Measurement of Tobacco Enterprise Technological Innovation Capacity and Synergetic Development Mechanism Based on DEA Model

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Adherence to new development concept, integration of integrity and innovation, and improvement of enterprise technological innovation capacity are the essence of new economic development in China. Tobacco economy is an important part of national economy, whose development is facing the internal and external pressure of development. Therefore, the enterprises above the designated scale in Shandong Province from 2011 to 2019 are selected as the holistic research sample to measure the R&D input-output index by DEA non-parametric method. It is found that (1) the technological innovation capacity of enterprises has been greatly improved but not reached the leading edge level; (2) the efficiency of technological innovation of enterprises has changed in the form of V; (3) the redundancy of full-time personnel equivalents exists and the technological efficiency and scale benefit do not meet the development expectation. The study indicates that the Chinese government should treat the development of tobacco economy carefully, adopt multiple measures of regulation and control, construct a healthy and synergetic development mechanism with the participation of innovation subjects, and realize the agglomeration and optimization of innovation factors, so as to make the development of tobacco enterprises meet the economic needs of China in the new era.

Keywords: tobacco economy; innovation capacity; DEA method; synergetic development
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1. Introduction

With the significant development of the trend of economic globalization, China's economic development has also entered a new historical period, in which a new round of scientific and technological revolution and industrial revolution gradually deepen, and the new norm becomes a new label of economic development. In this context, the Chinese government put forward the strategy of innovation-driven development at the 18th National Congress of the Communist Party of China to make technological innovation a strategic support for the all-round development of social productivity under the development pattern of the new era. The publication of National Innovation-Driven Development Strategic Outline (2016) has laid an important position for technological innovation at the national level, with a view to continuously promoting technological innovation through relevant policies and thus further stimulating economic development.

The Outline of the National Long-term and Medium-term Scientific and Technological Development Plan (2006-2020) clearly states that it is necessary to "improve the capacity of independent innovation and build an innovative country", and to use it as an important strategic requirement and evaluation index in all fields of China's future economic and social development. In the same way, the 19th National Congress of the Communist Party of China held that innovation was the primary source of development. From the perspective of globalization of economic development, the agglomeration of innovative factors of production can drive economic development and regional social change. The global outbreak of COVID-19 in 2020 has put forward higher requirements for the sustainability of economic development and the endogenous power of science and technology. It also makes the ability of independent innovation become the survival and decisive factor for the development of enterprises in the normalized and abnormal economic field. In the Recommendation of the CPC Central Committee on Making the Fourteenth Five-Year Plan for National Economic and Social Development and the Vision Target for 2035, it is pointed out that "the new development concept, the unity of integrity and innovation, and the enhancement of enterprises' technological innovation capacity should be adhered to." Enterprises should play an active principal role in the development of innovation and attract and optimize various innovative elements.

The tobacco economy plays an important role in China's national economy, which is an essential source of government revenue. In 2020, the total profit of China's tobacco industry was 12800.3 billion yuan, up 6.2% year on year, with 1203.7 billion yuan turned over to the government, up 2.3%. Since China officially became a state party to the WHO Framework Convention on Tobacco Control in 2003, China's tobacco industry under the state monopoly system has been facing internal and external development pressure, and had to make appropriate adjustments and adopt more moderate reform strategies. In 2016, the "*Healthy China 2030*" plan was officially promulgated. Based on the population health strategy, the Chinese government emphasized that it will take 15 specific actions to promote the health and well-being of the Chinese people for the first time. The "*Healthy China 2030*" Plan is also regarded as an opportunity and a commitment by the Chinese government to strengthen the enforcement of tobacco control.[1] At present, when tobacco control has become a global consensus, in order to build modern governance capability and governance system, Chinese government must carefully weigh and resolve the contradiction between tobacco control and economic development, and seek an industrial transformation road, which is based on technological innovation, for the development of the tobacco economy.

At present, China's North-South economic innovation driven development is increasingly differentiated, and Shandong is in a critical period of accelerating progress from transitional development to innovative development. As a traditional agricultural economic crop in Shandong province, the tobacco industry is an important project for farmers to generate income and increase tax. In Shandong province , the tobacco industry has formed its own brand series, with as many as ten famous tobacco brands in market, some of which have become internationally competitive and are sold all over the world. There are two large tobacco groups here, both of which are enterprises above the scale. These two groups are still under the government's mode of "unified leadership, vertical management, and monopoly".

How to promote technological innovation, speed up the construction of a strong province with science and technology, and promote high-quality tobacco industry development is a common problem faced by the government, tobacco enterprises and other multi-market players. What is the relationship between enterprise science and technology innovation and R&D input-output? How should the Chinese government construct a synergistic innovation mechanism under the new economic development pattern? The above problems will provide beneficial Shandong experience for tobacco enterprise technological innovation from the empirical point of view.

2. Literature Review

2.1 Research on enterprise innovation capacity

The research on enterprise innovation capacity stems from the rapid prominence of scientific and technological power in the western industrial tide. The concept of "technological innovation" first appeared in Schumpeter's *Economic Development Theory*, which pioneered the development of economic innovation theory on the basis of technological innovation. Enterprise innovation serves the production purpose of sustainable development of enterprises, and produces products or services with higher value through processing or restructuring by using the internal production factors of enterprises. It can be divided into technological innovation, thinking innovation, management mode innovation and cultural system innovation according to different contents. Fritsch and Slavtchev[2] discussed in detail the possible influencing factors of the efficiency of regional innovation systems and concluded that knowledge spillover between public research institutions and the private sector often has a positive impact on the organization's innovation activities, as well as population density, which has a positive impact on innovation performance. Hurtado-Torres[3] believed that developed countries can provide an effective way for enterprises in their countries to grow their performance, and high-quality enterprises with high performance, which can be imitated, can be used as development blueprints. In terms of enterprise innovation capacity evaluation, foreign experts Cohen and Levinthal[4] and Schildt[5] agreed that the measurement of enterprise technology absorbability can be used as an important indicator of enterprise R&D investment. Du Jinmin[6] et al. believed that R& D investment of Chinese enterprises has a high conversion rate for innovation patents. Zou Ying et al.[7] believed that technological innovation has a positive role in improving the competitiveness of enterprises and reducing the cost of equity capital.

