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Thesis for the Degree of Doctor of Philosophy

Research on the Technological Innovation Efficiency Evaluation of Chinese Manufacturing Industry Based on the DEA Model

by

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Graduate School of Management of Technology

Pukyong National University

February, 2022

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(DEA 모델을 기반으로 중국 제조업 기술혁신 효율성 평가에 대한 연구)

Advisor: Prof. Young Seok, Ock

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Approved by:

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DEA 모델을 기반으로 중국 제조업 기술혁신 효율성 평가에 대한 연구

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요 약

기업이 점차 혁신의 주체가 되는 현재의 상황에서 지식생산은 통상적으로 기업을 통해 이루어지고 있다. 제조업계 기업들은 지역의 기술혁신에서 중요한 구성체가 되고 있으며, 제조업계에서 기술혁신의 주체이다. 제조업계 기업의 기술혁신 수준은 한 국가의 혁신능력의 수준을 광범위하게 보여준다. 따라서, 이러한 상황에서 중국 각 성 및 지역의 제조업계 기업에 대한 기술혁신 효율성을 과학적으로 측정하고, 이를 개선하기 위한 대책을 제시하는 것은 중요한 실천적 의의를 갖는다.

본 논문은 국내외 다수의 참고문헌과 전문가들의 연구결과를 바탕으로 국내외 기술혁신 효율성 평가이론과 기법에 대한 연구현황을 요약하고자 한다. 또한, 본 논문에서는 비모수적 DEA 기법의 이론적 토대를 바탕으로 수평적인 지역적 차이와 종적인 동적 진화를 포함한 두 가지 측면에서 중국 각 성 및 지역의 제조업계 기업의 기술혁신 효율성 현황을 조사하고, Tobit 모델을 활용하여 기술혁신 효율성의 영향요인을 분석한다.

먼저, 본 논문은 중국 제조업계 기업의 현황을 분석하여 기술혁신 효율성 평가 수행의 필요성을 살펴보고, 국내외 기술혁신 효율성 평가이론과 기존의 평가기법을 요약하며, 과정 연구의 의의, 연구

아이디어와 혁신적인 항목들을 제안한다. 다음으로 제조업계 기업의 기술혁신 효율성 평가 지표체계를 구축하고, Pearson의 관련 분석을 적용하여 데이터에 대한 상관관계 검증을 수행한다. 또한, DEA-BCC 모델을 활용하여 각 성 및 지역의 기술혁신 효율성에 대한 수평적인 정적 측정을 수행하고, 동부, 중부 및 서부 지역별 차이를 조사하며, 지역별 기술혁신 효율성의 역동적 변화를 분석하기 위해 DEA-Malmquist 지수를 적용한다. 마지막으로 Tobit 모델을 활용하여 기술 혁신 효율성의 영향 요인을 분석하여 광범위한 적용 가치를 보여주고, 중국 제조업계 기업의 기술혁신 효율성을 위해 추진해야할 정책적인 조언을 제공한다.

키워드: 대기업 및 중소기업, 기술혁신 효율성, DEA, Malmquist 지수기법, Tobit 모델

I. Introduction

1. Research Background

Under the background of economic globalization, the contact between domestic enterprises and the international market is increasingly intimate. Products with high-tech content show a competitive edge in the international market. Technological innovation can improve the quality of enterprises, strengthen enterprise vitality, change technology into practical productive force and promote the economic growth of enterprises. In today's world, technology is rapidly developing. The upgrade of products is accelerating. Enterprises don't implement technological innovation anymore, resulting in poor product quality and bad situations in international competition.

In the past, the Chinese manufacturing industry made great contributions to high-speed growth of the Chinese economy by manufacturing foreign products and gaining processing charges, but developed countries only transfer low-end technologies with low added value to make in China. Overseas transnational corporations master the core technology to gain most of the economic profits. To own the core technology and win through high quality is the key to sustainable economic growth. At present, the Chinese economy remains in the key stage of low technological transformation and upgrading. Since enterprises lack top technologies, it is difficult to realize enterprise transformation and upgrading. With the purpose of looking for a technological breakthrough, promoting transformation and upgrading of manufacturing industry structure, and closing to the technological gap with developed countries, the state positively advocates and supports Chinese enterprises to "go out". China proposes the plan of "Made in 2025", transforms made in China into created in China, gets rid of the label that the Chinese manufacturing industry is big but not strong, and further enhances the competitiveness of the Chinese manufacturing industry around the world. Overseas merger and acquisition (M & A) gradually replace the greenfield investment to be a leading pattern. An increasing number of enterprises are merged in the high-tech field from the low-tech field at the very start. They go to target countries in a short time, learn innovative experience, gain the core resources of target enterprises, expand the overseas market scale, and enhance international competitiveness.

2. Research Significance

With the constant progress and development of society, the superior resources of enterprises in the competition are also changing. They are transitioned to financial advantages or even today's intangible assets from the initial labor resource advantages. With the in-depth comprehension of the innovation concept and policy encouragement on innovative activities, enterprises gradually increase innovation input. Nowadays, the academic world has studied enterprise technology innovation and enterprise profit relations. Even if they may use different indexes and all kinds of ways, most of them regard manpower and material resource input of enterprises as initial input and consider corporate profits as the output to measure the correlation between them. However, such a way is unscientific. For this reason, this study has the following significance to analyze the technological innovation of large and medium-sized industrial enterprises.

