Research on Efficiency of Sci-tech Input-output of the Pillar Industries in Shaanxi Province from Symbiotic Perspective

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Abstract

In this paper, we divide the R&D project in Shaanxi province by different national economy industry, build the innovation network system of Industry-University-Research Institute of pillar industries in Shaanxi province and explore the symbiosis efficiency of regional innovation networks by using network DEA model with multi-stage production progress. We regard the efficiency of each Innovation Network System of Industry-University-Research Institute as the efficiency of Sci-tech Input-output from Symbiotic perspective in order to realize the evaluation of the input-output efficiency of Sci-tech from 2009 to 2014 of the pillar industries in Shaanxi province. The results show that the number of integrative symbiosis and continuous symbiosis of pillar industries are more than that of intermittent symbiosis and dot symbiosis of pillar industries.

Keywords

Symbiosis efficiency; Network DEA model; Pillar industries.

1. Introduction

The Outline of National Middle and Long-term Plan on Scientific and Technological Development (2006-2020) clearly states that the core objective of development in the next 15 years is independent innovation, that is, following the road of building an innovative country. Under this background, China started the implementation of national technology innovation projects and listed Shaanxi as a pilot province for innovation. Meanwhile, economic and social development in Shaanxi in the "12th Five-Year Plan" released by Shaanxi Provincial Bureau of Statistics pointed out that the ratio of the three industrial structures in Shaanxi Province at the end of the 12th Five-Year Plan was 8.8: 51.5: 39.7. We know that industry is the top priority of Shaanxi's economy. Computer and other electronic equipment manufacturing industry, energy and chemical industry, equipment manufacturing industry, pharmaceutical manufacturing industry, food industry, textile and garment industry and non-ferrous metallurgy industry have been called seven pillar industries promoting the economic development of Shaanxi province after 2003[1]. Their main indicators have been absorbed by national statistical system. Data shows that the average share of seven pillar industries of the province's total industrial output value of 97.40%, in Shaanxi Province from 2009 to 2014, is crucial to the province's economy.

However, due to the economic downturn and the sluggish of market demand, the pressure on the stocks of industrial enterprises in Shaanxi Province persisted during the 12th Five-Year Plan period. From January to November in 2015, the rate of produce and sale above designated size in Shaanxi Province was 95%, lower than the national average by 2.5 percentage points. From January to October in 2015, the province's inventories of finished goods inventory above designated size reached 83,340.3 million yuan and increased by 8.3%.

The government pointed out that the key to solving the inventory problem of industrial enterprises in Shaanxi Province lies in intensifying innovation, upgrading the technological content of products and enhancing their own competitiveness. Therefore, it is necessary to conduct a scientific evaluation of the input-output efficiency of Sci-tech investment in pillar industries in Shaanxi Province, analyze the main factors that affect efficiency, find out the problems in the process of innovation and propose improvement measures to increase innovation efficiently.

2. Literature Review

Data Envelopment Analysis (DEA) is a method of measuring the relative efficiency of multiple-input, multiple-output decision making units. It uses the envelope model of input data and output data for relative effectiveness evaluation and gives suggestions for improvement [2].

However, with the development of economy and society, the traditional DEA model is powerless to evaluate the dynamic processes with different time periods. In this context, Färe (1997), Färe and Grosskopf (2000), Zhu and Cook (2007) proposed a multi-stage network DEA model, assuming that a certain stage of the system output variables become the input variables in other phases, which opened up the black box of complex network systems [3].

It was in 2010 when Chinese scholars started research on the evaluation of innovation efficiency by using network DEA technology. These studies analyze the efficiency of innovation from three aspects: business, industry and region.

Fang Jianwen and Qiu Yonghe (2014) analyzed the research and development efficiency and operational efficiency of large and medium-sized industrial enterprises in 30 provinces (autonomous regions and municipalities) in China in 2010 based on the SBM network DEA model [4]; Peng Youyuan and Wang Ting (2016) analyzed the improvement of investment efficiency and non-efficiency investment of GEM in China from 2012 to 2014 with two-stage network DEA method [5].

Hu Yinghui and Chen Wei (2013), Zhao Jiaqian et al. (2013), He Zhengchu et al. (2014), Gong Guangming and Shan Hong (2015), Li Yang (2015), Dong Yanmei and Zhu Yingming (2015), Wang Yan and Zhou Jingjing (2016) evaluated the technological innovation efficiency of related industries by two-stage related network, chain network and dynamic network DEA model [6-8]. Yin Weihua and Yuan Wei (2012), Xiao Renqiao et al. (2014), Peng Cheng and Cheng Changde (2014), Ye Bin and Chen Liyu (2016) and Li Ning et al. (2017) evaluated the technological innovation efficiency of different levels of regions through improved network DEA model [9,10].

