands with local characteristics. In view of the possible short-term negative impact of R&D input, the continuity and stability of government policy should be enhanced to support and increase the tilt of funds to remote and backward areas to strengthen the innovation foundation of the region and accelerate the rate of R&D and transformation of science and technology. At the same time, western provinces should actively undertake the industrial transfer from developed provinces, gradually abandon the backward processes and production capacity with high cost, high consumption, and heavy pollution, increase the proportion of tertiary industries, play the leading and guaranteeing role of industrial innovation in the process of economic growth, scientifically coordinate the relationship between technological innovation and rationalization of the industrial structure, and build an all-around innovative development model of "Industrial Upgrading + Economic Growth".

Author Contributions: Methodology, supervision, resources, X.Z.; software, validation, writing—original draft preparation, writing—review and editing, Z.Z. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: The study did not involve humans or animals.

Informed Consent Statement: Not applicable.

Data Availability Statement: The R&D investment, industrial structure rationalization, and economic growth data for the 30 provincial-level regions selected in this paper come from the China Statistical Yearbook and statistical yearbook of each province. Website: https://data.cnki.net/Yearbook/ (accessed on 3 May 2022).

Acknowledgments: This paper was supported by Hebei University in 2022.

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

References

1. Garces, E.; Daim, T.U. Impact of renewable energy technology on the economic growth of the USA. *J. Knowl. Econ.* **2012**, *3*, 233–249. [CrossRef]
2. Fu, Y.P.; Peng, Z.Q. Green Finance development, R&D investment and regional economic growth: An empirical study based on provincial panel threshold model. *Stat. Decis.* **2020**, *36*, 120–124.
3. Li, Z.T.; Yao, C.S.; Qian, S.S. R&D investment, construction land expansion and economic growth. *J. Lanzhou Financ. Econ.* **2017**, *33*, 73–86.
4. Zhang, Y.H. Dynamic analysis of R&D input and economic growth. *Sci. Manag. Res.* **2010**, *28*, 102–106.
5. Yang, W.J.; Jiang, X.Y.; Zhu, S.H. Industrial structure, macroeconomic instability and economic growth. *Stat. Decis.* **2022**, *38*, 112–115.
6. Wang, Z.; Wang, L.H.; Ma, Y.T. Economic Growth Effect of Coordinated Industrial Development—Empirical Study Based on the Coupling of Strategic Emerging Industries and Traditional Industries. *Southwest Univ. Soc. Sci. Ed.* **2020**, *46*, 69–78.
7. Zhuang, L.; Wang, F. Research on Technological Innovation, Financial Constraints and Industrial Structure. *J. Yunnan Financ. Econ.* **2020**, *36*, 40–50.
8. Tang, Q.Q.; Li, H.W. Research on the Internal Mechanism of Transformation and Upgrading of China's Industrial Structure—Based on Empirical analysis of Guangdong R&D investment and industrial structure. *Sun Yat-Sen Soc. Sci. Ed.* **2011**, *51*, 191–199.
9. Zhao, X.C.; Yuan, R. Impact of R&D Inputs and Technological Innovation on Industrial Structure Upgrading: Empirical Analysis Based on Provincial Panel Data in China. *Sci. Technol. Manag. Res.* **2021**, *41*, 1–7.
10. Jin, C.G.; Huang, W.X. Research on R&D Capital Investment Intensity and Export Trade of High-Tech Industry. *Technol. Econ. Manag.* **2022**, *5*, 16–20.
11. Wang, Z.; Wang, L.H. A Study on the Relationship Among R&D Input, Upgrading Industrial Structure and Carbon Emission. *Ind. Technol. Econ.* **2019**, *38*, 62–70.