2.1 Theoretical significance

There are lots of technological innovation efficiency evaluation methods, but there are fewer achievements about using non-parametric DEA to analyze Chinese manufacturing enterprises. At present, there are domestic and overseas technological innovation efficiency evaluation achievements. Most of them concentrate on the industrial analysis, but there are fewer references for regional analysis, let alone analytical achievements about influence factors. As a result, the studies on the technological innovation efficiency of the Chinese manufacturing industry are insufficiently comprehensive and in-depth. In this thesis, to combine regional technological innovation analysis of manufacturing enterprises with temporal evolution analysis and analyze its influence factors shows the significance of perfecting and enhancing the theoretical research for the technological innovation efficiency of Chinese manufacturing enterprises.

2.2 Practical significance

Due to the lower technological innovation efficiency of Chinese manufacturing enterprises and poor market competitiveness, such a status occurs. In addition to self-development causes of enterprises, another important reason is that the government doesn't have the scientific and effective guidance measures. Under the background, the author in this thesis conducts the scientific measurement on the technological innovation efficiency of Chinese manufacturing enterprises and investigates the technological innovation efficiency status of Chinese manufacturing enterprises from the perspectives of the horizontal regional analysis and longitudinal dynamic evolution based on the non-parametric DEA method. Moreover, the author utilizes the Tobit model to analyze the influence factors of the efficiency and proposes the improvement countermeasures, which show the important practical significance.

3. Research Objectives

While research of previous scholars on the technology innovation efficiency in specific industry mainly focused on the analysis and comparison of the technological innovation efficiency in each province in that industry, and only few scholars analyzed the differences of industry innovation efficiency between the industry segmentations, this paper analyzed not only the differences of technological innovation efficiency between regions in manufacturing industry, but also the differences between industry segmentations within manufacturing industry. To be specific, this paper conducted an empirical analysis on the technological innovation efficiency of Chinese manufacturing enterprises by using DEA method and Tobit model to achieve three objectives. One is to investigate the technological innovation efficiency of Chinese manufacturing industry from a horizontal region perspective. The second is to analyze the dynamic evolution features of the technological innovation efficiency in each Chinese province from a vertical time perspective. The last is to analysis critical factors that influence the technological innovation efficiency of Chinese manufacturing enterprises. Therefore, theoretical support and decision-making basis could be provided, and further, more targeted suggestions could be put forward to improve the overall efficiency of technological innovation of Chinese manufacturing enterprises.

4. Research Methods

In this thesis, the author comprehensively uses qualitative and quantitative combination methods of the literature research method, comparative analytical method and empirical analytical method to do an analytical evaluation on the technological innovation efficiency of the Chinese manufacturing industry. The specific research methods are stated as follows:

(1) Literature research method: the literature research method is one of the kinds in the qualitative analytical method. It means to summarize lots of domestic and overseas references and provides the theoretical guidance for the construction of the index system and method selection. In this thesis, the author collects, sorts out and summarizes numerous previous research achievements, constructs and selects the index system and empirical research method.

(2) Comparative analysis method: The comparative analytical method is used to analyze and evaluate measurement results of technological innovation efficiency in the manufacturing industry of Chinese four major areas and 16 market segments of the manufacturing industry. By analyzing and evaluating empirical results, the author compares and analyzes the gap of technological innovation efficiency in the manufacturing industry between areas and market segments.

(3) The empirical analytical method: Through the reasonable index selection principles, the author scientifically selects innovation input and innovation output indexes, constructs the DEA-BCC model and DEA-Malmquist index model to do the empirical research on market segments of manufacturing industry and cultural manufacturing industry in each Chinese area from 2009 to 2018. On the basis of the empirical analysis, the author further analyzes the change trends for technological innovation efficiency of the manufacturing industry and the cultural manufacturing industry in each Chinese area.

II. Current research status

1. Theoretical background and previous research

1.1 Foreign research statis of technological innovation efficiency

Joseph Schumpeter, an Austrian economist, proposed the theory of technological innovation, which came from his works the Theory of Economic Development. Schumpeter came up with the concept of “innovation” and defined it as the variation of the production function, which combines production factors with production conditions in the production system. Schumpeter’s concept of “innovation” is a broad theory, including changes in organizational forms and market innovation. He further divided the definition of innovation into five aspects: (1) a new product is developed or an old product is improved. As long as the product has the new performance; (2) A new production mode is used. Perhaps, it is not the new application of technologies or it can be the transformation of products’ handling method; (3) Entry of the new market means the products enter into a completely new market field; (4) There is a supply approach for new raw materials or semi-products, no matter whether it exists or it is the first time to be developed and utilized; (5) A new organizational structure is initiated. In other words, the original market structure is changed. Schumpeter’s innovation definition has a great difference in the invention. The former emphasizes that the invention has no real economic role before it is recognized by the market. Innovation comes from invention and contains its development and utilization to be generalized in the market. The invention only can be based on the market to make innovations. After the Second World War (WWII), with the rapid development of technologies, neoclassical economics faced the role of technological innovation in economic growth. Therefore, such difficulty couldn’t be explained. R. Solow proposed two necessary conditions of technological innovation for the first time after doing lots of comprehensive studies: the establishment of new ideas and their realization process. Such a concept has been recognized by the theoretical cycle to the narrow definition of technological innovation. Freeman defined as the new commercial market application of new products and new technologies. Glynn defined technological innovation from the perspective of time development. The technological innovation contains the overall process from technologies to commercial products. M. Mansfield proposed in Industrial Economics: when a technology is first used in commercial activity, it can be deemed as innovation. The Science and Technology Advisory Committee of Canada defined innovation as the process to develop new products and services in the market. US Council on Competitiveness considered innovation as the transformation process from knowledge to new products, new technologies and new services. It not only gets involved in technologies, but also contains the market survey and satisfaction. American Industrial Survey Association as the economically feasible market of new product popularization and the overall process of success. By studying lots of references, Musser argued that technological innovation is non-continuous, and it is featured with new thinking and successful application. The definition of overseas scholars on the technological innovation probably should be divided into two categories: one is the technological innovation in the narrow sense, while the comprehension on the technological innovation is based on technologies and products, represented by R. Solow and Freeman. Another is a technological innovation in a broad sense. The comprehension of the technological innovation not only contains technologies, but also includes management, organization and system, represented by Zapf and definition in EU's Green Book of Innovation.