Since China's attitude towards the global consensus on tobacco control has not been extremely firm, the government has been attacked by public opinion. The relevant critical research is mainly dominated by foreign scholars. At the same time, a small number of domestic scholars have participated in this debate. The analysis of the tobacco monopoly system, local tobacco economy, and tobacco technology are the key questions which brings the blame of the disadvantages of tobacco control in China.[8] There is not so much research on the issue of technological innovation and coordinated development of tobacco enterprises.

2.2 Research on DEA Model

Data Envelopment Analysis (DEA), a purely quantitative mathematical model, is commonly used to evaluate the input and output efficiency of Decision-Making Unit (DMU). Operational research experts Charnes and Cooper first proposed this data analysis method, which has become a relatively mature and widely used evaluation method in the comprehensive evaluation method. In this method, input and output indicators are set, and decision units are projected to the production frontier using the linear programming of the model and the panel data collected to further measure the deviation degree of decision units, thus evaluating the input and output efficiency of decision units. Domestic and foreign scholars not only use DEA model to measure utility efficiency in various fields of economic and social development, but also gradually improve the non-parametric method of DEA in practice. Lewis[9] et al. used the network DEA model to determine the output efficiency of subunits. Chinese scholar Wei Quanling[10] cooperated with A. Charnes and W. Cooper to introduce Data Envelopment Analysis (DEA) into Chinese theoretical circle and created CCWH model, which further enriched the theoretical system and practical value of DEA model.

Compared with other models, DEA method can adopt several adjustable models to quantify the correlation of decision units from different perspectives. The research and application of DEA method are more extensive in China. In the field of technological innovation, DEA is also one of the main methods to implement scientific research performance evaluation and resource allocation, but mostly focuses on regional innovation, provincial and municipal innovation, enterprise innovation, university management, etc. When Chinese scholars evaluate scientific research performance, they directly substitute the scientific research input and output of the evaluated object into the model for efficiency calculation without analyzing the internal mechanism of the decision-making units (DMUs). Xia Caiyun et al.[11] accurately calculated the R&D efficiency of science and technology in multiple provinces and cities in China using the DEA-Malmquist index method, and believed that technological progress is an important factor to promote the efficiency of technological innovation. Wang Weiji[12] constructed a "standard index" to be used as a key index for evaluating the innovation efficiency of high-tech industries. Li Jiang et al.[13] innovatively adjusted the input and output of resources in two directions by using the non-oriented model.

A comprehensive review of the existing literature shows that there are relatively many studies on the index system of technological innovation achievements in the above aspects, but few studies on the factors influencing the internal measurement of tobacco enterprises' technological innovation capabilities, and the research on the development mode of collaborative innovation is still in the exploratory period.

3. Variable Selection and Research Design

This study mainly discusses and focuses on the independent innovation capability of enterprises above designated size in Shandong Province, meanwhile constructs the innovation capability of tobacco enterprises through the universal characteristics of innovation capability of these enterprises. In a certain policy environment, the calculation scope of the measurement of the enterprise's independent innovation capacity needs to be fixed in a specific region. If the calculation scope is increased, it means that there is a big error in the accuracy of the enterprise's innovation capacity assessment. Therefore, in this study, large-scale enterprises are set as the economic regions within the province, and the ability of independent innovation is mainly represented by the ability of technological innovation and the transformation level of scientific and technological achievements, because in this study, the ability of technological innovation of enterprises is mainly assessed through the DEA model.

3.1 Evaluation Model - Non-parametric DEA Method

The DEA method can calculate multi-input and multi-output, calculate the allocation result which is in line with the decision unit game strategy by integrating the information and characteristics of the evaluation object after the production frontier is constructed, and can directly obtain the redundancy value and the improvement value of the decision unit without predicting and setting a production function, so it is remarkably superior to other calculation models.

A precondition for the use of nonparametric methods is that the technical conditions are irreversible. On this basis, a three-dimensional measurement index system is constructed in this study, namely, input index, enterprise activity and business efficiency, among which R&D activity personnel FTE and R&D expenditure are selected as input indexes, effective patents and R&D new product projects are selected as output indexes for measuring enterprise innovation activity, and new product sales revenue and technology market turnover are selected as output indexes for measuring business efficiency.

When using DEA data envelopment method to evaluate the technological innovation capacity of enterprises with uncertain preference information of related variables, two data envelopment models are usually used, one is Constant Returns to Scale (CRS) model, which is usually called CCR model, and the other is Variable Returns to Scale (VRS) model, which is called BCC model by researchers. The latter is evolved from the former, which is the optimization and perfection of CCR model. In this paper, considering the variability of enterprise innovation capacity, BCC Variable Returns to Scale model is adopted. In BCC model, technical efficiency can be divided into pure technical efficiency and scale efficiency, and the latter can be measured under variable conditions, and certain constraints can be added to CCR model, which can be distinguished from the equations of the two models.