However, there are also some shortcomings. These studies made the black box of the innovation process into gray boxes, they omited the fact that they regarded each sub-process as an independent part ignoring the interaction between the various sub-processes, so the result is biased. As a result, this paper observes innovation network in Shaanxi Province from a symbiosis perspective.

The co-existence relationship among industry, university and research from overseas dated back to that proposed by Hisrich (1988) [11]. Symbiosis formed due to the transfer of technology and knowledge between business and university. In the domestic research on the symbiosis, Sishang Qi (2009) [12] made it clear that there was a symbiotic relationship between research institutes and enterprises, universities and research institutes were regarded as similar Symbiotic unit, and research-enterprise symbiosis had four organizational modes and four behavioral modes.

3. Research Design

In this paper, we divide the R&D project in Shaanxi province by different national economy industry, build the innovation network system of Industry-University-Research Institute of pillar industries in Shaanxi province and explore the symbiosis efficiency of regional innovation networks by using network DEA model with multi-stage production progress. Each innovative subject (symbiotic unit) in Shaanxi innovation network of industry, university and research institutes exchanges the material, information and energy through the symbiotic cooperation mechanism (symbiotic interface) to obtain innovative output (Figure 1) from the perspective of symbiosis.

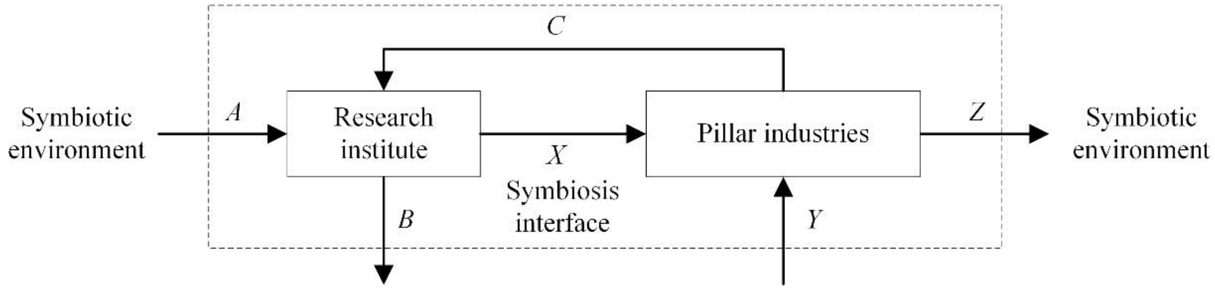

Fig. 1 Schematic diagram of symbiosis process

In Fig. 1, A represents the input of funds and human capital from the symbiotic environment. The output of the research institute consists of two parts: X is the talent and technology elements that are exported to the pillar industries; B is the output of research institute to the symbiotic environment. Y means the external input such as funds and talents obtained from the symbiotic environment. Like the research institutes, the output of the pillar industries also includes two parts, one is C such as capital provided to the research institute, and the other is Z which is the final product or service of pillar industries.

We suppose that there are N decision-making units. In the first stage, research institutes have p types of input A from a symbiotic environment, have s types of inputs C from a symbiotic environment. Research institutes in the first phase have r types of intermediate outputs X, and q kinds of output B in the symbiotic environment. In the second stage, there are k kinds of input Y from the symbiotic environment in pillar industries, and there are r kinds of input X from the research institutes. In the second stage, there are s type of output C providing by research institutes, and there are m final output Z. The weights of A, B, C, X, Y and Z are denoted by U1, U2, V1, V2, W1 and W2. Based on the above conditions, this paper constructs the following network DEA model:

$$E_i^1 = \max U_2^T B^i + W_2^T Z^i$$
$$s.t.\begin{cases} U_1^T A^i + W_1^T Y^i = 1 \\ \left(U_2^T B^j + W_2^T Z^j\right) - \left(U_1^T A^j + W_1^T Y^j\right) \le 0 \\ \left(U_2^T B^j + V_2^T X^j\right) - \left(U_1^T A^j + V_1^T C^j\right) \le 0 \\ \left(V_1^T C^j + W_2^T Z^j\right) - \left(V_2^T X^j + W_1^T Y^j\right) \le 0 \\ U^1 > 0, U^2 > 0, V^1 > 0, V^2 > 0, W^1 > 0, W^2 > 0 \end{cases} \tag{1}$$

