Research on the Dynamic Interrelationship among R&D Investment, Technological Innovation, and Economic Growth in China

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Abstract: Technological innovation is an important driving force for a country’s sustainable economic development and social progress, and can be achieved through R&D investment, which would lead to sustainable economic growth. This process is one of the important steps for China to realize the transformation of the economic growth mode and the development from extensive to intensive type. Since R&D investment, technological innovation, and economic growth are mutually influential and inseparable, it is particularly important to understand the interrelationship between the three. By collating data from China from 1995 to 2016, this paper established an indicator system of R&D investment, technological innovation, and economic growth as research variables. Vector autoregression model, impulse response function, and variance decomposition function were adopted. A long-term stable dynamic interrelationship among the three was revealed. The empirical analysis showed that in recent years, the growth of R&D investment, technological innovation, and economic growth stagnated or even slowly declined, which indicated that the economic development had insufficient stamina. The conversion efficiency of R&D investment was not high, and R&D investment for short-term profit was ubiquitous. The innovation ability of scientific and technological achievements was not strong, the conversion rate of scientific and technological achievements was not high, and the market integration process was relatively slow. Overall, a good circular mechanism has not been established among R&D investment, technological innovation, and economic growth. Based on this, China should improve the mutual influence and interrelationship among R&D investment, technological innovation, and economic growth. The transmission mechanism among the three should be optimized and stable economic growth promoted, for example, by increasing R&D investment, enhancing the efficiency of R&D funds, improving the incentive system for scientific and technological innovation, and promoting the effective use and marketization integration of innovation achievements.

Keywords: sustainable economic development; R&D investment; technological innovation; economic growth; VAR model

1. Introduction

Technological innovation is an important embodiment of a country’s competitiveness. It has such characteristics as high difficulty of imitation, high added-value, and strong competitiveness, and is an important guarantee for sustainable economic development and national security. Since the founding of China, the Chinese government has carried out a series of effective attempts and strategic deployments for technological innovation. In recent years, technological innovation has been the strategic focus of long-term struggle. An innovation-driven development strategy proposed in 2012 [1] placed scientific and technological innovation as a strategic support for improving social
productivity and overall national strength and positioned such innovation at the core of China's overall development. In 2016, China published the “National Outline of the Innovation-Driven Development Strategy” [2], which proposed a multi-phase strategic deployment plan for technological development.

Owning to strategic planning and policy support, the environment for China’s technological innovation system has increasingly improved. The technology management structure and various scientific and technological plans have been optimized and integrated, and a sound supervision and evaluation system is being formed. The innovative project formation mechanism has achieved the deployment of a full chain integration from basic research to demonstration application [3]. The talent development environment has improved significantly, and the introduction of technological talents has achieved remarkable results. All kinds of Science and Technology Parks, Maker spaces, and technology business incubators and accelerators have been growing rapidly.

In recent years, with new changes in the international competition pattern, the drawbacks of the traditional Chinese economic growth model characterized by investment in exports have become prominent. Problems have emerged, including the excessive dependence of economic growth on exports, along with challenges related to increasing domestic market demand [4]. In addition, in the international market, China’s low-cost advantage has gradually weakened or even disappeared. The demand for the optimization and upgrading of China’s economic growth mode is becoming more urgent. At present, China is in a critical period of innovation-driven transformation and development. The economic development rate is slowing, and traditional industries are under great pressure as they face a downturn. In order to accelerate the transformation of economic development from low-cost advantage to innovation advantage as well as to improve economic quality and efficiency, there is an urgent need to further improve the technological innovation system and inject new impetus into economic development. Therefore, improving the technological innovation system are inherent requirements for sustainable economic development. Effective R&D investment will lead to technological innovation and ultimately economic growth. This path has become an important way to improve the economic development and competitiveness of a country or region. Thus, it is important to study the interrelationship among R&D investment, technological innovation, and economic growth.

In theory, there is a mutual influence among R&D investment, technological innovation, and economic growth. R&D investment can increase the resource endowment of innovation activities, optimize production conditions, and promote the output of technological innovation. Through the utilization of technological innovation achievements, such as patents and scientific papers, it is possible to achieve the goals of producing new products, reducing resource consumption, and reducing emissions of the three types of wastes, thereby achieving and increasing economic growth [4]. In addition, the improvement of patent output efficiency can generate incentives for R&D activities and promote more R&D investment. On the other hand, economic growth will make a country, region, and people more affluent and improve people’s living standards. Thus, more funds will be invested in scientific and technological innovation R&D activities, thereby promoting advances in technological innovation. Based on the research of Zhan et al. [4], the mechanism of influence among the three is shown in Figure 1, where the solid line represents the direct effect, and the dashed line represents the indirect effect.