12. Cohen, W.M.; Levinthal, D.A. Innovation and Learning: The Two Faces of R&D. *Econ. J.* **1989**, *99*, 569–596.
13. Iorweth, A.A. *Canada's Low Business R&D Intensity: The Role of Industry Composition*; Working Papers; Department of Finance: Ottawa, Canada, 2005.
14. Lucas, R. On the mechanism of economic development. *J. Monet. Econ.* **1988**, *22*, 13–42. [CrossRef]
15. Arrow, K.J. The Economic Implications of Learning by Doing. *Rev. Econ. Stud.* **1962**, *29*, 155–173. [CrossRef]
16. Xu, Q.Q. Impact of R&D investment and technological innovation on economic growth: An empirical study based on panel data from 30 regions in China. *Mod. Manag. Sci.* **2012**, *10*, 76–78.
17. Zhang, P. An empirical study on the impact of R&D investment on economic growth of industrial enterprises: Based on the data of industrial enterprises above scale in China from 2000 to 2012. *World Surv. Res.* **2014**, *12*, 9–12.
18. Li, Z.T.; Yao, C.S.; Wan, Z. R&D, local government fiscal intervention and provincial economic growth. *Nanjing Financ. Econ.* **2017**, *3*, 41–52.
19. Wan, Y.; Wen, Y.Q. Research and Development capital investment, Manpower investment and economic growth from a spatial perspective: An empirical study based on panel data. *Acad. Forum* **2014**, *37*, 29–33.
20. Xin, L.; Luo, S.G. Research on the Lag Effect of Economic Growth Caused by Scientific and Technological Innovation Based on Provincial Panel Data. *Mod. Manag.* **2020**, *40*, 39–42.
21. Wu, F.; Cao, M.; Ren, X.Y. The Impact of Local Economic Growth Goals on Enterprise R&D Investment and Its Mechanism: Based on the Paradigm of Development Mode-Performance Evaluation-Government Behavior-Economic Effect. *West. Forum* **2021**, *31*, 46–68.
22. Gan, C.H.; Zheng, R.G.; Yu, D.F. An Empirical Study on the Effects of Industrial Structure on Economic Growth and Fluctuations in China. *Econ. Stud.* **2011**, *46*, 4–16.
23. Pei, Y.F. Study on the Impact of Spatial Imbalance of Industrial Structure Change on Regional Economic Disparity in China. Quant. *Technol. Econ.* **2022**, *39*, 3–23.
24. Han, Y.H.; Huang, L.X.; Zou, J.H. The Advent of the Era of China's Economic Structural Slowdown. *Stat. Res.* **2016**, *33*, 23–33.
25. Zhang, R.; Li, A.L.; Li, G. Research on the Relationship Between Industrial Structure Upgrading and Economic Growth in China: Based on Semi-parametric Smooth Coefficient Model. *Econ. Prob.* **2019**, *5*, 19–27.
26. Li, C.G.; Yang, B.; Miao, Q.X. Economic Growth Effect of Technological Innovation and Industrial Structure Transformation—An Empirical Analysis Based on Dynamic Spatial Durbin Model. *Sci. Technol. Prog. Policy* **2019**, *36*, 33–42.
27. Zheng, R.; He, S.; Wang, X.J. The influence of China's industrial structure rationalization on Economic Growth—Based on the Perspective of Structural Deviation Improvement. *Commer. Econ.* **2017**, *18*, 164–166.
28. Wang, H. An empirical study on the relationship between industrial structure upgrading and economic growth. *Stat. Decis.* **2014**, *16*, 138–140.
29. Liu, W.L.; Yang, J.Y. Kirzner Arbitrage or Schumpeterian Innovation: The Impact of Entrepreneurship on the Quality of Economic Growth. *Stat. Res.* **2022**, *39*, 93–107.
30. Chang, J.X.; Lou, M.M. A Study on Employment Potentials in Industry Section in China. *Shanghai Financ. Econ.* **2004**, *3*, 32–38.
31. Chang, Z.Z.; Mao, P.; Zhang, J. An Empirical Study on Industrial Investment and Industrial Structure Optimization in China. *Hebei Econ. Bus.* **2018**, *39*, 31–44.
32. Benassy, J. Analytical solutions to a structural signal extraction model; Lucas 1972 revisited. *J. Monet. Econ.* **1999**, *44*, 509–521. [CrossRef]
33. Chinn, M.D.; Ito, H. Global Current Account Imbalances: American Fiscal Policy versus East Asian Savings. *Rev. Int. Econ.* **2008**, *16*, 479–498. [CrossRef]
34. Gan, C.H.; Zheng, R.G. An Empirical Study on Change of Industrial Structure and Productivity Growth since the Reform and Opening-up—A Test for the Structure-bonus Hypotheses from 1978 to 2007 in China. *Chin. Ind. Econ.* **2009**, *2*, 55–65.
35. Ba, S.S.; Wu, L.L.; Xiong, P.H. Government Subsidies, R&D Investment and Enterprise Innovation Performance. *Stat. Decis.* **2022**, *38*, 166–169.
36. Andrews, D.W.; Lu, B. Consistent model and moments selection procedures for GMM estimation with application to dynamic panel data models. *J. Econom.* **2001**, *101*, 123–164. [CrossRef]
37. Wang, X.D.; Wang, Y.R. Research on the Adjustment Effect of Fiscal Expenditure on Urban-Rural Income Gap: PVAR Model Test from Chinese Provincial Panel Data. *East Chin. Econ. Manag.* **2022**, *36*, 88–97.
38. Sun, H.Y.; Lei, Z.; Yang, Y.W. Technological Innovation, Local Government Behavior and Long term Economic Growth. *Stat. Decis.* **2022**, *38*, 113–117.
39. Zhang, X.Y.; Wang, Y.C.; Zhang, L. Coordination between Government Departments and the Allocation of Public Resources: Theory and Empirical Evidence. *Econ. Stud.* **2019**, *54*, 24–40.