The first constraint in Eq. (1) is the production frontier condition that the innovation symbiosis network of production to meet as a whole. The second and third constraints are the production to be met in the first and the second phases. From (1) we can see that the first constraint is exactly equal to the sum of the second and third constraints, so the first constraint can be removed. Therefore, equation (1) can be further simplified as:

$$E_i^1 = \max U_2^T B^i + W_2^T Z^i$$
$$s.t.\begin{cases} U_1^T A^i + W_1^T Y^i = 1 \\ \left(U_2^T B^j + V_2^T X^j\right) - \left(U_1^T A^j + V_1^T C^j\right) \le 0 \\ \left(V_1^T C^j + W_2^T Z^j\right) - \left(V_2^T X^j + W_1^T Y^j\right) \le 0 \\ U^1 > 0, U^2 > 0, V^1 > 0, V^2 > 0, W^1 > 0, W^2 > 0 \end{cases} \tag{2}$$

4. Calculation Results And Analysis

In this paper, we choose the pillar industries in Shaanxi Province as the research object. The external inputs, intermediate inputs and intermediate outputs of this paper adopt the data from 2009 to 2013 and the external outputs of this paper adopt the data from 2010 to 2014, taking into account the lag of input-output. All data is from the Shaanxi Statistical Yearbook and the Shaanxi Science and

Technology Statistical Yearbook of the relevant year. All indicators of research institutions data, are the sum of related data of scientific research institutes and colleges and universities.

In the yearbook, there is no specific indicator data for the seven pillar industries. As a result,this paper use the data from Shaanxi Statistical Yearbook in 'The Situation of Industrial Enterprises above Designated Projects' and 'Developing, Producing and Sales of Industrial Enterprises above Designated', with the reference from in Table 1. Seven Pillar Industries in Shaanxi Province contain the following national economy industries.

Table 1. Seven Pillar Industries in Shaanxi Province contain the following national economy industries

Seven Pillar Industries	National Economy Industries	Seven Pillar Industries	National Economy Industries
Computer and other electronic equipment manufacturing industry	Manufacture of computers, communication and other electronic equipment	Pharmaceutical manufacturing industry	Manufacture of medicines
Energy and chemical industry	Processing of petroleum, coking, processing nuclear fuel	Food industry	Processing of food from agricultural products
	Manufacture of chemical raw material and chemical products		Manufacture of foods
	Production and supply of electric power and heat power		Manufacture of wine, beverages and refined tea
	Mining supporting activities		Manufacture of tobacco
	Manufacture of chemical fibers	Textile and garment industry	Manufacture of textile
	Manufacture of rubber and plastics		Manufacture of textile and clothing
	Mining and washing of coal		
	Extraction of petroleum and natural gas		
Equipment manufacturing industry	Manufacture of metal products	Non-ferrous metallurgy industry	Mining and processing of ferrous metal ores
	Manufacture of general purpose machinery		Mining and processing of non-ferrous metal ores
	Manufacture of special purpose machinery		Smelting and pressing of ferrous metals
	Manufacture of railway, shipping, aerospace and other transport equipment		Smelting and pressing of non-ferrous metals
	Manufacture of electrical machinery and equipment		
	Manufacture of measuring instrument and machinery		
	Automotive industry		

Descriptive statistics of each variable are shown in the Table 2.

Table 2. Evaluation index system of innovation network system of industry-university-research institute

Innovation Process	Indicator Type	Indicator
Interaction of research institutions and symbiotic environment	Input(*A*)	Scientific research institutes and institutions of colleges and universities R&D project staff full-time equivalent
		Internal expenditure of R&D projects of research institutes and colleges and universities (from non-enterprise part)
	Output(*B*)	Number of R&D project of research institutes and colleges and universities
Interaction of pillar industries and symbiotic environment	Input(*Y*)	staff full-time equivalent of pillar industries
		internal expenditure of pillar industries
	Output(*Z*)	New product output value of pillar industries
		New product sales revenue of pillar industries
Interaction of research institutions and pillar industries	Input from pillar industries to research institutions (*C*)	Internal expenditure of R&D projects of research institutes and colleges and universities (from enterprise part)
	Input from research institutions to pillar industries (*X*)	External expenditure on R&D projects of pillar industries (expenditure on research institutions)

The selection of input and output indicators in the DEA model is crucial. In order to ensure the reliability of the evaluation results, we need to test the correlation between input and output indicators [13]. This paper uses SPSS22.0 to test the correlation of each input-output index of Shaanxi industrial-university-research innovation network. As is shown in the Table 3 and Table 4.