Accordingly, this paper analyzed the interrelationship among China’s R&D investment, technological innovation, and economic growth from 1995 to 2016. In an attempt to ensure a more comprehensive perspective, the system development levels of R&D investment, technological innovation, and economic growth were obtained through the fitting of sub-indicators. By establishing the vector autoregression (VAR) model and using impulse response and variance decomposition analysis, this paper undertook a dynamic analysis of the correlation among the three systems. Through the results and analysis, the real status of technological innovation level in China could be revealed. It is of great use to guide the policy implementation and fill the gap for existing literature from a dynamic relationship and a more comprehensive perspective.
The study found that spending on technology investment played an important role in improving productivity, wherein the effect of R&D investment was significant. Guelec, et al. [14] compared the long-term effects of different types of R&D investments on productivity growth based on the statistics from 16 countries of the Organisation for Economic Co-operation and Development between 1980 and 1998. The results showed that every 1% increase in R&D investment could drive a 0.13 percentage point of increase in productivity. Xu and Zhou [15] examined the relationship between different types of public R&D investment and economic growth in China from 1991 to 2005. The study found a long-term equilibrium relationship between public R&D investment and economic growth in China. Lu and Jin [16] found that China’s R&D investment promoted economic growth, but...
the effect of R&D personnel investment was significantly higher than that of R&D funds investment. Zhang [17] used the gray relational method to explore the interrelationship among the various elements of high-tech industry innovation investment and the sales revenue of new products in China from 2000 to 2010. The study found that all the investment factors had obvious impacts on the innovation output of high-tech industries. Among them, the innovation efficiency of expenditure by R&D institutions was the most significant; the impact of personnel investment on high-tech industry innovation was less than that of R&D internal expenditure and new product development expenditure, but higher than that of technological transformation and acquisition expenditure. Batabyal and Yoo [18] analyzed the nature of research and development (R&D) that leads to Schumpeterian economic growth in Richard Florida, and found that process innovations lead to quality improvements in the machines used for producing a final consumption good. Fan, et al. [19] constructed a panel data model to examine the relationship between innovation and economic growth in the mining industry using data of 415 listed companies’ data in China from 2012 to 2014. The estimation results show that the innovation elements including government support, the technical employees’ rate and the technical assets rate have a significant positive effect on economic growth in the mining industry. Armeanu, et al. [20] examined several drivers of real gross domestic product (GDP) growth rate by panel data regression models and found that the total expenditure on R&D as well as employment rates of recent graduates contribute to sustainable development.

However, some scholars have pointed out that R&D investment cannot effectively promote economic growth and might even have a negative impact. For example, Aboody and Lev [21] and Wang and Wang [22] argued that for innovation activities, the probability of success was low, the risks of potential benefits were very high, and the risks were very likely to exceed the returns. Some studies have discussed the relationship between technological innovation and economic growth. Bosworth and Rogers [23] argued that the reason for the competitive advantage and performance difference among companies lies in their unique assets, including patents, know-how, reputation, and other monopoly resources. Reitzig [24] studied the German machinery manufacturing industry and concluded that having higher quality patents could improve a company’s business performance. Zhu et al. [25] concluded that patent output had a positive effect on performance based on the relevant data of the annual reports of listed pharmaceutical companies from 2006 to 2010, but the time lag period was not confirmed. Li and Xie [26] and Hu and An [27] showed that there was no significant correlation between the number of patent applications and the performance of Chinese companies. The results of Zhao et al. [28] showed that patent output had a negative effect on economic growth. Liu [29] used the panel data of 92 countries from 1970–2007 by the system generalized method of moments estimation and obtained the result that a positive and significant impact of IPRs protection on economic growth is found in both higher-income and lower-income countries. Niwa [30] analyzed the effect of patent protection for innovation and economic growth using a variety-expansion model. Results show that strengthening patent protection can raise the economic growth rate and social welfare through an endogenous survival investment.

Some researchers have studied the interrelationship among R&D investment, technological innovation, and economic growth. Griliches [31] studied 157 companies in the United States and concluded that R&D investment and patents had a positive impact on increasing the value of a company for the first time. Zhang [32] verified the interrelationship among Zhejiang’s technological R&D investment, patent output, and economic growth through empirical data. The research showed that different technological R&D input subjects had different effects on patent output. The authors further pointed out that the different effects of R&D investment and patent output significantly affected regional industrial economic growth performance. Xu and Tang [33] found that R&D activities and patent output could enhance a company’s value by studying the number of patents and patent types of listed companies in China. However, different types of patents showed different contributions. Pai and Luo [34] explored the influencing factors of knowledge outcomes (in the form of patents) and their impact on economic output using a two-stage research method. Based on data for operating
performance, R&D investment, patents, and investment amount of the six major industries in Taiwan’s Hsinchu Science Park from 1989 to 2012, Huang [35] found that the government’s R&D investment positively promoted the number of patents and business performance. However, there was only a weak correlation between the number of patents and business performance.

It can be seen that there is a complex and changing interrelationship among R&D investment, technological innovation, and economic growth owing to different environments and their own efficiencies. The following overall findings were discovered from the literature review. First, there are many studies on the interrelationship among R&D investment, scientific and technological innovation, and economic growth, but they have focused mainly on pairwise relationships. However, owing to technological changes, innovation involves three processes: (1) innovation investment, such as invested capital and human resources; (2) intermediate outputs, such as new inventions and new knowledge; and (3) innovative final outputs, such as increasing income and profit [11]. Therefore, separately researching the relationship between R&D investment and technological innovation, and the relationship between R&D investment and economic growth would miss the integrity of the research problem and result in the one-sidedness of policy attention. Second, almost all the existing literature has analyzed only the correlation or degree of influence of a single factor in the R&D investment system (capital investment and personnel investment) and a single factor in the output system (e.g., patent, new product sales, and main operating revenue). The lack of a holistic perspective cannot reflect the degree of correlation among R&D investment, technological innovation, and economic growth systems. Third, most research methods have failed to consider the existence of a certain lag among R&D investment, technological innovation, and economic growth, which makes it easy for the results to deviate from the actual situation. Fourth, previous studies have often explored the static pairwise relationships of the three variables, namely, technology R&D investment, technology patent, and economic growth. By comparison, deep analyses of the dynamic interrelationship among the three are lacking. Therefore, to explain the dynamic relationship between the variables effectively, a dynamic analysis of the correlation among the three variables was adopted in this paper, taking account of several related indicators. It could do help to policy making from a more comprehensive and dynamic perspective.