In economics, it mainly refers to the specific value between input and output. In essence, it is expected that resources receive effective allocation. Pareto efficiency is widely known. In other words, no change can make someone take a turn for the better without damaging any others. Such a state is economic efficiency. The academic world also has many opinions on the definition of efficiency. Marx considered the relation between operating costs and utility as economic efficiency. Tinbergen used the total factor productivity to represent the efficiency or used the input-output coefficient to stand for efficiency. The general opinion shows that under the given input and technological conditions, economic resources are not wasted, or economic resources are used to capacity. By analyzing the above-mentioned different opinions, it can be found that efficiency in essence describes the state of resource allocation, which can't be directly observed. Hence, such a way can indirectly reveal such a state. The frontier efficiency proposed by Farrdl introduces the frontier production function. Under certain conditions, the frontier of production for input and output can be obtained. If the actual input-output is closer to the frontier, the efficiency will be higher. The frontier of production is composed of Pareto optimal solution with the minimum input and maximum output.

The efficiency in the thesis refers to the frontier efficiency. The efficiency evaluation methods mainly include the parametric method (i.e. stochastic frontier analysis(SFA)) and non-parametric method(i.e. Data Envelopment Analysis(DEA)). The DEA method is used in this thesis.

Technological innovation efficiency is always the research hotspot for overseas scholars with abundant achievements. According to different research objects, it can be divided into two categories. To begin with, the regional innovation system is used as a research object. To be specific, Sharma and Thoinas (2008) investigated a high or low level of national innovation efficiency and analyzed the causes for forming differences between all kinds of countries. S. Rousseau and R. Rousseau (1997) mainly inspected the comparison of national innovation efficiency. Nasierowski and Arcelus (2003) studied the difference of innovation efficiency between regions and analyzed the causes; Wang et al., (2007) applied the DEA to study technological innovation efficiency between different countries and found out the causes for the efficiency difference. The following scholars considered enterprises as research objects: Gaylen (2001) considered American enterprises as research objects to find the significant positive correlation of enterprise-scale and market shares with enterprise innovation capacity. Akihiro and Shoko (2008) measured the technological innovation efficiency of Japanese enterprises and analyzed the influence factors; Oakey (1988) analyzed the innovation strategy of small-sized high-tech enterprises in the USA and UK. The findings indicated that enterprise innovation came from inside, while external innovation resources might be insignificant as a whole. Dodgson (1991) investigated the innovation behavior of small-sized enterprises in Europe and showed the greatest contributions of enterprise technology innovation to external resources. Reinhilde (1999) studied the manufacturing enterprises in Belgium and found out the technological innovation of high-tech enterprises from inside. Michael (2005) found that in the past 20 years, manufacturing enterprises in Holland increasingly depended on external innovation resources. The R&D strength of enterprises was present in a positive correlation with the technical outsourcing scale.

For the studies on the technological innovation efficiency evaluation methods and indexes, R. Solow (1957) used the total factor productivity and aggregate production function to further measure technologies and measured the input-output efficiency by assuming constant returns to scale, complete competitive equilibrium and technical change neutrality. Due to the "unreality" of assumptions and "oneness" of factors, such a model method is out of touch with the real world. By studying existing references, it can be found that the technological innovation efficiency evaluation gives priority to a non-parametric method and parametric method. The parametric method is represented by the SFA efficiency evaluation model proposed by multiple scholars, including Meeusen(1977), Aigner(1977) and Battese(1977). The non-parametric method is represented by DEA proposed by famous operational research experts A. Charnes and W. W. Cooper (1978), including the multi-input and multi-output DEA evaluation model—CCR model. After that, R. D. Banker, A. Charnes and W. W. Cooper (1984) proposed another DEA model—BCC model from the perspective of the axiomatization model and proved two models with the same form. Andersen and Petersen (1993) constructed the super-efficiency DEA model to overcome the problem that traditional DEA can't completely rank multiple decision-making units (DMUs) in the frontier. Fosfuri A (2008) and Kuen-Hung (2009) respectively constructed the innovation efficiency evaluation model from the influence factors of the technological innovation and organizational network.