It is assumed that there are n DMUs (DMU_j, j=1, 2,… , n), and each DMU_j (j= 1, ..., n) contains m types of inputs X_{ij} (i=1, ..., m) and produces s types of outputs Y_{rj} (r =1, …, s). $X_j = (X_{1j}, \ldots, X_{mj})^T$ and $Y_j = (Y_{1j}, \ldots, Y_{sj})^T$ are used to represent the input and output vectors respectively. Superscript t stands for transpose. $X=(X_1 \ldots X_n)$ represents the input matrix, and $Y=(Y_1 \ldots Y_n)$represents the output matrix. The evaluated decision unit is denoted as DMU_0, and its input and output vectors are X_0 and Y_0, respectively.

$$Min\,\theta - \varepsilon\,(S^- S^+)$$

$$s.t.\,.\begin{cases}\theta X_0 - S^- = X\lambda \\ Y_0 + S^+ = Y\lambda \\ \lambda,\ S^+ S^- \geq 0\end{cases}$$

Input-oriented CCR model is as follows:

Where, θ represents the efficiency value of unconstrained DMU, $\lambda=(\lambda_1,\ldots\lambda_n)^T$ is a "structure" variable vector, and S^- (input relaxation variable), S^+ (output relaxation variable) represent input redundancy and output insufficiency respectively, non-Archimedes infinitesimal and defined as less than any positive number. Assuming that convex constraints are added, the CCR model can be solved.[14]

Compared with CCR model, BCC model has one more constraint condition $\sum\lambda_j=1$, so the relative technical effectiveness among DMUs can be compared. BCC model is as follows:

$$st\ldots \frac{\sum_{r=1}^{k} u_r y_{rj}}{\sum_{i=1}^{l} v_i x_{ij}} \leq 1 (j = 1,2,\ldots,\ n, \sum \lambda_j = 1)$$

$$\max h_{j0} = \frac{\sum_{r=1}^{k} u_r y_{rj}}{\sum_{i=1}^{l} v_i x_{ij}}$$

Where, s=the number of input variables;

m=the output variable;

r ranges from 1 to k, and i ranges from 1 to l.

3.2 Construction of Evaluation Index System and Data Sources

3.2.1 Index system

There are three main factors that can

influence the independent innovation capacity of enterprises in production and operation: the investment of R&D funds, the investment of R&D personnel and the input of necessary material resources for related scientific and technological activities. Therefore, in this study, the construction of enterprise technological innovation capacity evaluation index system is mainly considered from three main dimensions, namely, input of scientific and technological elements, output of scientific and technological elements and business application. The input index of scientific and technological elements is divided into two aspects: human resources input and material input. The output index of scientific and technological elements mainly chooses from two aspects: the number of effective patents and the number of new products. In commercial applications, the actual revenue resulting from new R&D products, as well as technical outputs, needs to be fully considered. The index system determined in similar studies in the existing research literature has some reference significance for this study. In this study, the full-time equivalent of R&D personnel and R&D expenditure are included in the input index of science and technology elements, the input index is the expenditure of new product development, the output index is the number of valid patents with high activity and the number of new product projects every year, and the sales revenue of new products and the market turnover of technical products are taken as the output indexes. According to the scientific, effective, systematic, accurate, independent and complete indicators selected, the evaluation system of technological innovation efficiency of Shandong province was established, as shown in Table 1.

Table 1 Evaluation indexes of technological innovation capacity

Main dimension	Indexes
Investment in scientific and technological elements	R&D expenditure (including internal expenditure and external expenditure) R&D personnel full-time equivalent
Output of technological innovation	Number of valid patents Number of R&D new product projects
Commercial applications	Sales revenue of new R&D products Technical market turnover

3.2.2 Data specification

All data in this study are from the annual provincial data of the National Bureau of Statistics of China and the data of the Shandong Science and Technology Department and the Bureau of Statistics. In particular, due to different statistical specification, data under the same statistic are often different in the data collection stage, and the same data source is uniformly used for this part of data after cross-acceptance.

Because of the lag of statistical data, this study only systematically analyzes the data of R&D input and output in China from 2011 to 2019, and evaluates the efficiency of R&D resource allocation and the independent innovation capacity of enterprises. Among them, the data of the number and amount of loss-making enterprises in 2019 is still unavailable, which is zero in the overall analysis. However, the data does not participate in the construction of DEA model, and its impact on empirical research may not be considered. Besides, the outbreak of COVID-19 epidemic in 2020 has brought many uncontrollable factors in economic development, and all kinds of data collection were lagging behind and non-representative, so they were not used in the model.

Because the nonparametric DEA model has flexible analysis characteristics and does not need to set a clear regression coefficient in advance, it can be measured as long as each input and output index (A1-A4; B1-B2) keeps its data unit unified without unifying the measurement unit among the input and output indexes.

3.3 Empirical Analysis on enterprise's technological innovation capacity

3.3.1 R&D input and R&D resource allocation status (2011-2019)

R&D efficiency is the basic content of enterprise independent innovation capacity and technological research and development activities. Its effective implementation can promote the realization of enterprises' competitiveness to a great extent, and has an important influence on sustainable development and economic growth. Since the "12th Five-Year Plan" of the national economy, China's R&D investment has shown an obvious trend of total growth, and the proportion of R&D investment of enterprises above designated scale in the national R&D investment has also increased rapidly. The time series selected in this paper is 2011-2019. 2011 is an important year because the outline of the 12th Five-Year Plan for Science and Technology Development (2011-2015) in Shandong Province has just started this year. In 2011, the expenditure on R&D in Shandong Province was 74.31 billion yuan, while in 2019 it was 121.09 billion yuan, an increase of 16 times. Local fiscal expenditure on science and technology increased from 10.86 billion yuan in 2011 to 30.58 billion yuan in 2019, an increase of 182%. Table 2 shows that R&D investment of large-scale enterprises in the study time series shows two distinct stages, and the trend of each data is different in the development stages of "12th Five-Year Plan" and "13th Five-Year Plan". In the first stage, the number of enterprises above designated scale, R&D funds and investment intensity showed a trend of continuous increase. In the 13th Five-Year Plan period, although the overall growth trend remained unchanged, it occasionally declined, especially in 2019, R&D funds, investment intensity and local government expenditure all decreased significantly. For example, the R&D expenditure in 2015 was 129.18 billion yuan, which reached the peak of expenditure in 2017, but the total expenditure in 2018 and 2019 was less than that in 2015.