3. Methodology and Materials

3.1. Methodology

3.1.1. Entropy Method

The study selected the entropy method and fitted the corresponding indicators into the development level of a single system, which was then used as the research variable. The concept of entropy stems from thermodynamics. In 1948, C.E. Shannon [36] introduced information theory to measure system state uncertainty and named this theory information entropy. It is an objective weighting method that reflects the degree of dispersion of an indicator. We use information entropy to calculate the weight of each indicator and provide a basis for multi-indicator comprehensive evaluation. Suppose there are \( m \) plans to be evaluated and \( n \) evaluation indicators, and the original indicator data matrix is \( X = (x_{ij})_{m \times n} \). For an indicator \( x_j \), the larger the difference between indicator values \( x_{ij} \) is, the greater impact it has on the comprehensive evaluation. If the values of an indicator are all equal, then this indicator has no impact on the comprehensive evaluation. The specific calculation process is as follows.

1. In order to avoid the case in which data for the entropy value does not exist, a data shift is performed.
   For positive indicators (a larger value is better):
\[ X'_{ij} = \frac{X_{ij} - \min(X_{ij}, X_{2ij}, \ldots, X_{nj})}{\max(X_{ij}, X_{2ij}, \ldots, X_{nj}) - \min(X_{ij}, X_{2ij}, \ldots, X_{nj})} + 1, \quad i = 1, 2, \ldots, n; \quad j = 1, 2, \ldots, m \] (1)

For negative indicators (a smaller value is better):

\[ X'_{ij} = \frac{\max(X_{ij}, X_{2ij}, \ldots, X_{nj}) - X_{ij}}{\max(X_{ij}, X_{2ij}, \ldots, X_{nj}) - \min(X_{ij}, X_{2ij}, \ldots, X_{nj})} + 1, \quad i = 1, 2, \ldots, n; \quad j = 1, 2, \ldots, m \] (2)

2. Calculate the ratio of the jth indicator in the ith plan to the sum of the jth indicator.

\[ P_{ij} = \frac{X_{ij}}{\sum_{i=1}^{n} X_{ij}} \quad (j = 1, 2, \ldots m) \] (3)

3. Calculate the entropy of the jth indicator.

\[ e_j = -k \sum_{i=1}^{n} p_{ij} \ln(p_{ij}), \quad \text{where} \quad k > 0, \quad k = 1/\ln(n), \quad e_j \geq 0 \] (4)

4. Calculate the coefficient of variation of the jth indicator. The coefficient of variation is defined as

\[ g_j = \frac{1 - e_j}{m - E_{e}}, \quad \text{where} \quad E_{e} = \sum_{j=1}^{m} e_j, \quad 0 \leq g_i \leq 1, \quad \sum_{j=1}^{m} g_j = 1 \] (5)

5. Determine the weight of each coefficient of variation:

\[ \omega_j = \frac{g_j}{\sum_{j=1}^{m} g_j} \] (6)

6. Calculate the level of development of each variable:

\[ s_i = \sum_{j=1}^{m} \omega_j \cdot p_{ij} \] (7)

3.1.2. Vector Autoregression Model

The study aimed to empirically examine the interrelationship among R&D investment, technological innovation, and economic growth by establishing a three-variable VAR model. The traditional econometric method relies only on economic theory to describe the relationship between variables and cannot provide a strict explanation of their dynamic relationship. It also needs to consider modeling the hysteresis function of all endogenous variables for each endogenous variable in the system [37]. Therefore, it is very complicated to analyze economic problems with time series using traditional econometric methods. The VAR model constructs the model by using each endogenous variable in the system as a function of the hysteresis of all endogenous variables in the system. The model is not based on economic theory and does not distinguish between internal and external variables in advance. In this way, it can effectively control the complexity and difficulty of model estimation and analysis [38].

The mathematical expression of the VAR model is as follows:

\[ y_t = A_1 y_{t-1} + \ldots + A_p y_{t-p} + B_1 x_t + \ldots + B_r x_{t-r} + \epsilon_t \] (8)

where, \( y_t \) is an m-dimensional endogenous variable vector; \( x_t \) is a d-dimensional exogenous variable vector; \( A_1 \ldots A_p \) and \( B_1 \ldots B_r \) are matrices to be evaluated, and the endogenous variable and exogenous variable have p and r order lag periods, respectively; and \( \epsilon_t \) is the random disturbance term.
3.1.3. Impulse Response Function

In order to study the long-term dynamic interrelationship among R&D investment, technological innovation, and economic growth, the study aimed to use the impulse response function (IRF) to characterize and verify the long-term dynamic interactions among the three variables. The IRF expresses the influence of the current and future impact of a standard deviation of random disturbance terms on all endogenous variables of the model. IRF can clearly and intuitively describe the dynamic reaction process of each endogenous variable to its own change or that of other variables. IRF is defined as:

\[
I_Y(n, \delta, \omega_{t-1}) = E[Y_{t+n}|\epsilon_t = \delta, \epsilon_{t+1} = 0, \ldots, \epsilon_{t+n} = 0, \omega_{t-1}] - E[Y_{t+n}|\epsilon_t = 0, \epsilon_{t+1} = 0, \ldots, \epsilon_{t+n} = 0, \omega_{t-1}]
\]  

(9)

where, \(n\) is the impact response period; \(\delta\) refers to the impact from variables; \(\omega_{t-1}\) represents all the available information when an impact occurs; \(I_Y\) is the impulse response value of the \(n\)th period; and \(E\) is the expected value.

3.1.4. Variance Decomposition

In order to further understand the degree of mutual interaction among R&D investment, technological innovation, and economic growth, this study intended to use variance decomposition for the calculation. Variance decomposition was proposed by Sims in 1980. It quantitatively analyzes the contribution rate of the self-impact of a variable and the impact of other variables in the system to the fluctuation of each endogenous variable. Based on this, the relative importance of the impact of each variable on the endogenous variable can be understood. The basic idea is to decompose the predicted mean square error (MSE) of each endogenous variable in the system into \(m\) relevant parts, and then to determine the degree of contribution of each disturbance term relative to the overall variance. The relative importance of each piece of information to the endogenous variables of the model can thereby be obtained [38].