1.2 Domestic research progress of technological innovation efficiency

Domestic scholars including Fu Jiayi, Jiang Yanfu and Lei Jiahan argued that "the technological innovation is the potential profit chance for entrepreneurs to seize the market, targets at gaining commercial profits, reorganizes production conditions and elements, and establishes the production management system with the stronger efficacy, the higher efficiency and lower costs, so as to develop new products and new production(process) methods, open the new market, gain the supply source of new raw materials or semi-products or construct new organizations of enterprises. It contains the comprehensive process of a series of activities, such as technologies, organizations, commerce, and finance." Two aspects should be noticed in this concept: firstly, this definition does not have the special strict requirement for technological advancement. Secondly, this definition classifies the market technology and management technology relating to technological development application into the range of technological innovation.

Technological innovation efficiency evaluation methods of domestic scholars are mainly concentrated on two methods. For the non-parametric DEA method, Chi Renyong et al.,(1998) and Yu Xiaofen(2004) studied the regional economic development disparities in China from the perspective of regional technological innovation efficiency and argued that the central and western regions must promote enterprise system reform, enlarge talent team construction, and transform the economic development model, for the sake of enhancing our regional technological innovation capacity and reducing the gap of economic development level in three regions. Bai Junhong and Jiang Keshen(2008, 2009, 2010) evaluated the regional innovation system efficiency in China, drew a conclusion of the lower regional innovation efficiency in China, and proved that it might be attributed to too low pure technological efficiency. Li Jing et al., (2008,2010) conducted the empirical research on innovation efficiency in each Chinese province and area, analyzed the innovation efficiency difference between the Eastern Region, the Central Region, and the Western Region, and argued that areas with the lower technological efficiency was approaching to leading areas, showing the convergent tendency. Wu Yanbing(2008) utilized the DEA method to empirically analyze knowledge productivity of large and medium-sized industrial enterprises of 29 Chinese provinces and areas from 1996 to 2003, divided it into technological efficiency change and technological advance, and investigated its astringency. Guan Jiancheng and Ma Ning (2003), Guan Jiancheng and Chen Kaihua (2009) applied the DEA method to study the technological innovation efficiency of Chinese industrial enterprises and proposed the targeted improvement countermeasures and suggestions.

Through study on previous definition scholars proposed, and combining with the technological innovation characteristics of Chinese large and medium sized industrial enterprises, evaluation and research on the technological innovation efficiency of large and medium sized industrial enterprises in this paper mainly focuses on the R&D of new technology and new products, using the development efficiency of new technology and new products to represent the technological innovation efficiency of large and medium sized industrial enterprises. For the parametric SFA, Zhang et al., (2003) applied the SFA to measure R&D efficiency of Chinese enterprises and analyzed its influence factors. Xiang Benwu(2019) applied the SFA to measure the technological innovation efficiency of the Chinese industry and found that the technological innovation efficiency of the industry was not enhanced with the passage of time. Jing Baofeng et al., (2011) utilized the SFA to analyze the technological innovation efficiency of the high-tech industry in Guangdong Province, made a comparison on the difference between industries, and provided the decision basis for enhancing technological innovation efficiency in Guangdong Province.Guo Yujin (2011) utilized the SFA to analyze impacts of the technological environment in each province and area on regional technological innovation efficiency, and investigated the situations in the Eastern Region, the Central Region, and the Western Region. Xia Yeliang and Cheng Jia (2010) applied the SFA to do empirical analysis for impacts of foreign investment on technological innovation efficiency of Chinese industrial enterprises and found out the good effect in wholly foreign-owned enterprises and foreign holding companies.

In the field of evaluation of technological innovation efficiency, domestic scholars nowadays start using mathematical statistics, osculation value method, grey system theory, rough set theory and BP neural network and studying the technological innovation efficiency evaluation methods. For instance, Liu Changnian(2006) used factor analysis as the means to do a comparative analysis between regions on the technological innovation efficiency in each Chinese province. Si Jiangwei(2010) applied the rough set method to figure up the index weight and applied the fuzzy comprehensive method to evaluate the innovation performance of enterprise talents. Zhang Xiaofang(2010), Zhan Jie(2011) and Liang Xin(2011) respectively used the BP neural network, grey comprehensive assessment and grey clustering method to the empirical studies of the innovation efficiency evaluation.

Chinese scholars have done a lot of research and analysis on the selection of evaluation indexes of technological innovation efficiency. One is to divide innovation into different stages according to the technological innovation process and determine the index system from the macro, medium and micro levels respectively. The other is to establish the overall innovation input and output index system. About the selection and construction of the efficiency evaluation indexes, EIS(2001) constructed the innovation input indexes including personnel, subsidies, and enterprise input and the innovation evaluation index system including cost reduction and economic effect. Such a system is relatively authorized and comprehensive. John Hagedoorn(2004) utilized a series of evaluation indexes including R&D expenditure, the number of patent applications, the number of patent quotations, and the number of new products to study the innovation efficiency of 4 high-tech industries in the US and 1200 international enterprises. For the staging evaluation, Tao Ye and Xu Long (2019) divided the innovation process into four stages of input, implementation, management and realization to respectively construct the index system. Started from the input-output factors of the technological output and transformation stage, Zheng Jian and Ding Yunlong (2007) constructed the index system to obtain the technological development efficiency and output efficiency. Ma Jianfeng (2020) divided the innovation process into “technological R&D” and “technological application”. According to initial input, middle output and additional input, as well as different periods involved by the ultimate output, the DEA series model of two stages and three periods has been constructed. Du Dong (2019) argued that the design of the index system should be concise, intuitive and clear, so the input index including labor and capital and the output index with the proportion of new product value in all product outputs were constructed. During the process of studying the small and medium-sized high-tech companies, Wu Cuihua(2012) argued that enterprises not only should have the assessment of technical goals, but also should contain the assessment of economic goals and established the technical indexes(high-tech conversion rate, technologies and products, and R&D input level), economic indexes(new product development capacity, World Bank shares, and financial incomes) and comprehensive indexes(employee quality and environmental factors). Sun Kai (2021) et al., evaluated technological efficiency in Chinese provinces and selected total R&D internal expenditure as the input index and technical market trade value and the number of three patents as the output indexes.