Table 2 R&D expenditure and R&D resource allocation from 2011 to 2019

Years	Number of enterprises	Main business income (100 million yuan)	Total profits of enterprises (100 million yuan)	Number of loss-making enterprises	Loss amount (100 million yuan)	R&D expenditure (100 million yuan)	Annual GDP (100 million yuan)	Investment intensity (%)	Local fiscal expenditure on science and technology (100 million yuan)
2011	35813	99766.2	7097.7	1715	230.8	743.1	45361.9	1.6	108.6
2012	37625	118087	8016.4	2301	346.2	905.6	50013.2	1.8	125
2013	40467	132130.3	8715.4	2403	279.4	1052.8	55230.3	1.9	149.1
2014	40756	143140.3	8843.9	2646	357	1175.5	59426.6	2.0	147.1
2015	41485	133507.2	8660.5	3106	525.1	1291.8	63002.3	2.1	159.1
2016	39567	150641.2	8820.0	2781	579.4	1415	68024.5	2.1	167
2017	38147	140856.8	8128.2	3362	613.1	1563.7	72634.2	2.2	195.8
2018	38333	92703.6	4872.2	7047	598.5	1418.5	66648.9	2.1	232.8
2019	28358	84541.9	3652.7	0	0	1210.9	71067.5	1.7	305.8

There are two obvious characteristics in the data time series. First, since 2011, enterprises have kept roughly the same trend as the overall development trend of local economy, and the main business income and total profits of enterprises have obviously increased positively. Second, in 2017, it experienced an obvious demarcation point, because from the beginning of this year, the number of enterprises, main business income, corporate profits and annual GDP all showed a sharp downward trend.

3.3.2 Main problems

(1) R&D expenditure accounts for a low proportion of DGP. The general experience of R&D in developed countries that have experienced a complete industrialization process shows that the ratio of R&D investment to GDP, that is, the investment intensity mentioned in this study, is closely related to the economic development level of the region. In the initial stage of industrialization development, the investment intensity is usually lower than 1.5%, and the medium-term investment intensity can reach about 1.5%-2.5%. Table2 shows that the proportion of independent technological innovation research and development investment of enterprises above designated scale in the GDP of the region where they are located, i.e. the intensity of scientific research investment, is obviously low, reaching a peak in 2017, with a maximum of 2.2%.

(2) The technological innovation capacity of enterprises is greatly influenced by local economy. From 2011 to 2019, the development of enterprises above designated scale was greatly influenced by local economy. Fluctuations in the local economy will seriously affect the number of enterprises above designated scale, main business income, corporate profits, research funding and other aspects. It is very difficult for the technological innovation of enterprises to strip away the shackles of the external economy and form an independent and stable development model, so as to achieve the goal of innovation-driven development.

(3) The effect of factor agglomeration has not appeared. The number of loss-making enterprises above the designated scale increased year by year, while the R&D expenses and input intensity also increased simultaneously. However, the number of loss-making enterprises and the loss amount increased inversely. The loss of enterprises above designated scale was 23.08 billion yuan in 2011 and 61.31 billion yuan in 2017. Thus it is clear that the agglomeration effect of innovation factors in enterprises above designated scale has not appeared.

information from the internet or advertisements which does not support prudent and responsible knowledge. The general score attests to a tendency to take on higher risk in the self-medication process.[35]

3.4 Data Processing and Analysis

The data used in this paper are from *China Statistical Yearbook* and *Shandong Statistical Yearbook*. The number of samples is more than that of input and output, which can basically meet the model requirements of Data Envelopment Analysis (DEA). See Table 3 for specific input and output data.

Table 3 Statistical analysis of R&D investment and output from 2011 to 2019

Years	Input		Output			
	R&D expenditure (100 million yuan)	Scientific and technical activity personnel (FTE)	Number of R&D new product projects	Number of valid patents	Sales revenue of new products (100 million yuan)	Technology market turnover (100 billion yuan)
2011	743.1	180832	23040	11207	11184.4	126.4
2012	905.6	204398	28171	15104	12913.2	140
2013	1052.8	227403	31100	18340	14284.2	179.4
2014	1175.5	230800	34050	26122	14555.8	249.3
2015	1291.8	241395	28306	33785	14698.4	307.6
2016	1415	241761	32952	45917	16313.4	396
2017	1563.7	239170	38273	56076	18126.4	511.6
2018	1418.5	236515	40440	63496	15246.5	820
2019	1210.9	198205	44196	67896	13480.1	1110

In the BCC model, the effective output of each decision-making unit is calculated by DEA analysis software in the results obtained through DEA analysis. Under the output oriented model, the efficiency of technological innovation can be evaluated, the overall efficiency of scientific research input under the variable return on scale (BCC) can be calculated, and the input redundancy of input indexes and the possible output insufficiency of output indexes can be estimated. Table 4 shows a descriptive analysis of input-output variables. Table 5 is a table for measuring and calculating the technological innovation capacity of enterprises above designated scale, in which the technological efficiency refers to the efficiency of technological innovation input under the condition of constant returns on scale. Scale efficiency reflects whether the production scale of decision-making unit is appropriate in time series. Under normal circumstances, the scale efficiency = technical efficiency/pure technical efficiency. The result of pure technical efficiency reflects the technological innovation capacity of decision unit. The technological innovation capacity of DEA effective DMUs is at the best level among all DMUs, while the technological innovation capacity of non-effective DMUs needs to be improved.

