Empirical Research on Innovation Efficiency in China Based on SFA Model

Jiawei Wang*, Dongyang Han and Yifan Wang

School of Management, Wuhan university of technology, Wuhan, Hubei, 430000, China

*Corresponding author’s e-mail: 974173090@qq.com

Abstract. To study the specific situation of China's innovation efficiency over the years, and explore the impact of state-owned enterprise-scale, tax incentives, regional export environment, R&D funds and R&D personnel on innovation activities, this paper selects the panel data of provinces and cities from 2009 to 2015, divides innovation activities into scientific research and development stage and value realization stage, and constructs SFA model for research. The results show that China's innovation level is in the range of 0.5-0.8, and the overall development is unbalanced and uncoordinated. The government's capital investment has an obvious promotion impact on the local innovation efficiency, and the effect of other factors varies from stage to stage. Finally, according to the research results, the existing problems are analysed, and substantive suggestions are put forward.

1. Introduction
Since the implementation of the innovation-driven development strategy, China's achievements in innovation are obvious. Under the strategic background of innovation-driven development, only efficient innovation activities can give more significant support to China's economic growth. Government support is a useful supplement to market failure. On the one hand, it makes up for the dilemma of weak market incentives for innovation subjects, and plays an incentive effect of reducing the input cost of subjects and sharing market risks [1]; On the other hand, it has played a regulatory role in adjusting the direction of industrial development, optimizing the allocation structure of innovative resources and enhancing the vitality of economic growth [2]. Academia tends to divide the government's innovative activities into different categories, involving talent introduction, intellectual property protection, financial support, direct subsidies, tax incentives, etc. Existing research shows that the effect of China's innovation-driven policy is unstable. Wang Zhixin and others [3] pointed out that there is always a natural and inseparable close connection between intellectual property protection and innovation-driven development. Wang Jingsheng [4] pointed out that strengthening the introduction and protection of talents will provide a steady stream of the powerful driving force for regional innovation development and gradually form a virtuous circle. However, some scholars had demonstrated that the government's innovation-driven cannot effectively promote the improvement of innovation efficiency. For example, Xiao Wen and other [5] scholars had found that the tendency of fiscal policy to specific innovation activities and government intervention distort the effective allocation of resources in various stages of innovation, and may not be able to realize the initial promotion of fiscal policy to innovation efficiency. According to previous studies by scholars, environmental factors such as the nature of state-owned property rights, the intensity of preferential tax policies, and the intensity of regional exports have certain effects on the innovation process of
enterprises [6]. The inclination of fiscal policy allows high-risk and high-complexity R&D activities to obtain risk compensation, to a certain extent, alleviates information asymmetry, reduces investment costs and investment risks in the process of enterprise innovation, and further encourages more R&D investment. And high-level R&D investment further promotes the output of patent achievements [7]. State-owned and state-controlled enterprises' residual control and claim over innovation, as well as the strong bureaucratic promotion mechanism, have led to the failure of the incentive mechanism [8], thus weakening the role of tax incentives in promoting innovation. Trade export drives not only economic growth, but also supports technological progress [9]. Under the "self-selection effect" and "export learning effect", enterprises realize product technology and even technological innovation [10], which is more conducive to stimulating high-tech patent output efficiency.

Whether the government's innovation-driven activities are effective has gradually become the focus of research. Therefore, this paper divides the process of innovation value creation into two stages: scientific and technological research and development and value realization. In this paper, we use the stochastic frontier analysis method to examine the effect of innovation factors in each province, such as preferential tax policies, nature of state-owned property rights, the export intensity of industries, and input of R&D personnel on innovation efficiency. Finally, we discuss the internal relationship between each factor and innovation efficiency deeply.

2. Research design

2.1. Research samples and data sources

In this study, panel data of 30 provinces in China for a total of seven years from 2009 to 2015 are selected. As the data of Tibetan autonomous region in Tibet are too seriously missing, so this province is excluded, and a total of 210 observations are obtained. The data used are all from the Statistical Yearbook of Scientific and Technological Activities of Industrial Enterprises and are compiled manually by the author. For the above samples, Frontier4.1 software was used to calculate and analyse.

