International Journal of Technology Management

ISSN online: 1741-5276 - ISSN print: 0267-5730
https://www.inderscience.com/ijtm

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DOI: 10.1504/IJTM.2023.10052650

Article History:

Received:	23 June 2021
Last revised:	07 February 2022
Accepted:	09 February 2022
Published online:	20 December 2022

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Abstract: In order to improve the economic benefits of enterprises under continuing influence of COVID-19, the technological innovation effect of industrial chain under the 'double cycle' pattern in the post epidemic era is studied in this paper. The fractional planning and integral planning functions of the industrial chain are obtained by constructing the CCR model, and the BCC model calculation of the innovation effect of the enterprise industrial chain is realised by the Chames-Cooper transformation. The data efficiency value of technological innovation effect of industrial chain under the 'double cycle' pattern is obtained via the SBM network model for analysis on the technological innovation effect of industrial chain. The experimental results show that the effect of industrial chain technological innovation is analysed from the aspects of main business income and the profit margin of enterprises extending the industrial chain and connecting the industrial chain. The highest profit margin after connecting the industrial chain technological innovation is 34.2%, which proves that technological innovation can improve the economic benefits of enterprises.

Keywords: double circulation; industrial chain; effect of technological innovation; economic performance.

Reference to this paper should be made as follows: Ruan, S. and Choi, S. (2023) 'The technological innovation effect of industrial chain under the 'double cycle' pattern in the post epidemic era', *Int. J. Technology Management*, Vol. 91, Nos. 1/2, pp.68–81.

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1 Introduction

The so-called double circulation refers to the "new development pattern with domestic large circulation as the main body and domestic and international circulation supporting each other." Taking domestic large circulation as the main body means to strive to open up all links of domestic production, distribution, circulation and consumption, give full play to advantages of China's super large-scale market, and take meeting domestic demand as the starting point and foothold of economic development. Domestic and international double cycles support each other, which emphasises domestic economic cycle and is not 'self-closed'.

Under the 'double circulation' pattern, the development of the technological innovation effect of the industrial chain needs the support of the international logistics channel, and the operation of the international logistics channel is inseparable from the connection of the nodes of the International Logistics Park (ILP) (Izikowitz, 2021), which provides an important support for the trade countries to realise the organic unity of logistics, information flow and commodity flow (Wong and Ngai, 2019). Today's enterprises accelerate the digital transformation process of R&D, production, management, service and other key links through technological transformation, business cloud, business innovation and organisational change (Reis et al., 2018). However, in the epidemic crisis, the logistics industry is facing severe problems such as the sharp reduction of social demand, slow logistics, and circulation difficulties.

Industrial chain can be defined as an industry set with certain internal relations, which is composed of a series of industries which are mutually dependent and based on a series of contents involved in the production (and provision of services) of characteristic products or serving a specific demand. From the industrial chain of modern industry, a complete industrial chain includes raw material processing, intermediate product production, finished product assembly, sales, service and other links. In fact, any industry can form an industrial chain. In real society, there are various industrial chains, and many industrial chains will interweave to form an industrial network.

Technology innovation effect refers to the development of new technology or application innovation of existing technology to improve the economic efficiency of enterprises, so as to alleviate the unbalance between production and market demand. The mechanism of technological innovation in industrial chain refers to a series of complex systems of power, rules, procedures and systems, in which the contradiction between

technological innovation and market demand can be continuously unfolded and solved. This system can also be used as the operation mechanism of scheme design, financing and investment for technological innovation projects, which can coordinate various forces to jointly carry out technological innovation to obtain the cooperation mechanism.

In the post epidemic era, the epidemic situation has gradually improved, with the economy begging to recover, and the domestic logistics industry gradually returning to the normal level (Hansen et al., 2020). China-EU freight trains are playing an increasingly important role in the global anti epidemic cooperation. At the same time, the rise of domestic consumption level has stimulated international investment and trade. As an important carrier connecting the international market and the domestic market, the ILPs play an increasingly important role, with inestimable significance in the construction of 'double cycle' pattern (Pietrobelli and Staritz, 2018). Therefore, it is the top priority to vigorously promote the construction of ILPs, further strengthen the cooperation between the industrial chain and countries along the line under the 'double circulation' pattern in the post epidemic era, and realise a higher level of opening up in stabilising China's foreign trade economy and even the world's economy (Golrizgashti et al., 2019).