The s-step predicted variance of the VAR(\(p\)) model is

\[
\epsilon_{t+s} + \varphi_1 \epsilon_{t+s-1} + \varphi_2 \epsilon_{t+s-2} + \ldots + \varphi_{s-1} \epsilon_{t+1}
\]

(10)

Its MSE is

\[
\Omega + \varphi_1 \Omega \varphi_1' + \ldots + \varphi_{s-1} \Omega \varphi_{s-1}' = pp' + \varphi_1 pp' \varphi_1 + \ldots + \varphi_1 pp' \varphi_{s-1}
\]

(11)

where \(pp' = \Omega\). The predicted MSE of any endogenous variable can be decomposed into the impact contribution value of each variable in the system. Then, the relative importance of the impact of each variable is calculated, that is, the percentage contribution of the variable to the total contribution.

3.2. Materials

The sample time-series interval of the data analyzed in this study is from 1995 to 2016, and the data are sourced from the China Technological Statistical Yearbook and China Statistical Yearbook in the corresponding years. Under the premise of fully considering the availability of data, the representative indicators of R&D investment, technological innovation, and economic growth were selected for metrological analysis. Based on the objectivity, representativeness and the principle of availability of statistical data, the representative indicators were selected as follows.
3.2.1. Input Indicator

1. R&D investment system

R&D investment is an important indicator for evaluating a country’s overall national strength. It also reflects the potential of a region’s technological development and economic growth. As lots of literatures referred, such as Zhang [39] and Zhao, et al. [40], the R&D investment system consists of two parts: funding investment and personnel investment. Funding investment uses R&D expenditure in the relevant statistical yearbook as the measurement indicator, and personnel investment is measured by the full-time equivalent indicator of personnel. Moreover, since China began to implement large-scale innovation policies in 1998, the R&D investment before 1998 was very unstable. We simply use the mean method to adjust it.

2. Technological innovation system

The level of a technological innovation system can be characterized by scientific and technological achievements. According to the Science and Technology Development Center, Ministry of Education of the People’s Republic of China, scientific research can generally be divided into three parts based on tasks and methods, namely, basic research, applied research, and development research. The scientific and technological achievements of basic research are mainly based on papers, and the achievements of applied and development research are mainly based on patents [41]. Therefore, according to the research of Markovic, et al. [42] and Zhao, et al. [40], this study used the total number of Chinese papers and the number of papers published by Chinese researchers in domestic and foreign journals collected by the major international search engines as the measurement indicators of scientific and technological achievements of basic research. The number of patent applications and the number of patent grants were used as the measurement indicators of the achievements of applied and development research. These indicators could provide a relatively complete measurement of the technological innovation level.

3.2.2. Output Indicator

GDP is the core indicator of national economic accounting and is an important indicator of a country’s overall economic situation. Residents’ consumption level is an important criterion for measuring the living standards of people in all countries [40]. It is also an effective tool for grasping the macroeconomic performance of a country or region.

The evaluation indicator system of R&D investment, technological innovation, and economic growth is shown in Table 1.

| Target Layer | System Layer | Indicator Layer | Unit       |
|--------------|--------------|----------------|------------|
| R&D investment | R&D expenditure | 10,000 yuan |
|               | Full-time equivalent of personnel | People/year |
|               | Number of patent applications |
|               | Number of patent grants |
| R&D investment, technological innovation, and economic growth evaluation system | Total number of Chinese papers collected by major foreign search engines |
|               | Number of papers published by Chinese researchers in domestic and foreign journals collected by major foreign search engines |
| Economic growth | GDP | 100 million yuan |
|               | Residents’ consumption level | Yuan |
3.2.3. Variable Selection

By using the entropy method, the corresponding indicators were fitted to the development level of a single system, which was used as the research variable. The R&D expenditure (unit: 10,000 yuan) and the full-time equivalent of personnel (unit: people/year) were fitted to obtain the value of the R&D investment level, which was recorded as $F_1$. The number of patent applications and the number of patent grants were fitted to obtain the value of the technological innovation level, which was recorded as $F_2$. GDP (unit: 100 million yuan) and residents’ consumption level (unit: yuan) were fitted to obtain the value of the economic growth level, which was recorded as $F_3$. In order to make the data comparable and to reflect the actual growth effect of each indicator, the year 1995 was used as the base period. The expenditure portion of R&D investment, GDP, and residents’ consumption level over the years were adjusted according to the consumer price index in the corresponding year.

The natural logarithm of the data does not change the cointegration relationship among the variables. The relationship between the variables can be linearized. The logarithmic change of the original data can also eliminate the ubiquitous heteroscedastic phenomenon in the time series to some extent. Therefore, this study took the logarithmic of the data of the three variables, R&D investment, technological innovation, and economic growth, and the transformed indicators are recorded as $LNF_1$, $LNF_2$ and $LNF_3$, respectively.

4. Results

4.1. Development Level Trend

4.1.1. Development Level Trend

The development levels of R&D investment, technological innovation, economic growth over the years analyzed in this study were obtained using the entropy method, as shown in Table 2 and Figure 2. The figure shows that during the research period, although the three variables have different development levels, the overall trend is rising. They all developed from a development level of less than 0.1 in 1995 to a level above 0.8 in 2016.

| Variables | Max   | Min   | Mean  | Std.Dev |
|-----------|-------|-------|-------|---------|
| $F_1$     | 0.8240| 0.0140| 0.3132| 0.2752  |
| $F_2$     | 0.8300| 0.0052| 0.2459| 0.2570  |
| $F_3$     | 0.8145| 0.0282| 0.3181| 0.2583  |

Table 2. Summary statistics of variables selected, 1995–2016.