According to data features of small and medium-sized listed enterprises, Li Qiang (2018) selected R&D expenditure and the number of technicians as the input indexes of the DEA model and products' net margin as the output index to evaluate innovation efficiency for small and medium-sized listed enterprises. By considering innovation safeguard, input, implementation and output as the first-level indexes, Yu Jiayu (2012) subdivided them into 22 the second-level indexes to evaluate the innovation capacity. Starting from the innovation input-output ratio of the industrial industry, Wang Weiguang(2017) found out the indexes of affecting the technological innovation of the Chinese industry, including R & D expenditure and R &D personnel. Zhang Zongyi and Zhou Yong (2006) used the logarithmic Cobb-Douglas SFA as the model to study the technological innovation efficiency in different Chinese areas. Long Ruyin(2009) constructed the super-efficiency DEA model and combined with the compound DEA method to analyze Chinese provinces, finding that the overseas technological innovation shows the obvious significance of efficiency promotion. Guo Lei and Liu Zhiying(2011) used the DEA cross model in the efficiency evaluation, ranked the technological innovation efficiency in all provinces, and finally constructed the simple input-output transformation model of the technological innovation. Liu Jinfang(2012) applied the DEA-Malmquist method to construct the input-output index system of two stages and studied the technological efficiency and product innovation efficiency in Chinese domestic capital industrial enterprises from 2000 to 2009.

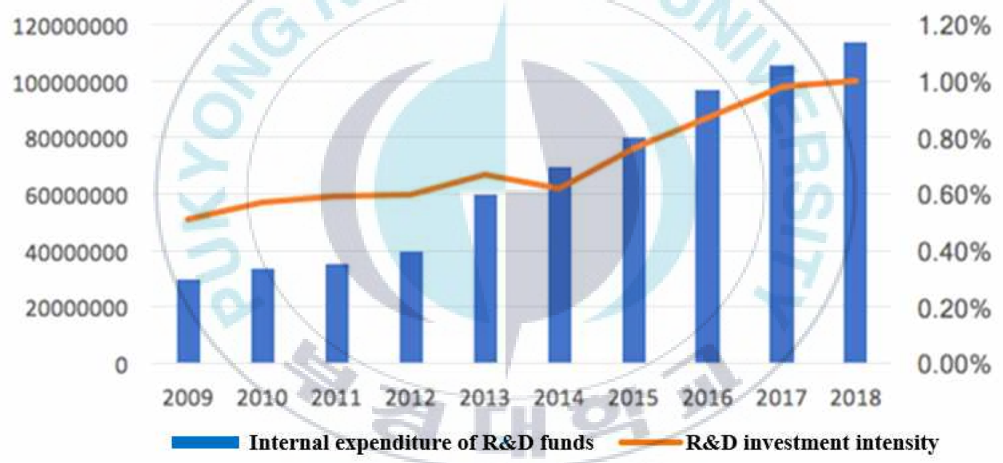
2. The Input-output Status of the Technological Innovation in Chinese Manufacturing Enterprises

2.1 The Overall Overview of the Technological Innovation Status in Chinese Manufacturing Enterprises

Since the reform and opening-up, the Chinese manufacturing industry has been continuously developing and it has become the important pillar industry of the national economy. China owns the title of “the No.1 Great Power of Manufacturing”. With the technological progress, technological innovation becomes the key factor of corporate development. The Chinese manufacturing industry is transforming and upgrading and turns into “created in China” from “made in China”. Also, technological innovation has become an important driving force to transform and upgrade the Chinese manufacturing industry. Enterprises have two path choices for innovation: self-dependent innovation of enterprises’ self-innovation input and technological introduction for innovation. China closely keeps up with technological paces to shrink the gap with the world.

Chinese manufacturing enterprises conduct technological innovation. To begin with, enterprises apply self-innovation input, which is the foundation for enterprises to do technological innovation. Innovation input of the Chinese manufacturing industry is present in the rising trend in R&D appropriation expenditure and the number of researchers and employees. Figure 1 shows the change trends of internal expenditure and research input strength during 10 years from 2009 to 2018 in the Chinse manufacturing industry. Figure 2 shows the full-time equivalence of researchers. The proportion of researchers in employees of the manufacturing industry represents the changing trend of R&D human capital input in the Chinese manufacturing industry. Figure 3 reveals the appropriation expenditure of developing new products and change trends of research input strength.