Table 4 Descriptive analysis of input-output variables

Years	Number of R&D new product projects （A1）	Number of valid patents (A2)	Sales revenue of new products (100 million yuan) (A3)	Technology market turnover (100 billion yuan) (A4)	R&D expenditure (100 million yuan) (B1)	Scientific and technological personnel (FTE) (B2)
	Output variables				Input variables	
2011	23040	11207	11184.4	126.4	743.1	180832
2012	28171	15104	12913.2	140	905.6	204398
2013	31100	18340	14284.2	179.4	1052.8	227403
2014	34050	26122	14555.8	249.3	1175.5	230800
2015	28306	33785	14698.4	307.6	1291.8	241395
2016	32952	45917	16313.4	396	1415	241761
2017	38273	56076	18126.4	511.6	1563.7	239170
2018	40440	63496	15246.5	820	1418.5	236515
2019	44196	67896	13480.1	1110	1210.9	198205
Mean	33392	37549.22	14533.6	426.7	1197.433	222275.4
Standard error	6674.53	21560.58	1988.299	337.069	262.7805	22217.51

Table 5 Measurement of technological innovation capacity of enterprises

Years	Comprehensive technical efficiency	Pure technical efficiency	Scale efficiency	Returns to scale
2011	1.000	1.000	1.000	-
2012	0.999	1.000	0.999	drs
2013	0.976	1.000	0.976	drs
2014	0.950	0.966	0.984	drs
2015	0.887	0.893	0.993	drs
2016	0.947	0.957	0.989	drs
2017	1.000	1.000	1.000	-
2018	0.932	1.000	0.932	drs
2019	1.000	1.000	1.000	-
mean	0.966	0.980	0.986	

Note: "-"means constant return on scale, and "drs" means decreasing return on scale.

Table 5 shows that from 2011 to 2019, the technological innovation efficiency of enterprises above designated scale in Shandong Province showed a "V"-shaped change. Specifically, the efficiency of technological innovation in 2011-2012 was close to 1, which indicates that the efficiency of technological innovation of enterprises in the above years has reached the frontier level and the ability of technological innovation is good. After 2013, the efficiency of technological innovation began to decline, reaching the lowest level in 2015, with the comprehensive technical efficiency of 0.887, the pure technical efficiency of 0.957 and the scale efficiency of 0.989 in the corresponding year, indicating that 79.63% of the loss of comprehensive technical efficiency comes from the ineffectiveness of pure technical efficiency and 20.37% is due to the loss of scale efficiency. Subsequently, the comprehensive technical efficiency showed an upward trend. In the whole time series year, only the comprehensive technical efficiency in 2011, 2017 and 2019 reached the frontier level, and the enterprises in the above years showed the same return on scale. Comprehensive technical efficiency is the product of pure technical efficiency and scale efficiency. The pure technical efficiency in 2011-2013, 2017-2019 was 1. The comprehensive technical efficiency in 2012, 2013 and 2018 did not reach the cutting-edge level. The efficiency loss is attributed to the loss of scale efficiency. From the perspective of scale efficiency, except for the years when the comprehensive technical efficiency reached the forefront, all the other years showed the loss of scale efficiency and were in a state of diminishing returns to scale. To sum up, in the whole sample period, the comprehensive technical efficiency, pure technical efficiency and scale efficiency of enterprises above designated scale are 0.966, 0.980 and 0.986, respectively. The efficiency of technological innovation has not yet reached the frontier level, and the efficiency loss comes from the ineffectiveness of pure technical efficiency and the loss of scale efficiency.

Table 6 Input-output redundancy analysis

	Output variables				Input variables	
Years	A1	A2	A3	A4	B1	B2
2011	0	0	0	0	0	0
2012	0	0	0	0	0	0
2013	0	0	0	0	0	0
2014	0	5029.127	0	125.685	0	0
2015	4760.436	0	0	49.089	0	195.788
2016	3070.782	0	0	65.023	0	5209.459
2017	0	0	0	0	0	0
2018	0	0	0	0	0	0
2019	0	0	0	0	0	0

The redundant results of input and output over the years are further summarized in Table 6. The first four columns are redundancies of four outputs. A non-zero result indicates an insufficient output for the year, and a larger value indicates a larger shortfall in output. The result of output A1 in 2015 and 2016 is not 0, and the remaining years are all 0, indicating that the number of R&D new product projects in the above years is obviously insufficient, especially in 2015, with a deficit of 4,760.436. Output A2 is not 0 in 2014, indicating a deficit of 5,029.127 valid patents in 2014. The results of output A3 are all 0 over the years, which indicates that there is no deficit in the sales revenue of new products of Enterprises above designated scale. The results of output A4 in 2014-2016 are not zero, which indicates that the transaction amount of technology market in these three years is insufficient, especially in 2014, with a deficit of 12.5685 billion yuan. Similarly, the input situation can be analyzed. A non-zero result means that the input is excessive. The results of B1 input over the years are all 0, indicating that there is no redundancy in R&D investment of Enterprises above designated scale. The results of B2 input in 2015 and 2016 are not 0, which indicates that the redundancy of personnel input in science and technology activities in the above years, especially in 2016, is the most obvious, with 5,209.359 FTE redundancy.

3.5 Empirical Conclusions

3.5.1 Not synergistic scale and efficiency of R&D innovation input of enterprises

Data analysis shows that the innovation efficiency is not necessarily high in the years when the scale of technological innovation capital, total equivalent input and technological output are relatively high. For example, 2018 witnessed an all-time high input scale of technological innovation and a high output scale, but a low level of comprehensive efficiency. In the sample time, only 2011, 2017 and 2019 achieved a high level of comprehensive technical efficiency. Comparatively speaking, the innovation efficiency in 2011 with lower innovation scale is higher, which indicates that the input efficiency of science and technology innovation is not directly related to the scale, and the scale effect is not obvious in the transformation of innovation input.