2.2. Model Setting

The stochastic frontier production function model in this study is set as follows:

\[
\ln \text{Patent}_i = \beta_0 + \beta_1 \ln \text{RD}_i + \beta_2 \ln \text{Labor}_i + \varepsilon_{it}
\]  
\[
\ln \text{Income}_i = \beta_0 + \beta_1 \ln \text{RD}_i + \beta_2 \ln \text{Labor}_i + \varepsilon_{it}
\]  

Equation (1) and (2) are SFA models for the scientific research and development stage and the value realization stage respectively, in which patent and income represent the output of the two steps respectively, RD represents the government funds in R&D funds input, labor represents the input of scientific and technical personnel, \( i \) and \( t \) indicate the order of industry and year. \( \beta_0 \) is a constant to be estimated, \( \beta_1 \) and \( \beta_2 \) represent R&D funds and the output elasticity of R&D activists respectively. \( \varepsilon_{it} = V_i - U_t \) is a random error term, \( V_i \) refers to the noise error impacted by uncontrollable factors in the economic system, obeys the normal distribution \( N(0, \sigma^2_i) \), and is independent of \( U_t \); \( U_t \) is a non-negative random variable, which inspects the technical inefficiency in R&D activities and obeys truncated normal distribution \( N(M, \sigma^2_u) \), \( e^{-M} \). Indicates the technical efficiency of the industry's R&D activities during the \( t \) period. The greater the \( M \), the lower the technical efficiency, i.e. the higher the degree of technical inefficiency, which means the less R&D output that can be obtained by investing the same amount of R&D capital and R&D personnel. For the influencing factors of inefficiency, the influences of the nature of state-owned property rights, regional export intensity and tax preference intensity on the inefficiency of R&D activities are mainly considered. The inefficiency function is set as follows:

\[
\text{MP}_i = \lambda_0 + \lambda_1 \ln \text{property}_i + \lambda_2 \ln \text{expr}_i + \lambda_3 \ln \text{tax}_i + \omega_i
\]  
\[
\text{MS}_i = \lambda_0 + \lambda_1 \ln \text{property}_i + \lambda_2 \ln \text{expr}_i + \lambda_3 \ln \text{tax}_i + \omega_i
\]  

\( \lambda_0 \) is the constant term to be estimated, \( \lambda_1, \lambda_2 \) and \( \lambda_3 \) respectively represent the influence coefficients of the above variables on the R&D inefficiency term. If the coefficient of a certain variable is positive, it indicates that the variable has a positive influence on the inefficiency term, that is, the variable has a
negative influence on the R&D efficiency. \( \omega_t \) is a random error term subject to normal distribution. In the formula \( \gamma = \sigma_u^2 / (\sigma_u^2 + \sigma_v^2) \), the closer \( \gamma \) is to 1, indicating that the inefficiency term accounts for the main component in the deviation between the production unit and the front surface, and the stochastic front function model is the most suitable at this time. If \( \gamma \) is close to 0, the traditional production function can be used.

2.3. Variable setting
There are 7 variables set up in this study, which can be divided into two categories according to types. The variables characterizing innovation efficiency include government research and development input (RD), scientific and technological personnel input (labor), patent for invention and new product output efficiency (income). The control variables include state-owned enterprise scale (property), export intensity (expr) and tax preference intensity (TAX), as shown in Table1.

Table 1. Variable Settings

| Name | Definition |
|------|------------|
| RD   | Government R&D Investment, Government Funds in Internal Expenditure of R&D Funds/Internal Expenditure of R&D Funds |
| labor | Science and technology personnel input, R&D personnel equivalent to full-time equivalent/average R&D personnel equivalent to full-time equivalent |
| patent | Invention patent ratio, application amount of invention patent/total application amount of patent |
| income | Output efficiency of new products, sales revenue of new products/expenditure on new product development |
| property | Scale of state-owned enterprises, sales revenue of new products of state-owned enterprises/sales revenue of local new products |
| expr | Export intensity, new product sales revenue (export)/local new product sales revenue |
| tax  | Tax preference intensity, (using research and development funds from government departments+research and development expenses plus deduction of tax reduction and exemption+tax reduction and exemption for high-tech enterprises) /R&D funds internal expenditure |

3. Empirical Results and Analysis

3.1. descriptive statistics
Table 2 describes the data of the main variables as follows.

Table 2. Descriptive Statistics of Main Variables

| variable | Observations | Mean  | Std. Dev. | Min  | Max   |
|----------|--------------|-------|-----------|------|-------|
| tax      | 210          | 39.480| 46.866    | 0.245| 286.018|
| RD       | 210          | 9.686 | 9.467    | 0.024| 40.914|
| labor    | 210          | 6.899 | 9.275    | 0.053| 44.130|
| patent   | 210          | 5415.338| 9190.143 | 23.000| 55624.000|
| income   | 210          | 3638.813| 4869.455 | 8.566| 24463.270|
| property | 210          | 1196.209| 1112.722 | 0.165| 5590.798|
| expr     | 210          | 697.429| 1372.609 | 0.000| 7484.136|

3.2. Empirical Results
The results of econometric analysis are shown in Table 3, where M1 represents the scientific and technological research and development stage with the number of patent applications as the output
variable, and M2 represents the value realization stage with the sales revenue of new products as the output indicator. From Table 3, it can be seen that $\gamma=0.02$ for M1 but not significant, $\gamma=0.9$ for M2 and significant at the level of 1%, which indicates that the error term in this research model has a very obvious composite structure, and SFA method is necessary for estimation.