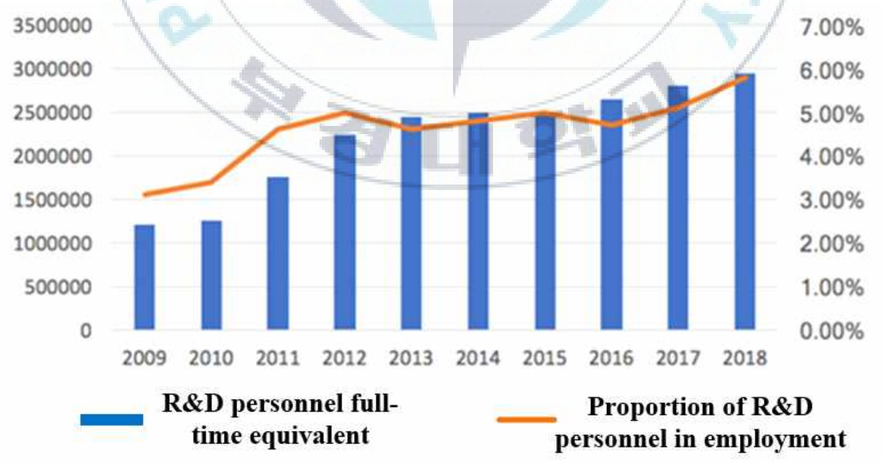
R&D appropriation expenditure: R&D appropriation expenditure is an important foundation for enterprises to do technological innovation to ensure sustainable implementation of enterprises’ innovation activities. Meanwhile, it is the material precondition for researchers to carry out innovation activities. According to the R&D appropriation expenditure input scale of the Chinese manufacturing industry, internal R&D expenditure is present in the rising trend. In 2009, internal R&D expenditure was 7.775 billion RMB and that of 2008 was 1055.142 billion RMB. It was increased by 134 times during 10 years. After 2006, the annual growth rate of internal R&D expenditure was increased. In 2009, internal R&D expenditure accounted for 0.17% of the main business incomes, showing weak research input strength. In 2018, the research input strength was increased by 1.00%. As a whole, R&D expenditure input showed the rising trend, showing that the Chinese manufacturing industry has valued the self-research input to strengthen self-dependent innovation. However, by comparing with developed countries in the international market, the research input strength has had the small input strength, so the Chinese manufacturing industry should still continue increasing research input and enhance the foundation of technological innovation.



The data source: the Technological Statistical Yearbook of Chinese Industrial Enterprises and Chinese Technological Statistical Yearbook

[Figure 1] Internal R&D Expenditure and Input Strength of the Chinese Manufacturing Industry

The full-time equivalence of researchers: technicians are subjects to engage in technological innovation in enterprises and serve for technological innovation of enterprises, the more technicians are, the better for technological innovation in enterprises will be. Relevant references measure R&D human capital input according to the full-time equivalence of researchers. The full-time equivalence of researchers in the Chinese manufacturing industry and the proportion of researchers in the number of manufacturing employees remain consistent and show the stably growing trend. In 2009, the full-time equivalence of researchers was 140183 man-year and that of 2008 was 2585954 man-year. During 10 years, it was increased by 17 times. The annual average growth speed was 16.7%. In 2009, the number of researchers only accounted for 0.14% of the manufacturing employees. In 2009-2013, the proportion was stabilized around 0.3%. In 2013, it broke through 1%. In 2018, such a proportion even reached 4.76%, showing that after China joined the WTO, the R&D human capital was dramatically increased. More and more talents have mastered R&D technology. Also, enterprises have valued the cultivation of research talents. With the increasingly close association between China and the international market, technological innovation becomes a powerful safeguard for enterprises' competitive advantages, while talents of mastering technological advantages are the precondition for enterprises to do technological innovation.



The data source: the Technological Statistical Yearbook of Chinese Industrial Enterprises and Chinese Technological Statistical Yearbook

[Figure 2] The Full-time Equivalence of Researchers in the Chinese Manufacturing Industry and Its Proportion

The R&D expenditure of new products: the R&D expenditure of new products in 2009 and 2018 respectively reached by 6.114 billion RMB and 1157.336 billion RMB, which was increased by 70.82 times. The annual average increasing rate was 23.32%. According to the annual amount of growth, the R&D expenditure growth of new products in 2009-2015 didn't have a great gap, but the input gap was increased after 2015. The research input strength of new products was increased to 1.1% in 2018 from 0.35% of 2009, showing the rising trend year by year.

The data source: the Technological Statistical Yearbook of Chinese Industrial Enterprises and Chinese Technological Statistical Yearbook

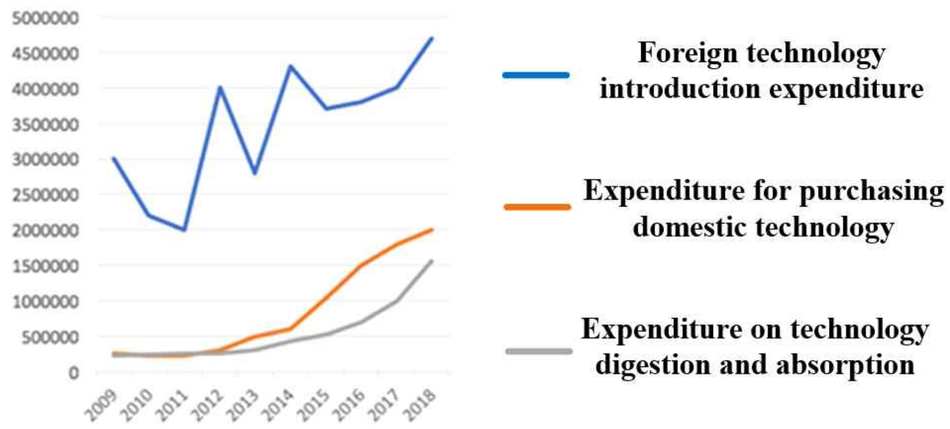
[Figure 3] R&D Expenditure of New Products and Input Strength