3.5.2 Significant annual difference in redundancy of investment in science and technology innovation

From the redundancy of technological innovation input, there are significant differences between different years, but the redundancy structure has little change. R&D investment does not produce redundancy in the whole time panel, which indicates that the enterprise has strong absorption capacity for R&D funds, whether government funds or self-raised R&D funds. The redundancy of personnel input varies in different years, with the most serious redundancy in 2015 and 2016, especially in 2016 when full-time personnel equivalent redundancy is the highest. Thus it is clear that the focus direction of innovation investment optimization should also vary between different years.

3.5.3 Obvious time lag effect in the transformation of science and technology innovation input-output

The low efficiency year of input conversion of technological innovation is manifested by insufficient output of effective patents in 2014 and insufficient output of domestic patent application, and at the same time, insufficient turnover of technical market, which shows that the conversion of input into output of technological innovation is not the same year but requires a long-term process. In the long run, the input and output of science and technology innovation, the number of new technology products, effective patents and the turnover of technology market are consistent as a whole.

4. Construction and Implementation of Synergetic Development Mechanism

4.1 Pluralistic synergy theory

In 1970s, Hermann Haken, a professor at Stuttgart University in the Federal Republic of Germany, put forward the concept of synergetics based on multidisciplinary research, which gradually formed and developed into a new discipline. The word "synergetics" comes from ancient Greek, which means coordination and cooperation, an important branch theory of system science. The theory of pluralistic synergy development originates from the rise of public governance theory. Jessop, a British expert, has made an in-depth study on the rise of governance and the risks it may face. He believes that "in order to enhance the effect of public project implementation and reflect the diversity value of citizens and organizations in the process of formulating policies and solving problems, governance strives to actively promote the common cooperative relationship among public, private organizations and non-governmental organizations".[15] This view affirms the possibility and necessity of the diversification of participants in the cooperative governance framework, and also gives theoretical recognition to the diversification of value rationality, which is also the basis of the theory of multi-dimensional and coordinated development. The development of tobacco enterprises is subject to the preference of government, market and consumers, so the problem of coordination should be fully considered in the development.

With regard to synergetic development, the domestic and foreign theoretical circles have proposed a cross-border governance network model based on the idea of "crossing borders and connecting gaps", believing that plural subjects including government, market and society should be constructed to realize the new governance model of "three-dimensional integration"[16] as shown in Fig. 1. In the pairwise correspondence between government and market, government and society, market and society, the fuzziness of governance boundary and governance mode is integrated. Similarly, the importance of government policy investment and capital investment can not be ignored in the technological innovation and development of enterprises. The most important thing for an enterprise to test in the market is its ability to create scientific and technological capabilities. The FTE in technological innovation also includes innovative forces from universities and other scientific research institutions.

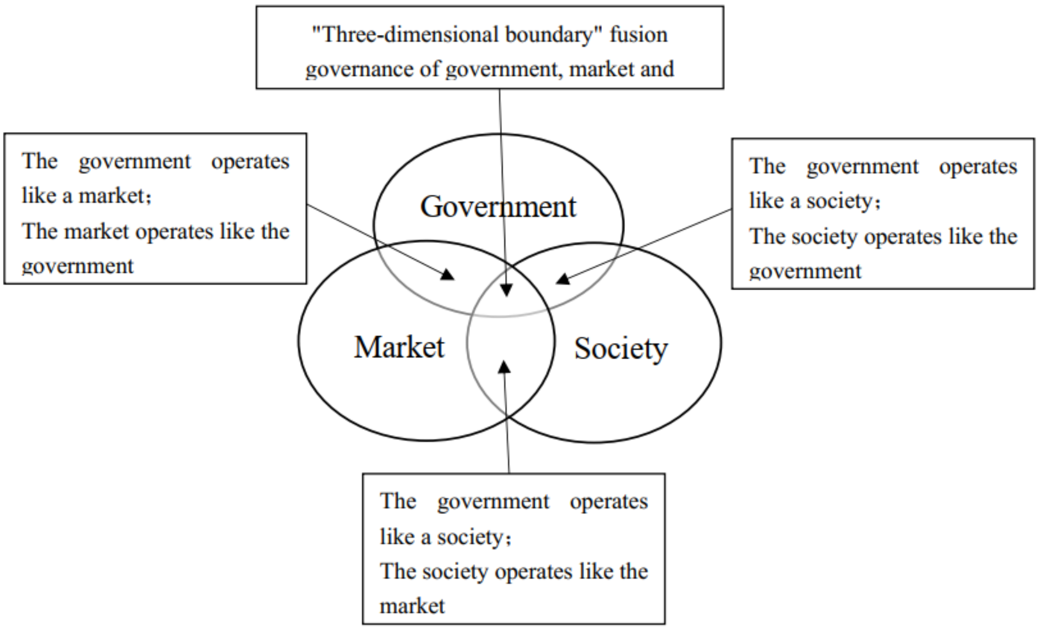

Fig. 1 Compound shaping of government, market and society in cross-sectoral governance [17]
(Graphic source: adapted from selected studies by Koliba C et al.)

When innovation becomes the driving factor of production, the new model of plural-subject cooperative innovation development becomes the trend. Based on the development of cross-border integration and pluralistic governance theory, it is theoretically and practically necessary to establish a collaborative development mechanism including government, enterprises, R&D institutions, universities and other plural innovation subjects.