It shows that $\beta_1=0.3842$ and is significant at the level of 1% and $\beta_2$ is not significant in the scientific and technological R&D phase (M1), which indicates that government investment in this phase can well mobilize regional innovation vitality and government investment in R&D has a good scale effect, but the investment of scientific researchers has failed to significantly promote the effective improvement of local innovation efficiency. In the value realization stage (M2), the government funds in R&D funds and the output elasticity of R&D personnel input are significantly positive, both of which can effectively improve the efficiency of regional innovation. Comprehensive two-stage analysis shows the input-output elasticity of R&D personnel is slightly lower than that of R&D funds. Therefore, the key to improve innovation efficiency is to mobilize the enthusiasm of R&D personnel.

Judging from the influencing factors of research and development efficiency, in the stage of scientific and technological research and development (M1), the stronger the local export intensity, the stronger the innovation efficiency. However, the data show that there is a significant negative relationship between the scale of state-owned enterprises and tax incentives and local innovation efficiency. In the value realization stage (M2), the effect of the three is not significant.

Table 3. Quantitative Analysis Results

| variable | M1 | M2 |
|----------|----|----|
| $\beta_0$ | 0.3231*** | 0.4562 |
| $\beta_1$ | 0.3842*** | 0.1424 |
| $\beta_2$ | 0.0111 | 0.1563 |
| $\lambda_0$ | 0.0480 | 0.1563 |
| $\lambda_1$ | 0.2030*** | 14.844 |
| $\lambda_2$ | -0.8421*** | -5.4806 |
| $\lambda_3$ | 0.3206** | 0.4214 |
| $\sigma^2$ | 0.0650*** | 40.1880 |
| $\gamma$ | 0.0201 | 0.0846 |

Log value | -7.4620611 | -480.08406 |

Note: * * * *, * *, * are significant at 1%, 5% and 10% respectively.

Table 4 lists the innovation efficiency of each province from 2009 to 2015, where M3 represents the scientific and technological research and development stage and M4 represents the value realization stage. It shows that the value of innovation efficiency in China's scientific research and development stage from 2009 to 2015 is distributed in the interval $[0.846, 0.894]$, showing an overall upward trend with an overall average efficiency of 0.873. The innovation efficiency value in the value realization stage is distributed in the interval $[0.512, 0.589]$, which is relatively stable and the overall average efficiency is 0.526. Table 4 shows that some regions are at the forefront of technological innovation in China, but the economic added value of innovative products is relatively low (e.g. Henan, Guangdong, Fujian, etc.). Some regions can well transform the innovation achievements into economic benefits (such as Xinjiang, Gansu, Hainan, etc.). Few regions can consider both the two stages of scientific research and development and the transformation of achievements. This shows that there are problems of uncoordinated development and unbalanced overall development at the innovation stage in China.
4. Research conclusions

This paper applies a stochastic frontier analysis (SFA) to empirically analyse the innovation efficiency and its influencing factors of provinces and cities in China from 2009 to 2015. The research found that: (1) the government's innovation activities have specific definite effects. The analysis of samples shows that the innovation efficiency in China's scientific and technological research and development stage is 0.873, but the value realization stage is only 0.526. The development of the two innovation stages is not coordinated. The overall innovation level of the samples is in the range of 0.5-0.8. The development of the innovation levels in various regions is uneven. There is an excellent room for improvement in science and technology, especially in the stage of achievement transformation. (2) The innovation efficiency of science and technology research and development stage is positively influenced by government funds and export intensity but is inhibited by the scale of state-owned enterprises and the depth of tax incentives. The value realization stage is positively influenced by government funds and R&D personnel input, while other factors are not significant.
According to the above two conclusions, it can be concluded that in the process of enterprise innovation, the government should correspondingly strengthen the implementation of relevant policies to guide scientific and technological innovation ability, and conduct social resources to flow and gather into innovative projects with high technological added value. Given the imbalance of regional development, the government should promote the innovation cooperation between provinces and cities at the system level, promote the diffusion of technical knowledge, coordinate the development of industry innovation efficiency, and realize sustainable innovation. Inadequate or excessive tax incentive policies cannot play their real role, but will lead to a waste of government resources. Therefore, the release of tax policy dividends should be more cautious, which is not only conducive to the increase of fiscal revenue, but also can better perform public service functions. State-owned enterprises have a certain inhibitory effect on the innovation efficiency in the research and development stage of science and technology. However, due to their supporting role in the strategic development of the country and the national economy, it is important to promote the reform of the state-owned system and encourage enterprises with multi-property rights to jointly carry out scientific and technological research and development activities when carrying out the top-level design of the country. Government departments should continue to encourage enterprises to export, with special emphasis on the foreign development of high-tech enterprises and policies to encourage exports of products with high technology and high economical added value.

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