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The analysis of the influencing factors of high-tech industry collaborative innovation efficiency in China based on two-stage DEA-Tobit model

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ABSTRACT. *The collaborative innovation of Industry-University-Research Institute (IUR) in high-tech industry is a complex and uncertain process, and its innovation efficiency is also affected by many factors. Previous studies have mostly considered the influencing factors of the whole stage innovation efficiency, ignoring the differences of some factors on the R&D efficiency values and the technology transfer efficiency values of high-tech industry. Therefore, based on the two-stage efficiency values of different industries in high-tech industry from 2014 to 2016, this paper makes an empirical analysis of five factors influencing the two-stage efficiency of the collaborative innovation of IUR, using the two-stage DEA-Tobit model. So as to provide reference for improving the efficiency of collaborative innovation of high-tech industry.*

KEYWORDS: *high-tech industries, two-stage DEA-Tobit, the R&D efficiency, the technology transfer efficiency*

1. Introduction

High-tech industries are knowledge-intensive and technology-intensive industries, strategic emerging industries, important indicator of national competitiveness, important engine of economic growth in the world, and they play important roles in the economic development of countries and regions. The high-tech industries have the characteristics of high R&D investment, high agglomeration, high industry penetration, high income and high risk. Only through continuous knowledge flow and technological innovation, the high-tech industries can maintain sustainable and stable development.

Collaborative innovation of IRU is an effective way to develop high-tech industries. The efficiency of collaborative innovation directly affects the development speed of high-tech industries. By deeply analyzing the influencing factors, relevant

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departments will formulate more targeted policies and measures, which will effectively improve the efficiency of collaborative innovation of high-tech industries, promote the rapid development of high-tech industries, and thus improve the national economic growth rate.

The efficiency of collaborative innovation is influenced by many factors in high-tech industries. It is a hot issue to use what methods can systematically identify the influencing factors that restrict its promotion. Most of the existing literature is based on quantitative research and empirical analysis to study the technological innovation efficiency of high-tech industries, but scholars have different research perspectives and quantitative methods.

Luca (2010) used the hierarchical multiple regression analysis and had an empirical study of high-tech enterprises in biopharmaceutical industry, found out market orientation had the positive impact on their R&D efficiency [1].Hong(2016) used stochastic frontier approach (SFA), discussed the impact on the efficiency of technological innovation of high-tech industry from two factors: government funding and enterprise owned funds. Government subsidies had a negative impact on the innovation of China's high-tech industry, while private R&D funds and other funds have a positive impact on innovation[2].Liu（2016） used the three -stage DEA model considering the impact of environmental factors, this paper compared and analyzed the technological innovation efficiency of China's high-tech industry in 2000-2007 and 2008-2014. It was found that the low scale efficiency lead to the low level of innovation efficiency of China's high-tech industries as a whole [3].

Another literatures analyzed the impact of one factor on innovation efficiency. For example, Barros (2013) proposed that policy environment can improve innovation efficiency[4]; Liu (2017) pointed out that the efficiency of technological innovation was affected by the relationship between innovation subjects, regional development and consumption potential[4];Chen (2018) proposed that the effect of external technology Absorptive Capacity on the efficiency of technological innovation showed a significant inverted "U"-shaped relationship[6]; Fan (2014) proposed that government R&D funding had a significant positive relationship with technological efficiency of high-tech industry, but Fan (2018) increased the time span of data collection, and government funding had a significant negative impact on the R&D efficiency of high-tech industry[8], Ren (2019) proposed that the impact of government R&D funding on the innovation efficiency of high-tech industry was shown as an inverted "U"-shaped relationship [9]; Diao(2018) proposed that the quality of enterprise scale had a significant positive impact on the efficiency of technological innovation [10].