Fan and Hua (2020) put forward a vertical market mechanism for the technical synergy analysis of industrial chain. Through the vertical market mechanism, the innovation knowledge and innovation orientation of the industry chain were fused, and the opportunities and challenges faced by China's supply chain under the new crown pneumonia epidemic situation were analysed. While coping with the public crisis, efforts should be made to accelerate the 'going global' strategy, develop in coordination with other countries, and improve the effect of technological collaborative innovation in the industrial chain. However, the overall research process of this method is time-consuming and difficult to be widely used. The scholar Guo (2020) put forward the analysis method of industrial chain related innovation effect of input-output model. With the method, the correlation between industrial chain and innovation effect by constructing input-output model was obtained; the innovation effect types were classified by the relationship between products and benefits. The direct distribution coefficient was calculated, and industrial correlation analysis was thus realised by using genetic algorithm. However, this method has the problem of high research cost. Sun et al. (2020) put forward the analysis of synergy effect of energy industry chain under COVID-19. The heterogeneity of industrial chain was analysed, and the economic development of energy industry chain was promoted through digital transformation to enhance the toughness of industrial chain. However, the analysis accuracy of this method still needs to be further improved.

All of the above methods can promote the development of industrial chain economy, but there is a problem that the analysis is not comprehensive when we study the effect of industrial chain technology innovation under the 'double cycle' pattern. Therefore, this paper studies the effect of industrial chain technology innovation under the 'double cycle' pattern in the post epidemic era. The overall scheme of this study is as follows:

Firstly, based on CCR model of DEA linear programming model, the fractional and integral programming functions of industrial chain are constructed.

Secondly, based on the above planning function, the Chames-Cooper transformation method is adopted to calculate the BCC model of enterprise industrial chain innovation effect. According to the calculation results, the network SBM model is used to obtain the data efficiency value of the technological innovation effect of the industrial chain under

the 'double cycle' pattern, and the analysis of the technological innovation effect of the industrial chain is completed.

Finally, a case study is carried out.

2 Research on the effect of technological innovation in industrial chain

2.1 Integral programming of CCR model

DEA is a linear programming model. Its evaluation object is relatively general (Fan et al., 2018). Many of the objects can be included in its evaluation. These objects are usually described as decision making unit (DMU). The main model form of DEA related to this article will be introduced below (Zhang et al., 2018). The proposal of the CCR model also marks the beginning of the study of the DEA theoretical system (Pietrobelli and Staritz, 2018).

It is supposed that there are n DMU (DMU_j, j = 1, 2, …, n); U is the output of industrial chain innovation technology; V is the input of industrial chain innovation technology; X_{ij} is the i^{th} input variable of enterprise industrial chain innovation technology DMU_j, and y_{rj} is the r^{th} output variable in the innovation goal of enterprise industry chain of DMU_j (Silva et al., 2017). The input of DMU_j is expressed by X, and the output of DMU_j DMU J is expressed by y_{rj}. According to the objectives of this paper, the input-oriented CCR model is shown in formulas (1)–(3) fractional programming and formulas (4)–(6) integer planning (Dehghanpoor, 2019):

$$\max \sum\nolimits_{x=1}^{s} u_r y_{ro} \Big/ \sum\nolimits_{i=1}^{m} v_i y_{io} \tag{1}$$

$$\text{s.t.} \frac{\sum_{r=1}^{s} u_r y_{rj}}{\sum_{i=1}^{m} v_i y_{ij}} \le 1,\ j = 1, 2, \ldots, n \tag{2}$$

$$v_i,\ y_i > 0,\ i = 1, 2, \ldots, m,\ r = 1, 2, \ldots, s \tag{3}$$

Through the Chames-Cooper transformation (Wang et al., 2018), the integral plan is obtained and shown in equations (4)–(6):