Through the comprehensive analysis, the R&D expenditure of the Chinese manufacturing industry, the full-time equivalence of researchers and the R&D expenditure of new products were present in the rising trend, while research input strength was also rising, showing that the independent development capacity of the Chinese manufacturing industry has been gradually enhancing. Enterprises have paid much attention to the role of independent development in technological innovation. To own the core competitiveness, it is necessary to own sufficient independent development capacity. However, due to small research input strength in current days, internal R&D expenditure and expenditure input strength of new products should be about 1%. Research talents who can master the core technology are still not enough and have a great gap with developed countries, showing insufficient independent innovation input strength of the Chinese manufacturing industry and weak knowledge reserve of enterprises. Therefore, it is still necessary to enlarge independent development input, value the cultivation of researchers, and reduce the gap with developed countries.

2.2 The Input Status of the Technological Innovation in Chinese Manufacturing Enterprises

Independent innovation of the Chinese manufacturing industry has a slow speed. Even if innovation input shows a stable rising trend, enterprise innovation input strength is still insufficient, which is only about 1%. Technological innovation capacity is weak. Technology import can cut down independent innovation time and reduce time costs. Technological innovation can be realized through digestion and transformation on the basis of introducing technologies. With the purpose of enhancing technological innovation capacity, overseas technologies are introduced on a large scale in the early stage, while domestic enterprises also show uneven technological development and also enhance technological innovation by purchasing domestic enterprise technologies. Figure 4 and Figure 5 show that large and medium-sized enterprises of the Chinese manufacturing industry introduced overseas technologies in 2009-2018, purchased domestic technologies and overseas M&A to gain technological expenditure and expenditure input strength. Figure 6 shows that large and medium-sized industrial enterprises of the Chinese manufacturing industry introduce technologies to realize technological transformation and digestive input strength.

Technological acquisition appropriation expenditure and input strength: according to the input scale, the input scale of introducing overseas technologies by the Chinese manufacturing industry is much greater than the input scale of domestic technologies. The input scale of introduction overseas technologies in 2009 was 30 billion RMB and that of 2018 was 47.3 billion RMB, showing the rising trend with fluctuation. And it was increased by 57.7%. The globalized development makes competition between countries turn into the competition in national scientific and technological progress, as well as technological innovation. Since the reform and opening-up, the technological innovation of the Chinese manufacturing industry is insufficient. China implements the technological introduction strategy of "changing technologies with the market" on a large scale. Through the large-scale overseas technological introduction and imitation of overseas technologies, the technological level of enterprises is enhanced to some extent. Overseas M & A becomes a new way for the Chinese manufacturing industry to introduce overseas technologies. Differing from purchasing patented products of overseas enterprises, target enterprises are merged to gain their technologies, human capital and market. It is a pity that the Chinese manufacturing industry has a late start in overseas M & A. The input scale just showed the fast growth trend after 2013. It even reached 30.1 billion USD in 2018, increased by about 55 times. The development momentum has been higher than the purchase of overseas technologies to be the leading way to gain new technologies. The input scale of purchasing domestic technologies in 2009 was 2.458 billion RMB and that of 2018 was 18.96 billion RMB, which increased by 87.04%. By comparing it with introducing overseas technologies, purchasing domestic technologies has a smaller input scale. After introducing technologies, the digestive expenditure scale in 2009 and 2018 respectively reached 1.219 billion RMB and 10.276 billion RMB, remaining consistent with domestic digestive expenditure as a whole based on the stable rising trend.



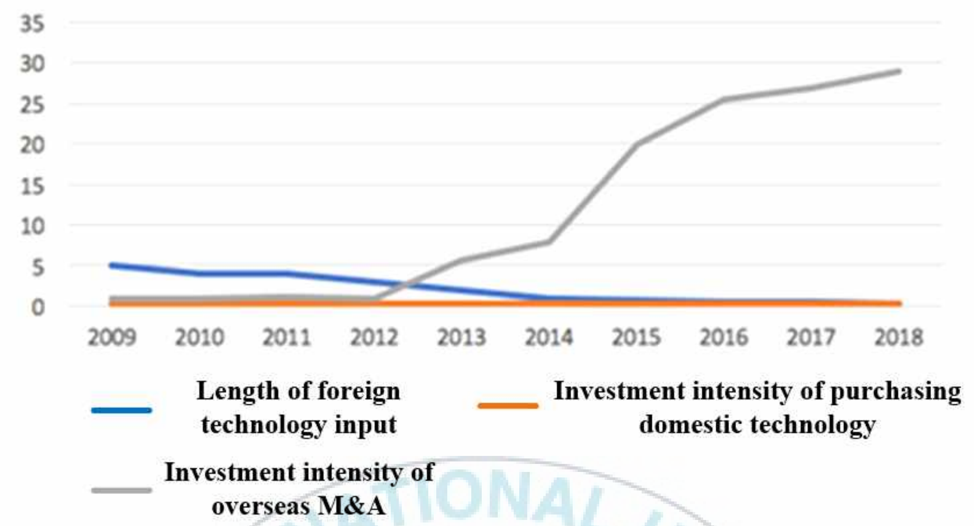
The data source: the Technological Statistical Yearbook of Chinese Industrial Enterprises and Chinese Technological Statistical Yearbook