Figure 2. Development level curves of China’s R&D investment ($F_1$), technological innovation ($F_2$), and economic growth ($F_3$) from 1995 to 2016.
4.1.2. Growth Rate Fluctuation of Development Levels

By observing the growth rate fluctuation of the development levels of R&D investment, technological innovation, and economic growth during the research period (as shown in Figure 3), the changes in the growth of the development levels of the three variables were further understood.

![Figure 3. Growth rate of China’s R&D investment, technological innovation, and economic growth development level from 1996 to 2016.](image)

The growth rate of R&D investment declined greatly from 1996 to 2001 and was relatively unstable. From 2002 to 2009, the fluctuation was small, and the growth rate remained above 20%. From 2010 to 2013, the growth fluctuation became even less, and the overall growth rate remained above 10%. From 2014 to 2016, the growth rate was generally less than 10%.

The growth rate of technological innovation fluctuated greatly from 1996 to 2000 and was relatively unstable. From 2001 to 2006, the fluctuation gradually slowed. However, the growth rate in the above two time periods basically remained above 20%. From 2007 to 2016, the growth rate was nearly stagnant. In recent years, the growth rate even had historically low values (5.0% in 2014 and 13.2% in 2016).

After a short-term decline in the rate of economic growth from 1996 to 2007, the fluctuation stagnated and remained at around 20%. The rate of economic growth after 2008 showed a downward trend and was only 7.7% in 2016.

Thus, the growth rate of the three variables experienced large fluctuations in the early years. Moreover, in the past decade, the trend has been slow or even declining. In particular, the growth rate of the development level of R&D investment and economic growth declined more obviously in the later period.

4.2. VAR Model for R&D Investment, Technological Innovation, and Economic Growth

The stationarity test (i.e., the unit root test of the three analytical variables) should be performed before establishing the VAR model. The most common test, the Augmented Dickey–Fuller (ADF) test was used in this study. Considering the sample size limit, the maximum lag order was 3. The test results are shown in Table 3.

**Table 3.** Augmented Dickey–Fuller (ADF) test results of the vector autoregression (VAR) model for R&D investment, technological innovation, and economic growth development levels.

| Variable Sequence | ADF Test  | Significance Level of 5% | Lag Period | Conclusion |
|-------------------|-----------|--------------------------|------------|------------|
| LNF1              | −7.3572   | −3.0123                  | 0          | Stationary |
| LNF2              | −4.0971   | −3.0300                  | 2          | Stationary |
| LNF3              | −7.2375   | −3.0124                  | 0          | Stationary |
The test results showed that in the sample interval, \( LNF_1 \), \( LNF_2 \) and \( LNF_3 \) had all passed the significance test, and hence rejected the presence of a unit root at a significance level of 5%. Therefore, all these three variables are stationary time series.

In this study, the VAR models are three two-way variable systems, including variables of the R&D investment level, technological innovation level, and economic growth level. Three independent VAR models were constructed using \( LNF_1 \), \( LNF_2 \) and \( LNF_3 \). According to information criteria (AIC and SC), and take the limit of time series lengthen into consideration, the optimal lag period of the model was chosen to be 3. The results are shown in Table 4. The VAR (3) model was established.

Table 4. Decision results of the optimal lag order for VAR.

| Lag | LogL   | LR    | FPE     | AIC     | SC     | HQ     |
|-----|--------|-------|---------|---------|--------|--------|
| 0   | 32.9390| NA    | 8.59e−06| −3.1515 | −3.0024| −3.1262|
| 1   | 107.4460| 117.6426| 8.86e−09| −10.0470| −9.4505| −9.9460|
| 2   | 121.1941| 17.3660| 5.88e−09| −10.5467| −9.5029| −10.3701|
| 3   | 147.3018| 24.73368 *| 1.24e−09 *| −12.34756 *| −10.85634 *| −12.09519 *|

Notes: * indicates lag order selected by the criterion.

The parameters of the dynamic equation were estimated using EVIEW 8.0. The results are shown in Table 5. Observed from the model fit (0.9988, 0.9988, 0.9998), the VAR model fitted well. In addition, the reciprocal of all roots is less than 1, which is shown in Figure 4. Within the unit circle, the VAR (3) model is stable. It can be seen that during the research period, although R&D investment, technological innovation, and economic growth showed complex and changing states, overall, the system development level of the three variables constituted a stable system.

Table 5. VAR dynamic equation parameter estimation results.

| Variable Sequence | LNF3     | LNF1     | LNF2     |
|-------------------|----------|----------|----------|
| \( LNF_1 \) (−1)  | 0.8073   | 0.0173   | 0.0798   |
|                   | −0.4777  | −0.6390  | −0.1819  |
| \( LNF_1 \) (−2)  | 0.0236   | −0.5369  | 0.2287   |
|                   | −0.4531  | −0.6060  | −0.1725  |
| \( LNF_1 \) (−3)  | −0.4314  | −0.0358  | −0.4148  |
|                   | −0.2742  | −0.3668  | −0.1044  |
| \( LNF_2 \) (−1)  | −0.0531  | −0.1782  | 0.0935   |
|                   | −0.1972  | −0.2638  | −0.0751  |
| \( LNF_2 \) (−2)  | −0.0337  | 0.3752   | 0.1024   |
|                   | −0.1525  | −0.2040  | −0.0581  |
| \( LNF_2 \) (−3)  | 0.2293   | 0.3217   | 0.1873   |
|                   | −0.2145  | −0.2869  | −0.0817  |
| \( LNF_3 \) (−1)  | 0.4097   | 1.0976   | 0.7403   |
|                   | −0.7775  | −1.0400  | −0.2960  |
| \( LNF_3 \) (−2)  | −0.4485  | −1.6277  | −0.7119  |
|                   | −0.7115  | −0.9518  | −0.2709  |
| \( LNF_3 \) (−3)  | 0.4343   | 1.6144   | 0.4729   |
|                   | −0.4594  | −0.6145  | −0.1749  |
| C                 | 0.1205   | 0.3758   | 0.0788   |
|                   | −0.0593  | −0.0794  | −0.0226  |
| R-squared         | 0.9988   | 0.9988   | 0.9998   |
4.3. Impulse Response Analysis

Through the IRF, this study described the dynamic impact trajectory and the long-term dynamic interrelationship among R&D investment, technological innovation, and economic growth. The impact response period was set to 10 in this paper. The analysis results are shown in Table 6 and the response curves are shown in Figure 5. The blue line in the figure represents the level of the IRF and the red lines represent the two standard deviation band.