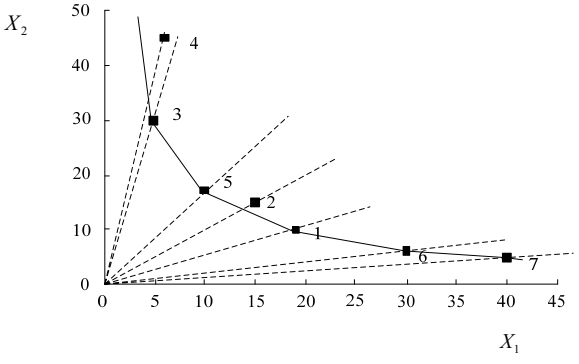
$$\text{s.t.} \sum\nolimits_{r=1}^{s} u_r y_{ri} - \sum\nolimits_{i=1}^{m} v \le 0,\ j = 1, 2, \ldots, n \tag{4}$$

$$\sum\nolimits_{r=1} v_i X_{io} = 1 \tag{5}$$

$$u, v, i = 1, 2, \ldots, m,\ r = 1, 2, \ldots, s \tag{6}$$

According to the planning results, this relatively effective method with complete theoretical basis and wide application fields can be applied to evaluate the innovation effect. After completion of the above planning, the projection of DMU can be obtained. The DMU projection is shown in Figure 1.

Figure 1 DMU projection diagram



In the above process, CCR model of DEA model is used to make integral planning for innovation technology of enterprise industrial chain, and DMU projection is constructed to provide data basis for the measurement of technology innovation effect of industrial chain.

2.2 BCC model calculation of technological innovation effect of industrial chain

CCR includes both 'scale effectiveness' and 'technology effectiveness' evaluation. Therefore, in order to distinguish the low performance of measurement from that caused by scale impact or technology impact (Wang et al., 2018). On this basis, the factor of 'return to scale' is added to build BCC model. BCC model can improve enterprise efficiency by implementing mode innovation of enterprise industrial chain. The weight of innovation effect of industrial chain is calculated by the multi-objective decision-making characteristics of CCR model (Hong et al., 2019). The improved CCR model is BCC model for profit calculation after technological innovation of enterprise industrial chain (Ma, 2019). In this case, the BCC model for measuring the technological innovation effect of industrial chain is expressed as equations (7)–(11):

$$\min \theta_0 \tag{7}$$

$$\text{s.t.} \sum_{j=1}^{n} \lambda_j X_{ij} \le \theta_0, X_{i0}, i = 1, 2, \ldots, m \tag{8}$$

$$\sum_{j=1}^{n} \lambda_j y_{rj} \ge y_{r0}, r = 1, 2, \ldots, s \tag{9}$$

$$\sum_{j=1}^{n} \lambda_j = 1 \tag{10}$$

$$\lambda_j \ge 0, \ j = 1, 2, \ldots, n \tag{11}$$

The performance evaluation is carried out based on DEA method. For the above formula, λ_j represents the innovation production function of the enterprise industrial chain. With the BCC model, the weight extremum of the innovation production function can be acquired by obtaining the relevant parameters of the enterprise innovation effect (Pu and Yang, 2020), and a group of technical profit series of the industrial chain can be acquired

by dimensionless processing. In addition, the lower boundary of the technical innovation effect of the industrial chain can be acquired by calculating the minimum value to determine the effect of technological innovation in the industrial chain.

Therefore, the paper studies the technological innovation effect of industrial chain with the 'double cycle' pattern according to the BCC model of the industrial chain technology innovation effect.

3 Research on the technological innovation effect of industrial chain in 'double cycle' pattern

3.1 SBM model construction

Based on the combinatorial thinking, SBM and network DEA are effectively combined to form a network SBM model, which is called NSBM for short. It is a non-radial DEA model. Based on the above mentioned selection of input oriented SBM (Zhao, 2020), it is combined with network DEA to form an input oriented network SBM model, that is, an input-oriented NSBM model:

$$\rho_0^* = \min \sum_{h=1}^{k} \omega_h \left(1 - \frac{1}{m_h} \sum_{i=1}^{m_h} \frac{S_i^{h-}}{X_{io}^h}\right) \tag{12}$$

$$\text{s.t.} \sum_{j=1}^{n} \lambda_j^h X_{ij}^h + S_i^h = X_{i0}^h, i = 1, 2, \ldots, m_h \tag{13}$$

$$\sum_{j=1}^{n} \lambda_j^h y_{rj}^h - S_i^{h+} = y_{r0}^h, r = 1, 2, \ldots, r_h \tag{14}$$

$$\sum_{j=1}^{n} \sum_{F(h,h')\equiv 1}^{F(h,h')} \lambda_j^h Z_{f(h,h'),j}^{(h,h')} \equiv \sum_{j=1}^{n} \sum_{f(h,h'')\equiv 1}^{F(h,h')} \lambda_j^{h'} Z_{f(h,h'),j}^{(h,h')}, \quad f\left(h, h'\right) = 1, 2, \ldots, F\left(h, h'\right) \forall \left(h, h'\right) \tag{15}$$