Table 3. Pearson correlation coefficients between input-output indicators

Indicator	Staff full-time equivalent in Scientific research institutes and institutions of colleges and universities R&D project	Internal expenditure of R&D projects of research institutes and colleges and universities (from non-enterprise part)	Internal expenditure of R&D projects of research institutes and colleges and universities (from enterprise part)
Number of R&D project of research institutes and colleges and universities	0.921**	0.771**	0.814**
External expenditure on R&D projects of pillar industries (expenditure on research institutions)	0.818**	0.813**	0.842**

Table 4. Pearson correlation coefficients between input-output indicators

Indicator	External expenditure on R&D projects of pillar industries (expenditure on research institutions)	R&D staff full-time equivalent	R&D internal expenditure
Internal expenditure of R&D projects of research institutes and colleges and universities (from enterprise part)	0.842**	0.727**	0.696**
New product output value	0.442**	0.947**	0.964**
New product sales income	0.436**	0.934**	0.958**

Note: ** indicates a significance level of 0.01.

The results show that all the input and output indicators are positively correlated at a significant level of 0.01, and the correlation coefficients between most of the indicators are above 0.7. Therefore, we can conclude that the input and output indicators of regional innovation network are appropriate.

In each pillar industry innovation network, main innovation research institutions are the same basically, according to the group of the R&D project (subject) service of the national economy industry. As a result we regard the innovative efficiency i of innovation networks made in Shaanxi province as efficiency of pillar industries' sci-tech input-output. According to the above network DEA model, we get the calculation results in Table 5 by using EMS1.3 software.

Table 5 Efficiency of pillar industries' Sci-tech Input-output in Shaanxi Province

Pillar industries	2010	2011	2012	2013	2014	Average value
Computer and other electronic equipment manufacturing industry	0.707	1.000	1.000	1.000	1.000	0.941
Energy and chemical industry	1.000	0.781	1.000	1.000	1.000	0.956
Equipment manufacturing industry	0.859	0.818	0.954	0.772	0.752	0.831
Pharmaceutical manufacturing industry	0.662	0.665	1.000	0.415	0.980	0.744
Food industry	1.000	1.000	1.000	1.000	1.000	1.000
Textile and garment industry	0.628	1.000	0.857	1.000	0.715	0.840
Non-ferrous metallurgy industry	1.000	1.000	1.000	1.000	1.000	1.000
Average value	0.837	0.895	0.973	0.884	0.921	0.902

The efficiency of sci-tech input-output of pillar industries from 2010 to 2014 is plotted in Fig. 2. We find that the efficiency values of the electronic equipment manufacturing industry, energy chemical industry, food industry and non-ferrous metallurgy industry mainly remained at 1from the year 2010 to 2014. On the contrary, there was a steady decreased in the efficiency of the equipment manufacturing industry. However, the efficiency value of pharmaceutical manufacturing and textile and garment industries suffered fluctuations during the five years.