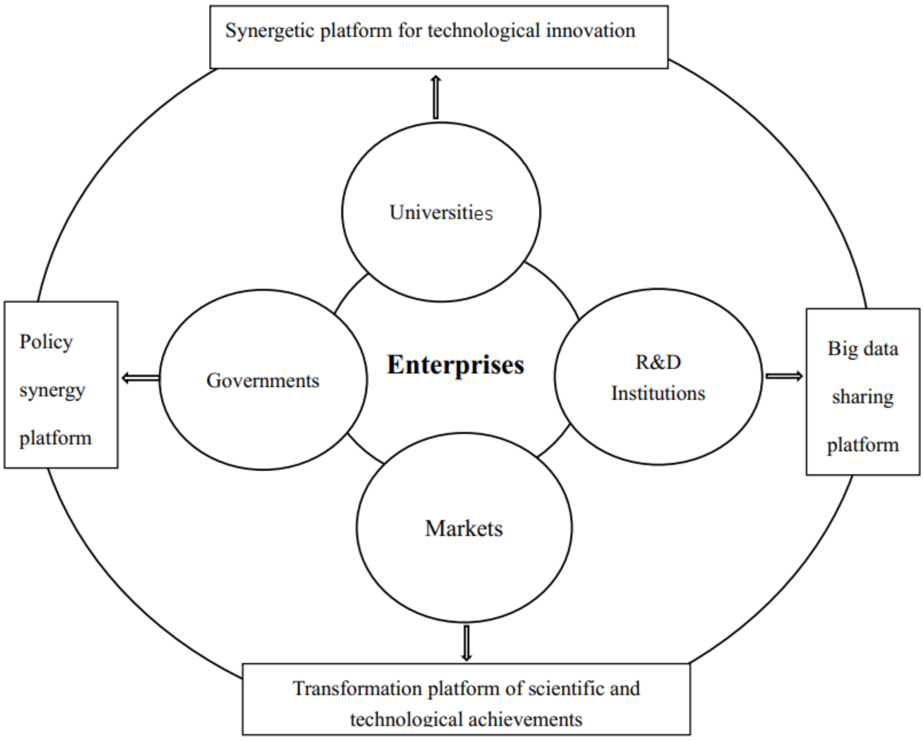

Fig. 2 Framework for synergetic development of multivariate innovation subjects

As shown in Fig. 2, the synergetic development framework takes tobacco enterprises as the core innovation subject, and forms a diversified innovation subject with the government, universities, social organizations and other research and development institutions as well as the market, among which the government-led science and technology innovation policy synergy platform, science and technology innovation platform, big data sharing platform, and science and technology achievement transformation platform are constructed to realize the efficient and orderly integration of innovation resources and the integrated development of economic elements. In the construction of each platform, the co-construction and sharing of science and technology innovation from research and development to transformation are formed through dialogue, negotiation, negotiation, compromise, etc. Within this framework, each innovation subject not only has its own unique interest demands, but also is bound by the common mechanism. In a word, the innovative cooperative relationship established by government, enterprises, industries, universities and research institutes can provide factor-driven and corresponding wisdom support for regional economic development.

4.2 Implementation of synergetic development mechanism

4.2.1 Government level

(1) Building a sound dynamic and sustainable policy system for technological innovation in the tobacco industry. For example, access restrictions could prompt users to switch tobacco brands/products or sources.[18] Attention should be paid to the gradual progress and continuity of technological innovation policies. The gradual progress of policies is reflected in the continuity and dynamics of policies. It is necessary to effectively plan the whole process of policy formulation and implementation, implement the whole process management of policy formulation from issues to evaluation, and ensure the integrity and sustainability of policies. At the same time, the policies are changeable and need to be adjusted to a certain extent

according to the stages of local economic development planning and the specific requirements of technological innovation. Besides, attention should be paid to the two-way impact of the policy to reflect the dynamic nature of the policies.

(2) Establishing and improving the protection mechanism of scientific and technological achievements, and maintain the fair market. To provide the corresponding institutional guarantee for the technological innovation activities of enterprises, it is necessary to establish and perfect the system of intellectual property protection mechanism. Government should fund a wide range of research studies, not just in the Methods development and modeling research (MDMR), which are the western research interests.[19] In particular, high-tech enterprises will face more uncertainties and overwhelming unfair competition in the global market competition. High-tech enterprises are still facing many uncontrollable factors in the process of participating in the global competition because of the need to strengthen the construction of both domestic and international protection mechanisms.

(3) Optimizing the portfolio of policy instruments. In the use of science and technology innovation policy instruments, the government should continuously innovate policy instruments according to the social and economic development practice, and adopt policy instrument portfolio and market policy instruments to avoid "path dependence" of traditional policy instruments. For the assessment of policy effect, the government should establish an assessment and evaluation mechanism on the basis of attaching importance to it, make a comparative analysis of the differences and advantages between different policy instruments, and at the same time increase the output efficiency of the science and technology innovation policy and make efficient decisions, so as to promote the improvement of the efficiency of technology innovation and drive the transformation and upgrading of the local economy.

(4) Constructing the information sharing platform of technological innovation. The system of making public the information and projects of the science and technology project should be strictly regulated, so as to improve the information transparent of the science and technology project. The government should be able to provide diversified policy guidance to build an all-round, all-stage and all-means innovation-driven development mode with the participation of multiple innovation subjects.

(5) Innovating and cultivating high-end human capital platform. Emphasis should be placed on the positive and important role of human capital in technological innovation of enterprises. For all types of high-end talents from internal education and external introduction, data should be unified to the human capital platform to realize the "valuable" scientific and technological knowledge of human capital, to realize the assessment and transformation of talents, and to drive a new pattern of innovation and development with human capital.

4.2.2 Enterprise level

(1) Sticking to the strategy of innovation-driven development to stimulate the endogenous power of enterprise innovation. Global markets are moving forward in the midst of shocks and China's economy is making progress in stability. Enterprise development should be repositioned under the international and domestic double-cycle pattern, while planning a layout with an eye to the influence of endogenous driving force and accumulation of innovative elements on enterprise development. By increasing the investment of enterprises, striving for the support of policy funds and avoiding catering to the negative effects of policy support, the long-term development of enterprises and scientific and technological planning can be closely integrated to guide

the development of enterprises.