$$S_i^{h-} \geq 0, i = 1, 2, \ldots, m_h \tag{16}$$

$$S_i^{h+} \geq 0, r = 1, 2, \ldots, r_h \tag{17}$$

$$\sum_{j=1}^{n} \lambda_j^h = 1, \lambda_j^h \geq 0, j = 1, 2, \ldots, n \tag{18}$$

$$\sum_{h=1}^{k} \omega_h = 1, \omega_h \geq 0, h = 1, 2, \ldots, k \tag{19}$$

3.2 Evaluation of technological innovation effect of industrial chain

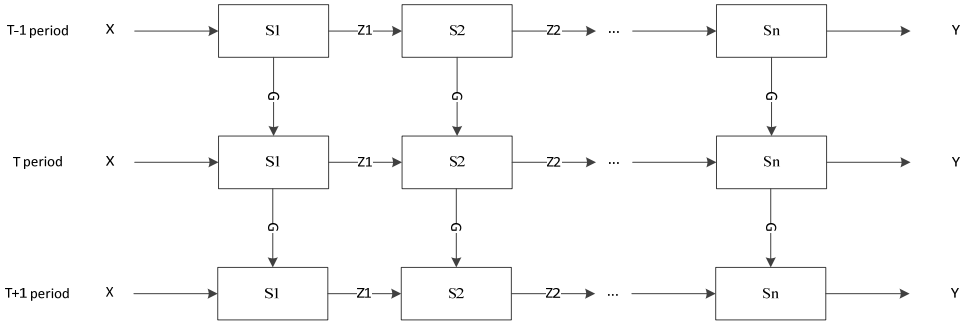
In order to realise the effective evaluation of the technological innovation benefit of the industrial chain, the input and output indexes of the evaluation are explained. The input and output indicators are shown in Table 1.

Table 1 Input and output indicators

Index type	*Index name*
Input index	Main business cost
	Total assets
	Total assets
	Current assets
	Intangible assets
	Current liabilities
	Non-current liabilities
	Total liabilities
	Management expenses
	Selling expenses
	Financial expenses
	Number of ordinary shares
Output index	Main business income
	Total profit
	Net profit
	Owner's equity
	Earnings per share
	Net assets per share
	Cash content per share
	Net cash flow from operating activities
	Net cash flow from investment activities
	Net cash flow from financing activities
	Balance of cash and cash equivalents

Based on the research experience of some scholars, this paper proposes to add the time carry forward variable to further improve the network SBM model and observe the efficiency difference brought by the time benefit, that is, to improve the NSBM model into the dynamic network SBM model, which is called DNSBM model for short. The operation mechanism of DNSBM model is shown in Figure 2.

Figure 2 Schematic diagram of operation mechanism of DNSBM model



In Figure 2, Z represents the intermediate output, while g represents the transition product between two periods, which is used to transfer the transition between two stages to form relevance. In order to show the core content conveniently, other input-output variables of each sub stage are not shown in the diagram. Therefore, the constructed DNSBM model combines the advantages of network SBM model and window DEA (Wang et al., 2020), which makes the analysis results more realistic. The formula of dynamic network SBM model based on input oriented is shown in formulas (20) to (22):

$$\rho_0^* = \min \sum_{t=1}^{T} \omega^t \left\{ \sum_{h=1}^{k} \omega_h \left(1 - \frac{1}{m_h} \sum_{i=1}^{m_h} \frac{s_i^{ht-}}{X_{io}^{ht}} \right) \right\} \tag{20}$$

$$\text{s.t.} \sum_{j=1}^{n} \lambda_j^{ht} X_{ij}^{ht} + S_i^{ht} = X_{i0}^{ht}, i = 1, 2, \ldots, m_h \tag{21}$$

$$\sum_{j=1}^{n} \lambda_j^{ht} y_{rj}^{ht} - S_r^{ht+} = y_{r0}^{ht}, r = 1, 2, \ldots, r_h^g \tag{22}$$