Table 6. Impulse response function results.

| Period | Response of LNF₁ to LNF₂ | Response of LNF₂ to LNF₁ | Response of LNF₁ to LNF₂ | Response of LNF₂ to LNF₁ | Response of LNF₁ to LNF₃ | Response of LNF₂ to LNF₃ |
|--------|---------------------------|---------------------------|---------------------------|---------------------------|---------------------------|---------------------------|
| 1      | 0.0000                    | 0.0448                    | 0.0000                    | 0.0030                    | 0.0000                    | 0.0122                    |
| 2      | −0.0008                   | 0.0062                    | 0.0122                    | 0.0058                    | 0.0045                    | 0.0167                    |
| 3      | −0.0007                   | −0.0088                   | −0.0111                   | 0.0057                    | 0.0014                    | 0.0220                    |
| 4      | 0.0085                    | 0.0134                    | 0.0083                    | 0.0096                    | 0.0024                    | 0.0113                    |
| 5      | 0.0092                    | −0.0178                   | 0.0117                    | 0.0086                    | 0.0067                    | −0.0045                   |
| 6      | 0.0123                    | 0.0033                    | 0.0004                    | 0.0107                    | 0.0031                    | −0.0098                   |
| 7      | 0.0127                    | 0.0071                    | −0.0001                   | 0.0097                    | 0.0025                    | −0.0067                   |
| 8      | 0.0118                    | −0.0017                   | 0.0075                    | 0.0084                    | 0.0037                    | −0.0076                   |
| 9      | 0.0087                    | −0.0044                   | 0.0010                    | 0.0061                    | 0.0026                    | −0.0050                   |
| 10     | 0.0077                    | 0.0067                    | 0.0034                    | 0.0057                    | 0.0017                    | −0.0017                   |
| Total  | 0.0694                    | 0.0487                    | 0.0333                    | 0.0734                    | 0.0286                    | 0.0269                    |

Figure 4. AR roots graph of the VAR model.
4.3.1. Analysis of Impulse response function results

1. Impact influence between R&D investment and technological innovation

In terms of the response of R&D investment to the impact from technological innovation, the response in the current period was 0, then reduced and turned negative to 0.0007 in the third period. Thereafter, the value increased rapidly to 0.0127 in the seventh period and then dropped slowly and tended to be flat till the tenth period (0.0077). In terms of the response of technological innovation to the impact from R&D investment, the value reached the maximum (0.0448) in the current period and then turned negative to −0.0088 in the third period. Thereafter, it showed a wave-like development and the overall trend was declining. So the changes in R&D investment immediately had the maximum impact on technological achievements, and overall, the short-term influence was greater.

It can be seen that the changes in the technological innovation achievement promoted inhibited R&D investment in the short term, and the impact was larger in the long term. However, the changes in R&D investment immediately had the maximum impact on technological achievements, and overall, the short-term influence was greater.
2. Impact influence between technological innovation and economic growth

In terms of the response of technological innovation to the impact from economic growth, the response in the current period was 0, and increased rapidly to 0.0122 in the second period. Then the response declined to a negative value of $-0.0111$ and increased until the fifth period. Thereafter, a wave-like fluctuation trend was showed. At last, it was 0.0034 and tended to be flat. The level of this impact was very low during these periods.

In terms of the response of economic growth to the impact from technological innovation, the response in the current period was 0.0030 and then increased to 0.0107 in the sixth period. Thereafter, it declined slowly and tended to be flat in the last period (0.0057 in the tenth period). It can be found that there could be long term for the impact from technological innovation on economic growth to reach the maximum value.

3. Impact influence between R&D investment and economic growth

In terms of the response of R&D investment to the impact from economic growth, the response increased from 0 in the first period to 0.0045 in the second period. It then gradually declined and reached 0.0024 in the fourth period. Thereafter it increased to the maximum value of 0.0067 and declined soon. At last the impact was 0.0017 and tended to be flat. The level of this impact was very low during these periods.

In terms of the response of economic growth to the impact from R&D investment, the response rapidly increased from 0.0122 in the first period and reached the maximum of 0.0220 in the third period. It then declined to a negative value of $-0.0045$ since the fifth period till the end. It tended to be flat in the last few periods ($-0.0017$ in the tenth period). Therefore, it is obvious that the short-term influence of R&D investment to the economic growth was larger. And the overall influence level of the impact from R&D investment on economic growth was very low.

4.3.2. Cumulative Effect of Impulse Response

From the cumulative effect of impulse response, R&D investment had the weakest influence on economic growth, and followed by the influence of economic growth on R&D investment. The impact influence between R&D investment and economic growth was the lowest in this system. It can be further seen that the output efficiency of R&D investment was very low, and the R&D investment resources were not rationally planned or utilized.