Summarizing the existing literature, scholars mostly analyze the efficiency of technological innovation from the perspective of enterprises, rarely from the perspective of industry; mostly from the perspective of single innovation subjects, rarely from the collaborative innovation factors; mostly from the perspective of innovation process as a whole, rarely from the two stage of collaborative innovation; mostly from the impact of single factors, rarely from the perspective of collaborative innovation systematically. In this paper, from the perspective of collaborative

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innovation, considering the difference of some factors on the efficiency value of R&D stage and technology transfer stage in the process of collaborative innovation in high-tech industry, we use two-stage DEA-TOBIT method to explore the impact of each factor on the efficiency value of the two stages systematically.

2 Two-stage DEA-Tobit model and index selection

2.1 Two-stage DEA-Tobit model

Two-stage DEA-Tobit model is a kind of calculation method combining two-stage DEA model with Tobit model. The specific steps are as follows:

1. Divide the collaborative innovation process of high-tech industry into R&D stage and technology transfer stage;

2. The efficiency of DMU is calculated by using the two-stage DEA model of shared input. The stage efficiency is the R&D efficiency value and the technology transfer efficiency value;

3. Since the efficiency values measured in the previous step are all in the range of [0,1], the direct use of the least square method may lead to biased and inconsistent parameter estimates. Tobit model can better deal with this problem. The efficiency value measured is regarded as the dependent variable of regression equation, the relevant influencing factors are selected as independent variables, then the models are established, finally the conclusions are obtained.

Tobit regression model was proposed by James Tobin and Probit in 1958. It is a kind of model that the dependent variable was limited. Because the efficiency values measured by DEA model are all in the [0, 1], the dependent variable of regression model is limited in the [0,1] as a limited dependent variable. Tobit regression model is suitable for limited variables, so it is reasonable to use the Tobit model.

In the above formula, Y_i^* is a latent variable,Y_i is an dependent variable that is observed actual, indicating the collaborative innovation efficiency value of IUR in the "i" industry of high-tech industry; X_i is an independent variable that is observed actual, indicating the influencing factors of the collaborative innovation efficiency of IUR in high-tech industry; β is a coefficient vector; $\varepsilon_i \sim N(0, \sigma^2)$ is an error term, and they are independent of each other.

2.2 Efficiency measure

Based on the DEA model of shared input association, this paper calculates the efficiency value of R&D stage and technology transfer stage of high-tech industries in 2014-2016, which the original data is sorted out by «China Statistical Yearbook on Science and Technology» and «China Statistics Yearbook of China's High Technology Industry», and calculated by MATLAB (R2018B).

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2.3 Index selection

The process of collaborative innovation in high-tech industries is affected by many factors. From the literature on the factors affecting the efficiency of collaborative innovation, it can be found that domestic and overseas scholars have studied this issue from the internal and external environment of the innovation system of the IUR. Within the system, it is mainly considered from the relationship of each subject of IUR(collaboration, trust between organizations, cooperation experience, interaction breadth, knowledge technology complementarity, etc.) and the factors of the subject itself (scale strength, enterprise technology Absorptive Capacity capacity); outside the system, it is mainly influenced by the external environment, such as social and economic development conditions, infrastructure conditions, market level, financial institutions, multi-dimensional proximity (geographical proximity, social proximity, technological proximity) and government policy conditions.

Therefore, based on the research results of relevant authoritative literature and the impact indicators of innovation efficiency from «China's regional innovation capability report», combined with the availability of data, this paper selected the following influencing factors of collaborative innovation efficiency in high-tech industries:

1. Industry Size (Is). The size of the industry directly affects the influence of enterprises on IUR and the level of investment on IUR, and it can bring scale effect. However, if the scale is too large, the innovation efficiency will be low due to ineffective management. This paper uses the number of employees in the industry to measure the size of enterprises.

2. Industry Technology Absorptive Capacity (Ac). Industry Technology Absorptive Capacity is an ability of enterprises, the ability is that can effectively utilize the scientific and technological resources of universities, R&D institutions, and governments, and effectively integrate with the internal R&D of enterprises. Ankraha (2015) pointed out that the technological Absorptive Capacity capacity of enterprises affected the efficiency of collaborative innovation of IUR [11]. The technology absorptive capacity of enterprises is an important factor in establishing effective technology transfer between universities and enterprises (Kodama (2008) [12]). Therefore, in this paper, the proportion of industry R&D personnel in employees is used to measure the Industry Technology Absorptive Capacity of the industry.