Window DEA model, in essence, regards the same DMU in different periods as different DMUs (Zhang et al., 2020a). For example, it regards the innovation activities in the same industry in 2015 and 2016 as two different DMUs, and then evaluates the relative efficiency by calculating the mean value of innovation performance in the same year from different windows. The main work flow after the combination of window DEA and network SBM model is as follows. The panel data of DMU to be evaluated are sorted by time, as shown in formula (23):

$$Mt_o : X_{ij}(t_o), y_{rj}(t_o); o = 1, \ldots, p, i = 1, \ldots, n, j = 1, \ldots, m, r = 1, \ldots, s \tag{23}$$

The window width is set to W, that is, each window includes W adjacent periods. Then the window includes [n * W decision unit (Zhang et al., 2020b)]. It is supposed that the research window is 3, the window between 2011 and 2013 included 2011, 2012, and 2013), the window between 2012 and 2014 included 2012, 2013, 2014), and so on. Then the network SBM model is used to calculate the DMU in each window (Zheng and Fang, 2020). Because the improved dynamic network SBM model improves the network DEA model by adding time transition variables to achieve the efficiency value of panel data (Hao, 2020), which combines the advantages of window DEA and uses window DEA to build, making the results of dynamic network DEA more effective.

Through the above calculation, the CCR model in DEA model is used to make the overall planning of enterprise industrial chain innovation technology, and construct DMU projection. The BCC model is used to calculate the relevant parameters of enterprise innovation effect, obtain the weight extremum of innovation production function, and realise the calculation of technological innovation effect of industrial chain.

4 Experiment

4.1 Research scheme design

4.1.1 Data sources

The basic data of this paper come from the statistical data of the national intellectual property website from 2014 to 2020. This paper makes statistics on the main economic indicators of national high-tech enterprises and the data of China's high-tech enterprises, and then divides the data of five major industries into 17 industries according to the industry classification of China's high-tech industry (manufacturing industry) to study the innovation status of enterprises in different industries. In this paper, through maxDEA 7.0 software, we used the improved dynamic network DEA model to calculate the innovation performance value of each DMU to realise the statistical analysis of DEA.

4.1.2 Data processing

The data needed for screening were collected according to the variable indicators of the following empirical study and the comparative years used in descriptive statistical analysis and empirical analysis. In order to avoid the limitation of data, the starting point of selection is to select the decision-making unit with complete data. There are many input-output variables of innovation performance evaluation studied in this paper. In order to improve the accuracy of data analysis, it is required to increase the number of decision-making units. Therefore, according to the statistical classification of China's high-tech industry yearbook, we subdivided the five high-tech industries into 17 industries, and the data of the same kind and individual name change are integrated in the industry segmentation according to the starting point of data integrity selection to maintain the integrity and consistency of the data.

In the process of sorting out the basic data, according to the data of *China Statistical Yearbook*, the price index table of 2014–2020 was sorted out. Because the statistics in the yearbook were the data of the same year, this paper converted the 2015 index to 100, and summarised the converted price index of technological innovation effect of industry chain into the same table. The price index of technological innovation effect of industrial chain is shown in Table 2.

Table 2 Price index of technological innovation effect of industrial chain

Date	*Consumer price index*	*Enterprise production price index*	*Fixed assets investment index*	*Composite price index*
2014	103.6	107.4	108.0	105.2
2015	104.2	105.7	106.3	104.5
2016	112.3	103.0	108.2	103.7
2017	115.6	101.8	112.6	105.2
2018	117.3	100.2	115.2	108.5
2019	119.2	98.3	116.8	106.3
2020	122.1	94.2	118.3	109.1

The average value of each year is calculated as the weight average of the price index of the three. The average value of the price index of labour cost, instruments and equipment

(i.e., assets) and others (such as raw materials) calculated from 2014 to 2020 is 36.07%, 9.68% and 54.25% respectively. Therefore, in this study, the price index obtained by the data reduction of internal expenditure of enterprises is the price index table after the weight of the three price indexes calculated above multiplied by the corresponding price index results converted to 100 in 2015.