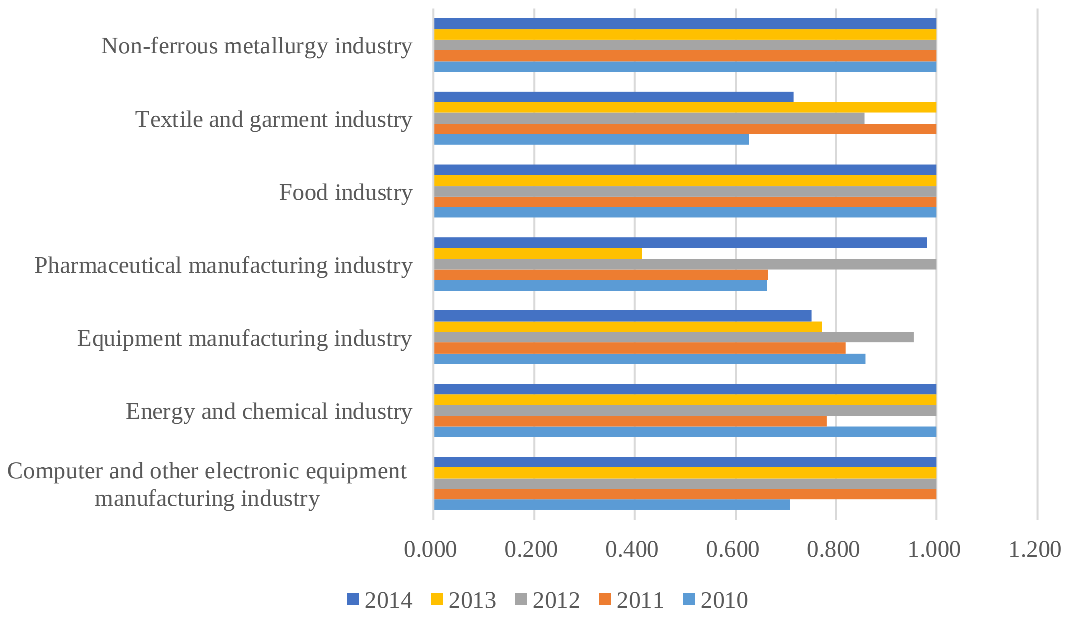

Fig. 2 Efficiency of Sci-tech Input-output of pillar industries in Shaanxi Province

According to the data of external science and technology input-output efficiency of pillar industries in Shaanxi Province from 2010 to 2014, we calculate the annual average data of pillar industries and do the cluster analysis by using 4 as cluster number. We get the calculation results in Table 6 by SPSS 22 statistical analysis software.

Table 6. Cluster center of efficiency of pillar industries' Sci-tech input-output in Shaanxi Province

Indicators	Cluster center			
	1	2	3	4
Efficiency of Sci-tech Input-output of pillar industries	0.744	0.835	0.948	1.000

Further, the pillar industries in Shaanxi Province can be classified according to Table 7.

Table 7. Classification of pillar industries' sci-tech input-output in Shaanxi Province.

Type	Level of efficiency of Sci-tech Input-output of pillar industries	pillar industries	Symbiotic model
1	Lower	Pharmaceutical manufacturing industry	dot symbiosis
2	General	Equipment manufacturing industry, Textile and garment industry	intermittent symbiotic mode
3	High	Computer and other electronic equipment manufacturing industry, Energy and chemical industry	continuous symbiotic model
4	Higher	Foods industry, Non-ferrous metallurgy industry	integrated symbiosis mode

It can be seen that the efficiency of sci-tech input-output of pillar industries in pharmaceutical manufacturing industry belongs to category 1, indicating that there is very little interaction between the pharmaceutical manufacturing industry and research institutes, and the instability and randomness of innovative cooperation are called dot symbiosis. The efficiency of sci-tech input-output of pillar industries in equipment manufacturing industry and textile and garment industry belong to category 2, indicating that their interaction with research institutes are relatively high. However, such cooperation is unstable and has discontinuities in time and randomness, which is called intermittent symbiotic mode. The efficiency of sci-tech input-output of pillar industries in the electronic equipment manufacturing and energy and chemical industry belong to category 3 , indicating that they interact with research institutions and play a multifaceted role through the continuous interaction of multiple symbiotic media such as personnel, funds, equipment and information .Symbiotic relationship is relatively stable and inevitable, which is called continuous symbiotic model. The efficiency of manufacturing industry in the food industry and non-ferrous metallurgy industry fall into category 4, indicating that there are full range of interactions with research institutes. The symbiotic relationship is stable and has inherent inevitability, which is called integrated symbiosis mode.

The results show that: (1) Among the industry-university-research innovation networks formed by pillar industries in Shaanxi Province, there are more symbiotic and continuous symbiotic modes than those belonging to symbiotic and symbiotic modes. (2) From the perspective of the proportion of total industrial output, energy and chemical industry and equipment manufacturing industry are the core pillar industries in Shaanxi Province. We find that the efficiency values of the electronic equipment manufacturing industry, energy chemical industry, food industry and non-ferrous metallurgy industry mainly remained at 1from the year 2010 to 2014. On the contrary, there was a steady decreased in the efficiency of the equipment manufacturing industry. However, the efficiency value of pharmaceutical manufacturing and textile and garment industries suffered fluctuations during the five years.

5. Conclusion And Inspiration

In this paper, we divide the R&D project in Shaanxi province by different national economy industry, build the innovation network system of Industry-University-Research Institute of pillar industries in Shaanxi province and explore the symbiosis efficiency of regional innovation networks by using network DEA model with multi-stage production progress. The results show that the number of integrative symbiosis and continuous symbiosis of pillar industries are more than that of intermittent symbiosis and dot symbiosis of pillar industries.

Therefore, we should not pay attention to the quantity of science and technology investment blindly. We should focus more on the structure of science and technology investment and the optimal allocation of scientific and technological resources.

In short, this paper evaluates and analyzes the efficiency of science and technology input and output of the seven pillar industries, which has an important theoretical and practical significance. We consider that the accuracy of the DEA method is susceptible to the selected indicators, so the follow-up study can be selected according to the more appropriate indicators model, other research methods can also be used.

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