3. Government Participation (Gp). The leverage effect of government funding can effectively guide enterprises and universities to establish the key R&D platforms. Government funding had a positive impact on the efficiency of the collaboration of IUR (Xiao (2013) [13]). Jiang (2017) used DEA-Tobit method to evaluate and analyze the efficiency of collaborative innovation in different provinces of China, and pointed out that the efficiency of collaborative innovation had obvious positive correlation with the level of local economic development, the funding intensity of local governments to enterprises and universities [14]. Therefore, this paper shows the government's participation degree by the proportion of government's investment of industry R&D in the internal expenditure of industry R&D funds.

4. Close Degree of Cooperation of IUR (Cc). Through mutual benefit sharing and resource integration, every party of IUR continue to promote the development of collaborative innovation, laying an organizational foundation for improving the efficiency of collaborative innovation (Zou (2013) [15]). On the one hand, the closeness of the cooperation between the industry, universities and research institutes influences the flow of knowledge, the closer the cooperation, the simpler the flow of knowledge and the higher the efficiency of collaborative innovation. On the other hand, the closeness of the cooperation is conducive to creating a harmonious cooperation atmosphere and promoting the cooperation (Dong (2013) [16]). Therefore, the proportion of external expenditure of industry R&D capital in total investment of industry R&D capital represents the close relationship between enterprises, universities and R&D institutions.

5. Industrial competition(Ic). The degree of industrial competition indicates the external environment in which an enterprise exists. The combination of enterprises with R&D institutions and universities helps to change the competitive situation of the industry and promote technological innovation of enterprises. Generally, the degree of industrial competition drives enterprises to have to carry out technology research and development. Therefore, this paper uses the proportion of exports in sales revenue to measure the degree of industrial competition.

The influencing factors of high-tech industry collaborative innovation efficiency are summarized in the below table.

Table 1 The influencing factors of collaborative innovation efficiency in high-tech industry

Influencing factors	**Measure index**	**Abbreviation**
Industry Size	The number of employees in the industry	Is
Industry Technology Absorptive Capacity	The proportion of industry R&D personnel in employees	Ac
Government Participation	The proportion of government's investment of industry R&D in the internal expenditure of industry R&D funds	Gp
Close Degree of Cooperation of IUR	The proportion of external expenditure of industry R&D capital in total investment of industry R&D capital	Cc
Industrial Competition	The proportion of exports in sales revenue	Ic

3 Empirical analysis

3.1 Model setting

In order to further study the influencing factors of the efficiency of collaborative innovation in high-tech industry, this paper established Tobit regression model of

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influencing factors as follows, according to the R&D efficiency and the technology transfer efficiency by the two-stage DEA calculation method of shared investment, and based on the above-mentioned influencing factors of the efficiency of collaborative innovation in high-tech industry:

$$E^1{}_{it}(E^2{}_{it}) = \alpha_0 + \alpha_1 Is_{it} + \alpha_2 Ac_{it} + \alpha_3 Gp_{it} + \alpha_4 Cc_{it} + \alpha_5 Ic_{it} + \varepsilon_{it}$$

3.2 Data sources

In the above formula, E_{it}^1、 E_{it}^2 are respectively the R&D efficiency value and the technology transfer efficiency value of collaborative innovation of IUR in high-tech industry, they are measured during the period from 2014 to 2016 (the fourth evaluation period), “i” represents the “i” industry, and “t” represents the “t” year. Is_{it} indicates the industry size of the “i” industry in the “t” year; Ac_{it} indicates the industry technology absorptive capacity of the “i” industry in the “t” year; Gp_{it} indicates the government participation of the “i” industry in the “t” year; Cc_{it} indicates the close degree of cooperation of IUR of the “i” industry in the “t” year; Ic_{it} indicates the industrial competition of the “i” industry in the “t” year. α_0 is a constant. $\alpha_1, \alpha_2, \alpha_3, \alpha_4, \alpha_5$ are the coefficients for preparation evaluation. ε_{it} is a random perturbation. The original data of this paper are collected from «China Statistical Yearbook on Science and Technology » and « China Statistics Yearbook of China's High Technology Industry ». This paper intends to analyze the influencing factors of the collaborative innovation efficiency of IUR based on the selected data from 2014 to 2016.