4.1.3 Experimental scheme

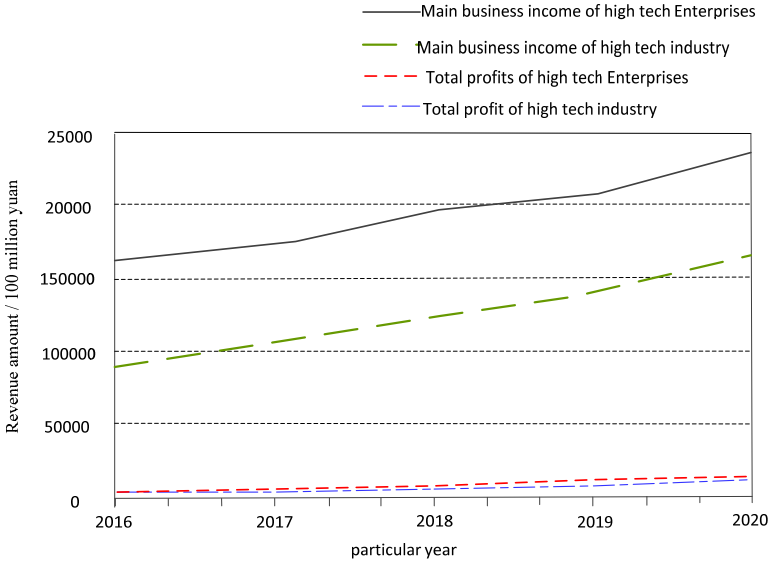
Based on the above experimental data processing results, a comparative experiment was carried out, and the overall experimental scheme was set as follows: analyse the overall basic situation of enterprise business income and profit and the main business income. On this basis, analyse the enterprise profit margin of extending the industrial chain and connecting the industrial chain before and after technological innovation, so as to verify the impact of technological innovation on the income of the industrial chain.

4.2 Analysis of research results

4.2.1 General information

In order to analyse the technological innovation effect of industrial chain under the 'double cycle' pattern in the post epidemic era, we first obtained the overall basic situation of business income and profit. The overall situation of business income and profit is shown in Figure 3.

Figure 3 Overall business income and profit (see online version for colours)



According to the data collected during the 12th Five Year Plan period and the first year of the 13th Five Year Plan period, it is found that the overall production and operation of high-tech enterprises in China are in good condition. The main business income of high-tech enterprises in 2020 is 1.44 times of that in 2016; the main business income of

high-tech industry in 2020 is 1.95 times of that in 2016; compared with the same period last year, the main business income of high-tech enterprises in 2019 was 1.06 times that in 2018, and the total profit in 2020 was 1.57 times that in 2016. The development of production and operation of high-tech industry is consistent with the overall development trend of high-tech enterprises. The overall main business income and total profit are on the rise. Based on the overall trend consistency, this paper analyses the development of innovation performance of high-tech enterprises by selecting the innovation development of high-tech industry. According to the comparison results, the main business income and profit are increasing year by year, but the growth rate of profit is greater than that of operating income. This reason, from the perspective of enterprise characteristics, may be brought about by the effect of scientific and technological innovation and continuous improvement of innovation performance. It also shows that enterprises can bring higher profits through innovation activities.

4.2.2 Changes in main business income

In order to verify the effect of technological innovation in the industrial chain under the 'double cycle' pattern in the post epidemic era, this paper reflected the effect of technological innovation in the industrial chain by analysing the changes of main business income in different regions. The changes of main business income in different regions are shown in Table 3.

Table 3 Changes of main business income in different regions

Particular year	*Main business income change/100 million yuan*			
	Eastern region	*Central region*	*Western region*	*Northeast China*
2014	68,000	8,760	6,754	1,234
2015	79,000	9,780	7,532	1,764
2016	85,000	9,980	8,325	1,875
2017	90,000	11,086	9,753	1,987
2018	100,000	11,990	9,987	2,012
2019	115,000	12,646	10,953	2,197
2020	132,000	15,895	11,075	2,351

According to the analysis of Table 3, in 2014, the main business income of the eastern region was 6,800 billion yuan; that of the central region was 876 billion yuan; that of the western region was 675.4 billion yuan; and that of the northeast region was 123.4 billion yuan. By 2020, the main business income of the eastern region will increase to 13,200 billion yuan; that of the central region to 1,589.5 billion yuan; that of the western region to 1,107.5 billion yuan; and that of the northeast region to 235.1 billion yuan. It can be seen from Table 3 that the business income of the eastern region is much higher than that of the other three regions, which is related to the rapid development of industrial chain technology in the eastern region, reflecting that the technological innovation effect of industrial chain can enhance business income and promote regional economic development.