4.4. Variance Decomposition Analysis

Variance decomposition analyzes the contribution of each structural impact to the endogenous variables. It is used to further evaluate the importance of different factors. The variance decomposition results of the VAR model established from R&D investment, technological innovation, and economic growth are shown in Table 7.

| Period | LNF1 | LNF2 | LNF3 | LNF1 | LNF2 | LNF3 | LNF1 | LNF2 | LNF3 |
|--------|------|------|------|------|------|------|------|------|------|
| 1      | 100.0000 | 0.0000 | 0.0000 | 57.8430 | 42.1570 | 0.0000 | 53.0622 | 3.2976 | 43.6403 |
| 2      | 99.3798  | 0.0179 | 0.0022 | 55.7617 | 40.2097 | 4.0286 | 64.8165 | 6.5300 | 28.6535 |
| 3      | 99.4624  | 0.0254 | 0.0122 | 51.2951 | 42.1476 | 6.5573 | 77.4696 | 6.0866 | 16.1218 |
| 4      | 98.0133  | 1.4273 | 0.5595 | 51.2640 | 41.1490 | 7.5869 | 74.4088 | 11.9885 | 13.6227 |
| 5      | 95.6369  | 2.9776 | 1.3855 | 50.8200 | 39.9140 | 9.2681 | 69.8604 | 15.9454 | 14.1943 |
| 6      | 92.8682  | 5.6226 | 1.5091 | 50.6582 | 40.1397 | 9.2021 | 66.4384 | 20.4470 | 13.1147 |
| 7      | 90.2417  | 8.2033 | 1.5550 | 48.7739 | 42.5325 | 8.6936 | 63.6262 | 23.8531 | 12.5207 |
| 8      | 88.3484  | 9.9763 | 1.6753 | 48.1410 | 42.2698 | 9.5893 | 62.2537 | 25.7878 | 11.9585 |
| 9      | 87.5475  | 10.7426 | 1.7099 | 47.3860 | 43.2247 | 9.3893 | 61.5001 | 26.7733 | 11.7266 |
| 10     | 86.8029  | 11.4736 | 1.7236 | 47.3117 | 43.2730 | 9.4154 | 60.5232 | 27.8018 | 11.6750 |
| Mean   | 93.8301  | 5.0467 | 1.1232 | 50.9255 | 41.7017 | 7.3729 | 65.3959 | 16.8833 | 17.2288 |
4.4.1. Analysis of Variance Decomposition Results

The results of the variance decomposition show that among the influencing factors of R&D investment fluctuations, R&D investment itself accounted for 100% in the first period and its proportion decreased slowly thereafter. Till the tenth period, the R&D investment itself remains the largest part (86.8029%) in the proportion. The proportion of technological innovation kept in a very low level at the first four periods (from 0 to 4.209% but increased quickly to 11.4736% till the end. The proportion of economic growth was very small during all these periods.

Among the influencing factors of technological innovation fluctuations, technological innovation itself accounted for 57.8430% in the first period. And R&D investment accounted for 42.1570%. In later periods, the proportions of these two factors changed very little. The proportion of the economic growth increased from 0 to 9.2661% during the first five periods. And it was stable and changed little thereafter.

Among the influencing factors of economic growth fluctuations, the proportion of R&D investment was consistently largest from the first period (53.0622 to the last period (60.5232%).

The proportion of technological innovation increased rapidly, from 3.2976% in the first period to 27.8018% in the last period. And the influence of economic itself decreased all these periods, from 43.6403% to 11.6750% in the tenth period.

4.4.2. Mean Value Analysis of Variance Decomposition

The mean values of the variance decomposition results showed that the overall fluctuation of R&D investment was most affected by R&D investment itself (93.8301%), followed by technological innovation (5.0467%), and economic growth (1.1232%). The overall fluctuation of technological innovation was most affected by R&D investment (50.9255%), followed by technological innovation (41.7017%), and economic growth (7.3729%). The overall fluctuation of economic growth was most affected by R&D investment (65.3959%), followed by economic growth (17.7208%), and technological innovation (16.8833%).

The variance results showed that the fluctuations of R&D investment and technological innovation were mainly affected by themselves. Furthermore, the economic growth relied more on the R&D investment. Therefore, there is no good transmission system established among the three.

4.5. Robustness Examination

In this paper, we tried to test the stability of the results by substituting variables and reducing indicators to change the values of variables. For example, we replaced the consumption level with per capita GDP and removed the index of papers published to change the variable value. It was found that the interrelationship of variables in this model did not change much, which supports the conclusions of the previous study, and the empirical results are robust.

5. Discussion of Empirical Results

Based on time-series data of China’s technological R&D investment, technological innovation, and economic growth system from 1995 to 2016, this study measured their respective development levels and established a three-system VAR model of R&D investment, technological innovation, and economic growth. The impulse response and variance decomposition methods were used to measure the long-term dynamic interrelationship among the three variables. From the results and data analysis, it can be found that although there was a stable interrelationship among R&D investment, technological innovation, and economic growth, a good transmission mechanism has not been established and the innovation system has not been very effective.

The main results are presented as follows. First, during the research period, R&D investment, technological innovation, and economic growth development levels all showed a trend of continuous growth. The growth rates of the three variables experienced large to small fluctuations, but in the later
period, they showed a trend of continuous decline. The growth rate of R&D investment and economic growth development levels showed even more obvious declines. In 2017, China’s R&D investment intensity was 2.12%, increasing by 0.01 percentage points compared with the previous year. However, there is still a large gap compared with the investment intensities of innovation-oriented countries, such as Israel (4.25%), South Korea (4.23%), and Japan (3.49%). In particular, China’s basic research funding is still relatively low. In 2017, China’s basic research funding was 92 billion yuan, accounting for 5.3% of R&D funds, reaching the highest level in the past decade. However, compared with the proportion of 15–25% in developed countries, there is still a big gap.