3.3 Result analysis

According to the relevant data, the Tobit regression analysis is carried out by using Eviews10, and the calculation results are as follows:

Table 2 Regression results of factors affecting efficiency in two stages of collaborative innovation in high-tech industry

Variable	**R&D Efficiency**	**Technology Transfer Efficiency**
	Coefficient	Coefficient
C	0.808834***	0.790324***
Is	2.84E-08*	-2.95E-10
Ac	0.90551*	0.638752
Gp	-6.52E-07***	-3.18E-07***
Cc	2.85E-07*	2.33E-07
Ic	0.086841	0.22773***

Note: *, **, ***respectively represent the significance level of 10%, 5%, 1%.

Through observation and analysis of the regression results, it is found that a certain proportion of the influencing factors pass the significance test in the two sub stages of R&D and technology transfer in the process of collaborative innovation.

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There are four factors that have a significant impact on the R&D efficiency value, they are Is (Industry size), Ac (industry technology absorption capacity), Gp (Government participation), and Cc (Close degree of cooperation of IUR); there are two factors that have a significant impact on the technology transfer efficiency value, they are Gp (Government participation) and Ic (Industrial competition). Here are the detailed analysis of the impact of the five factors on the efficiency of R&D stage and technology transfer stage in the process of high-tech industry collaborative innovation:

3.1.1. Is (Industry Size) has a positive impact on the R&D efficiency in the collaborative innovation activities of high-tech industry, but it has no significant impact on the technology transfer efficiency. For the high-tech industry with large scale, the higher the corresponding R&D efficiency, which has larger ability of enterprises to participate in the process of IUR. Large scale means that the industry has more resources to research and development. In addition, it is also related to the selection tendency of universities and R&D institutions. Most universities and R&D institutions with scientific research advantages may prefer to cooperate with large-scale industries and enterprises, so they have relative advantages in the output of achievements. Specifically, the size of the industry has a significant positive role in promoting the efficiency of technology R&D under the 10% test level. Expanding the scale of the whole industry can improve the R&D efficiency of collaborative innovation.

3.1.2. Ac (Industry Technology Absorption Capacity) has no significant impact on the technology transfer stage, but has a positive effect on the R&D stage. The technology absorptive capacity of an enterprise often represents the breadth and depth of knowledge acquired by the enterprise in the process of participating in the collaborative innovation activities of IUR. Specifically, technology absorptive capacity has a significant positive effect on R&D efficiency at the 10% test level. Improving the technology absorptive capacity of enterprises can improve the efficiency of R&D stage in the process of collaborative innovation, which is also in line with the reality of collaborative innovation of IUR.

3.1.3. The government's participation has a negative significant impact on the R&D stage and the technology transfer stage. The government plays an important guiding role in the process of collaborative innovation of IUR. In the early stage, it may promote the development of collaborative innovation activities of high-tech enterprises, universities and R&D institutions. However, with the increase of government investment and the issuance of administrative orders, it will lead to the low efficiency of fund management and scientific research activities management, which restricts the R&D efficiency and the technology transfer efficiency of high-tech enterprises. Specifically, the government's participation has a significant negative impact on the R&D efficiency and the technology transfer efficiency at the 1% test level. This means that the more funds the government invests, the lower the efficiency of collaborative innovation.

3.1.4. The closeness of the relationship between the participants of IUR significantly affects the R&D stage, but not the technology transfer stage. Efficient

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collaborative innovation activities must involve a high degree of close relationship between all parties. On the one hand, close cooperation establishes a solid organizational foundation, on the other hand it promotes the construction of a good innovation atmosphere and the smooth flow of knowledge, which is more conducive to the improvement of R&D innovation efficiency. Specifically, the closeness of the relationship of the IUR has a significant positive impact on the R&D efficiency at the 10% test level, and also has a positive impact on the technology transfer stage, but the impact is not significant. To strengthen the cooperation among the IUR, establish a good flow system of knowledge and technology among the innovation subjects of IUR, build a cross organizational collaborative innovation network, explore a sustainable and stable development mode and management mechanism of collaborative innovation network, which can promote the R&D efficiency and the technology transfer efficiency in the process of collaborative innovation of high-tech industry, especially the R&D efficiency.