(2) Integrating into the dynamic ecosystem of technological innovation. In order to better integrate into the regional innovation network, enterprises must have a strong sense of integration and development, and scientifically absorb knowledge, transform achievements and utilize resources on the collaborative innovation platform. In order to build a perfect innovation network ecology within the enterprise, it is necessary to realize the multiple nesting of its own innovation network with the external ecosystem, realize the unity of knowledge exploration and knowledge internalization, and enhance the dynamic learning ability and adaptability to the technological frontier.

(3) Scientific and efficient use and deployment of science and technology innovation resources to gradually narrow the gap with developed regions in the efficiency of science and technology innovation. To improve the comprehensive efficiency of technological innovation, it is necessary to keep the appropriate investment of technological innovation, reduce the redundancy of input, continuously improve the input of technological innovation, strengthen the rational allocation of self-financing projects and government funds supporting projects, and strengthen the technical cultivation with horizontal scientific and technological enterprises, scientific research institutions, high-end talents and other innovative subjects.

(4) Strengthening the internalization of human capital advantages. As talents are the most valuable resources for technological innovation, it is necessary to adhere to the implementation of the talent project, build a people-oriented technological innovation platform, strengthen the exchange of external talents in technological innovation, and improve the comprehensive efficiency of technological innovation.

4.2.3 Market level

(1) The market should play a leading role and optimize the system and mechanism of technological innovation. It is necessary to promote policy innovation for effective transformation of innovative achievements, strengthen the connection between technological research and development and innovative achievements, and try to make investors, persons with invention patents carry out their duties and promote by classification so as to free inventors from the burden of productivity transformation; and formulate a policy mechanism for cultivating top, leading, high-end and young talents around the leading industry so as to fully cover all categories and levels of talents.

(2) Establishing a market-oriented dual-evaluation mechanism of scientific and technological efficiency. The direction of investment in technological innovation and the transformation of achievements must be checked in the market, and the market also needs to evaluate the implementation effect and performance evaluation of technological innovation policies, and aggregate independent innovation elements into a dynamic collaborative system. In this way, the innovation elements can co-exist. It is also necessary to set up a large data platform for R&D, realize the sharing of regional project resources, avoid the waste of resources with duplicated investment, and improve the efficiency and synergy of technological innovation.

(3) Strengthening R&D market input intensity, enhancing technological innovation capacity and building an innovation platform. Form a technological innovation market pattern featuring accumulation of innovative resources and good innovation ecology, strengthen centralized connection and cooperation among market, rule of law and science and technology innovation policies, construct first-class innovative and entrepreneurial ecosystem, and realize innovation ecology to boost the efficiency of overall technological innovation.

4.2.4 Universities and other scientific

research institutions

(1) Promoting the industry-university-research cooperation alliance and the transformation of scientific and technological achievements. Universities and other scientific research institutions should give full play to the advantages of scientific and technological knowledge gathering, make full use of their scientific research platforms, internal knowledge reserve, realize the integration of schools and enterprises, and school land, and promote the normal flow of knowledge stock among different subjects of technological innovation. Industrial colleges in universities should be actively constructed to promote the construction of high-level application-oriented scientific research institutions and to play a unique advantage in scientific research and development and achievement transformation.

(2) Building a platform for sharing scientific and technological R&D resources and a large data platform, to achieve the combination of enterprise customized project R&D and the tracking R&D of scientific and technological frontiers, the sharing of platform resources and data resources, the sharing and co-construction of national and provincial laboratories, and avoid the repetitive input of a single project, especially the large redundancy of R&D personnel.

5. Conclusions

5.1 The DEA nonparametric analysis of the technological innovation capacity of enterprises above designated scale in Shandong province (2011-2019) shows that the Chinese government should play an active guiding role in the specific stage of enterprise development, not only in terms of financial support, but also in terms of policy environment construction, policy instrument optimization, innovation ecological construction and human capital cultivation, focusing on the forward-looking needs of science and technology innovation subjects.

5.2 The technological innovation efficiency of tobacco enterprises is greatly affected by the local economy and has not reached the cutting-edge level, and still lags far behind that of developed countries and regions. However, it has a strong ability to absorb R&D funds and no redundancy during the sample period, which indicates that the fund utilization efficiency is relatively high, and the use of self-raised funds and government funds are within a controllable range.

5.3 Strengthening the transformation of scientific and technological achievements and reducing the time lag effect. It is necessary in the tobacco industry, to strengthen the protection of intellectual property rights and patents, increase the number of effective patents for technological innovation, speed up the market-oriented application of scientific and technological achievements, increase the turnover of the technology market and improve the whole-process management of the technology market.

5.4 Achieving plural-subject collaborative innovation and development. R&D resources should be developed in a shared way in the region, so that enterprises and innovation subjects can complement each other, give full play to the status of the government, universities, scientific research institutions and enterprises as diversified cooperative innovation subjects, and realize the scale benefit and technical benefit of enterprises' technological innovation.

5.5 Tobacco enterprises should conform to the global consensus of tobacco control strategy, carefully adopt more explicit and implicit technology and innovation strategies, research new products, adjust brand structure, and find a balance between tobacco control and healthy development. The tobacco enterprises should carry out the dynamic reengineering of the tobacco inhibitions and protection, so as to make China's tobacco industry a cautious, healthy and steadily developing industrial cluster, but at the same time, it also follows the new pace of the global industry, innovates from the old, maintains good operation, and generates huge economic benefits of the tobacco industry.

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Conflicts of Interest Disclosure Statement
The authors declare no conflict of interest in the authorship or publication of this work. The authors declare no sponsored financial sources for the undertaken study.

Author Declaration
This research is not funded by any organization related to tobacco production.

Data Availability
The data that support the findings of this study are openly availability in public resources. The data used in the text are from 2011 to 2019 China City Statistical Yearbook, China Regional Economic Statistical Yearbook, China Statistical Yearbook and statistical yearbooks of provinces and cities. All the above data can be searched and downloaded from the official website. This paper guarantees that the data used in the text are true and effective.

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