Second, R&D investment brought many short-term technological innovation achievements and profits. Besides, the impact influence between R&D investment and economic growth was the lowest in this system. Its impact had a small influence on economic growth. Therefore, it can be observed that R&D investment resources were not rationally planned or utilized, resulting in a large number of scientific and technological innovations with low technological content or lack of actual economic value. R&D investment mostly concentrated on innovative activities with low technological content and rapid economic benefits, such as the follow-up R&D of intermediate products, the change of product image appearance, or the localization and adaptation of products. Only short-term profits could be obtained, and the overall benefit generated by investment was very low. Therefore, the impact of R&D investment is not reasonable and sustainable, which is not benefit for China to upgrade its economic growth mode as the innovation-oriented country in the future.

Third, technological innovation had an inhibiting effect on R&D investment in the short term, and there would be long term for technological innovation to realize to its maximum impact on economic growth Therefore, a long market integration period is necessary. It can be seen that technological innovation has failed to play its due role in leading economic development. Therefore, although technological innovation achievements have shown a rising trend over the years, their role in promoting the economy is still not ideal. Compared to developed countries, although the total number of paper citations and international invention patents is large, the overall quality and economic conversion rates are not high, and the market integration process is relatively slow.

6. Concluding Remarks

The empirical results and analysis verified the status quo of China’s scientific and technological innovation development. For a long time, technological development and economic development were disconnected from each other. The focus was only on investment in technological projects, rather than on how scientific and technological achievements could better form independent intellectual property rights and be turned into actual productivity and core competitiveness. The conversion efficiency of R&D investment is not high, and R&D investment for short-term profit is ubiquitous. There is a lack of core technologies with independent intellectual property rights. The conversion rate of technological achievements is not high, and the market integration process is relatively slow. Therefore, although China achieved initial results in implementing an innovation-driven development strategy, there is still a considerable distance away from its goal of becoming an innovation-oriented country. The state of China’s reliance on others for core technologies has not been changed. It is necessary for China to orient toward improving the interaction among R&D investment, technological innovation, and economic growth as along with their development, thereby improving the transmission mechanism among the three, and promoting stable economic growth. The following suggestions are made to further promote the development of China’s R&D activities and technological innovation, promote the transformation and upgrading of industrial structure, and achieve steady economic growth.

First, the government should continue to carry forward the optimization and integration of technological plans, as well as promote the formation of a joint planning and supervision platform. To improve a mutual influence relationship among R&D investment, technological innovation, and economic growth, it is necessary to pay attention to resource conversion efficiency at every stage. Any biased focus on management and investment would not be conducive to the coordinated
development of the three variables. Therefore, it is necessary to overcome problems caused by traditional management methods, such as a large number of regulatory departments, fragmented resource allocation, and lack of concentration on strategic objectives. By continuing to promote the optimization and integration of technological plans as well as a joint national and regional regulatory supervision platform, complicated research fund management can be united and form an entire process system of monitoring and evaluation.

Second, the government should continue to strengthen R&D investment intensity and improve the use efficiency of R&D funds as well as the pertinence and effectiveness of R&D funding through the reform of the scientific research project management system. With regard to R&D investment intensity, the government should encourage enterprises and institutions to strengthen basic research experiments, R&D for cutting-edge technology with a long scientific research cycle, and products with high added value in the industrial value chain. Government finance could adopt policies to grant more subsidies and reduce taxes. At the same time, in order to broaden the source of R&D funds, financial institutions, such as loan guarantee companies and investment service companies, can be set up to gather idle social funds, attracting private capital to invest in R&D institutions or enterprises. Thus, a fully market-based industry investment and financing operation system can be formed.

Besides, the government should actively promote the industry-University-Research collaboration and build an industrial agglomeration area composed of enterprises and research institutions with a high correlation degree in the industrial value chain. Therefore, the R&D overlapping investment and other costs of relevant scientific research institutions and enterprises could be reduced.

Third, the government should improve and optimize the evaluation system to upgrade scientific and technological innovation achievements. For example, we could raise the threshold for patent certification to have higher creativity requirements for technical solutions seeking protection in patent applications. In addition, the government should revise the past practice of using the number of scientific and technological achievements as a performance appraisal indicator. Instead, we should take the improvement of quality, practical value, or economic value as the basis for assessments and rewards. Thus, the R&D investment could be brought forward to the products with higher technology.

Besides, the government should effectively make full use of technological innovations achievement and create a platform for sharing as well as trading technical information and technological achievements. For example, establish a sound regional technology trading market and intellectual property trading center. The government should establish a relatively complete internal management operation mechanism to ensure that the transaction process is carried out simply and efficiently. At the same time, the government procurement system should pay equal attention to technology procurement and product procurement. They should create and expand market demand for technological innovation achievements, while guiding market demand and promoting the market integration of technological innovation achievements. In addition, local governments could help companies to explore overseas markets through good cooperation with overseas governments. The government should grant appropriate export subsidies and tax rebates for exported products, and exempt imported products for which it does not currently have production capacity from import tariffs. Such policies could maximize the economic benefits and promote technological innovation for overall economic growth.

In addition to the above, more policies should be enforced to improve the interrelationship among R&D investment, technological innovation, and economic growth. For instance, the local government could improve the existent talent introduction policy according to the regional situation, and at the same time, increase the preferential support on talent residence as well as welfare subsidies. Efforts could be made to encourage foreign capital to enter local industries, providing domestic enterprises with more opportunities to cooperate with multinational companies. Thus, more market opportunities could be gained and the cost of technology acquisition would be reduced, through the foreign spillover effect. Moreover, the government should continue to carry out the goal of eliminating backward production capacity, to promote industrial restructuring and upgrading.
The study limitation of this paper comes from index selection towards each variable. As impulse response and variance decomposition are chosen to reflect the dynamic development process, the selected time series must be very stable. Therefore, the choice of indexes for variables is limited to some extent, so that the different aspects of development level and relationship of each system cannot be fully estimated. Therefore, more appropriate and comprehensive index selection, or alternative ways to express the dynamic relationship of the system, will become a breakthrough problem in future research.

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