3.1.5. The degree of industrial competition has a significant impact on the efficiency of the technology transfer stage in the process of collaborative innovation of high-tech industry, but not on the R&D stage. The degree of industrial competition indicates the external environment in which enterprises live. The worse the external environment is, the more attention enterprises attach to the transformation of technological achievements. They are eager to achieve higher economic benefits and change the inferior position of enterprises. Specifically, the level of industrial competition at 1% test level has a significant positive impact on the technology transfer efficiency, and also has a positive impact on the efficiency of R&D stage, but the impact is not significant. The more fierce the competition in the external environment, the more conducive to give full play to the industrial effect brought by the changes in the market. Promote the collaborative innovation of IUR and the technological innovation ability, and then the technology transfer efficiency can be improved.

4 Conclusions and suggestions

After using the two-stage DEA model of shared investment to get the R&D efficiency values and technology transfer efficiency values in the process of high-tech industry collaborative innovation, we use TOBIT model to get the more reasonable five influencing factors on the above two stages.

Table 3 Five influencing factors on the above two-stage

Influencing Factors	R&D Efficiency	Technology Transfer Efficiency
Industry size（Is）	Positive significant	Negative no significant
Industry technology absorptive capacity（Ac）	Positive significant	Positive no significant
Government participation（Gp）	Negative significant	Negative significant
Close degree of cooperation of IUR（Cc）	Positive significant	Positive no significant
Industrial competition（Ic）	Positive no significant	Positive significant

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From table 3, it can be seen that there are obvious differences in the efficiency values of the two stages of collaborative innovation among the influencing factors in China's high-tech industry. Through theoretical and empirical analysis, we can get policy suggestions that more suitable for improving the innovation efficiency values of the two stages. The relevant departments should create development conditions actively to stimulate the relevant positive factors, while the negative factors should be promoted by improving the system and become the positive factors.

1). Establish the training mechanism of relevant innovative talents, introduce the concept of the open innovation, and improve the technological absorptive capacity of enterprises. By introducing high-end innovative talents and multi-level training system, improving the incentive measures for talents, updating the innovation concept of management personnel, and fundamentally improving the technology absorption capacity of enterprises, the R&D efficiency and technology transfer efficiency will be improved, especially the R&D efficiency.

2). Improve the use of government funds and the efficiency of government funds. The government's guidance is essential to the development of high-tech industry. The two ways of government guidance are capital investment and system guarantee. In this paper, the government participation mainly refers to the proportion of government investment and internal expenditure of R&D funds. The larger the proportion, the more "crowding out effect" will be caused, which will have a negative impact. Therefore, while strengthening government support, enterprises should also pay attention to optimizing the direction of government funds, improving the use of government funds, and improving the use efficiency of government funds.

3). Establish high-tech industrial park and create an open collaborative innovation network of IUR. Relevant departments should cultivate innovation and entrepreneurship culture in the industrial park, strengthen the management of intellectual property rights, improve the benefit distribution system, protect the initiative of each innovation subject in scientific and technological innovation, in order to form an open, harmonious, stable and benign operation of high-performance innovation network. Finally, it will form a sustainable and stable cooperation relationship, strengthen the close degree of cooperation between all parties of IUR, and improve the innovation efficiency of two stages in the process of collaborative innovation in high-tech industry.

4). Improve the marketization of enterprises and continue to deepen the state-owned reform. Relevant departments should strengthen the decisive role of the market in resource allocation, respect the market, and make full use of its guiding role in technological innovation and achievement transformation.

It will be the direction of further research to study the impact of different factors on all kinds of high-tech industries in every provinces and formulate corresponding policies and measures.

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