4.2.3 Enterprise profit rate of extending industrial chain and connecting industrial chain

In order to verify the impact of innovation effect on improving the profit efficiency of enterprises with extended industrial chain and connected industrial chain, eight enterprises with extended industrial chain and eight enterprises with connected industrial chain were selected to calculate their profit rate before and after technology. As shown in Figures 4 and 5 respectively.

Figure 4 Extension of industrial chain

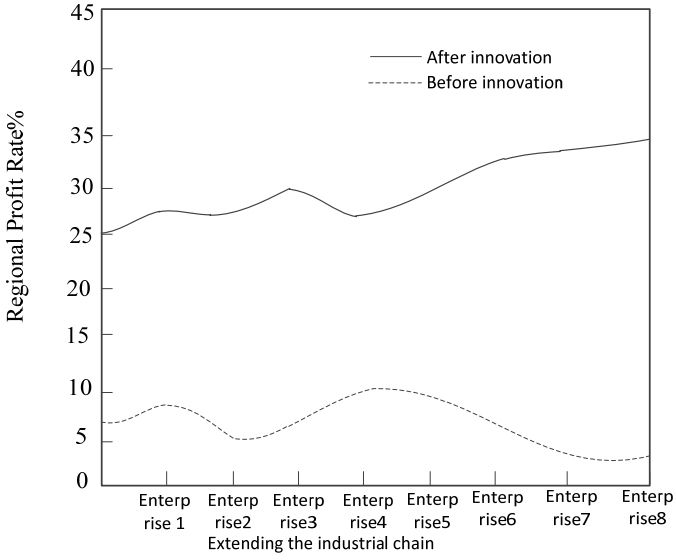
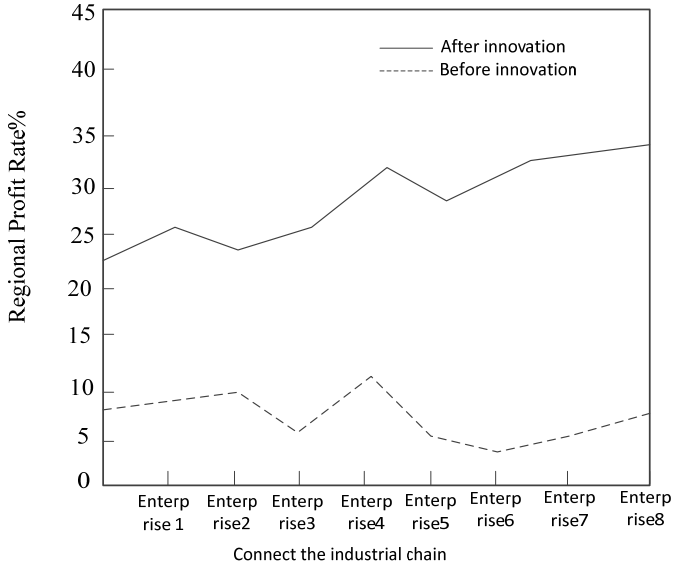


Figure 5 Connection of the industrial chain



According to the analysis of Figure 4, the profit margin of eight enterprises extending the industrial chain is calculated. For enterprise 2 and enterprise 5, the change of theoretical profit rate before and after technological innovation is more obvious than that of other enterprises, and the overall profit rate level of 8 enterprises after technological innovation has been significantly improved. The result of the above obvious changes is that through technological innovation, a series of costs in the production process can be reduced, and the production speed can be improved, so enterprises can make more profits for its extended related industries.

From the analysis of Figure 5, we can see that eight enterprises connected to the industrial chain are selected to calculate their regional enterprise profit margin results. For enterprise 2, the profit margin is 10.6% before technological innovation and 24% after technological innovation; for enterprise 8, the profit rate is 9.5% before technological innovation and 34.2% after technological innovation. The results show that the technological innovation of industrial chain has a certain role in promoting economic development under the 'double cycle' pattern.

5 Conclusions

The technological innovation effect of industrial chain under the 'double cycle' pattern in the post epidemic era is studied in this paper. The distributed planning and integral planning functions of industrial chain is obtained, and the BCC model calculation results of enterprise industrial chain innovation effect are determined; The network SBM model is used to obtain the data efficiency value of industrial chain technology innovation effect under the 'double cycle' pattern, so as to realise the analysis of industrial chain technology innovation effect. By analysing the profit rate of enterprises extending and connecting the industrial chain, it is verified that the technological innovation of industrial chain has a certain role in promoting economic development under the 'double cycle' pattern.

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