[Figure 4] Technological Acquisition Expenditure of the Manufacturing Industry and Technological Digestive Expenditure

The proportion of expenditure in the main business incomes of the Chinese manufacturing industry is used to represent the input strength. Introducing overseas technological expenditure input strength hasn't remained the rapid growth, but the downtrend year after year. To be specific, it reached 6.05‰ in 2009 and then showed the downtrend. In 2018, it was reduced to 0.45‰ because of the contradiction between overseas technologies introduced by China and the technological innovation competition trend of economic globalization in current days. In the past, China had weak technological innovation capacity, so it should depend on overseas technologies. According to the development experience of each country, the key to enterprise development and improvement in competitive capacity lies in core technologies of enterprises to enhance the capacity for independent innovation. Just depending on introducing overseas technologies can't gain the core technologies.

With deepening integration of the world economy in China, technological barriers between countries are increased, so it is more difficult to introduce core technologies. Therefore, introducing overseas technologies to develop the Chinese manufacturing industry can't solve the problem of insufficient technological innovation, while overseas M & A input strength could show the rising trend. The input strength in 2009 and 2018 respectively reached 0.81% and 19.94‰. Particularly, the amplitude of fluctuation in recent years has been increased to form a bright contrast with the downtrend for the input strength of introducing overseas technologies.

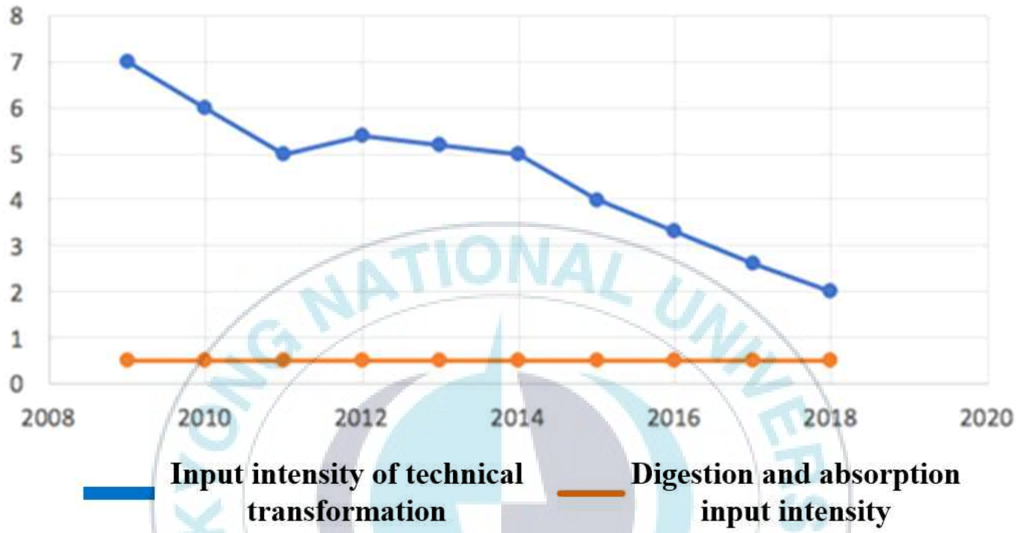
By comparing with just introducing overseas technologies, overseas M & A can gain relevant resources of target enterprises, master core technologies of target enterprises, and obtain R&D teams and institutions of target enterprises. Overseas M & A can be used to enhance technological innovation to own the advanced advantages. In terms of the downtrend of introducing overseas technological input and growth trend of overseas M & A input, purchasing domestic technological input strength is present in the stable change with the average input strength of 0.33‰. Perhaps, the Chinese manufacturing industry has weak domestic technological innovation and the domestic market technological trading supply is inadequate, so it can't satisfy the needs of enterprises for new technological development. Enterprises continue searching for overseas enterprises with more advanced technologies.



The data source: the Technological Statistical Yearbook of Chinese Industrial Enterprises, Chinese Technological Statistical Yearbook, and M & A Yearbook of Chinese Enterprises

[Figure 5] Technological Introduction Expenditure Input Strength of the Chinese Manufacturing Industry (%)

Technological digestion and technological upgrading and transformation input strength: on the basis of technological acquisition, enterprises should digest technologies obtained and conduct innovation upgrading for and innovation transformation the domestic enterprise development. Hence, during the technological innovation process, technological digestion shows an important role in enterprise technological innovation. The digestive expenditure input strength of the Chinese manufacturing industry has been less than 0.5‰. The average input strength in 2009-2018 was 0.24‰, which was strongly inferior to developed countries, showing that compared with technological introduction expenditure and technological purchasing expenditure scale, the digestive expenditure of enterprises for new technologies has been less. Moreover, input strength hasn't been dramatically increased. The technological transformation input strength on the contrary was reduced. The technological transformation input strength in 2009 was 21.62‰, but it was ascended to 32.02‰ in 2010. Then, it was reduced year by year. In 2018, it was reduced to 2.54‰, showing that enterprises have shown the inadequate digestive input for new technologies, insignificant attention, weak integration technologies after gaining technologies, so as to obstruct enterprise technology innovation.



The data source: the Technological Statistical Yearbook of Chinese Industrial Enterprises and Chinese Technological Statistical Yearbook

[Figure 6] Technological Transformation and Digestive Input Strength of the Chinese Manufacturing Industry (%)

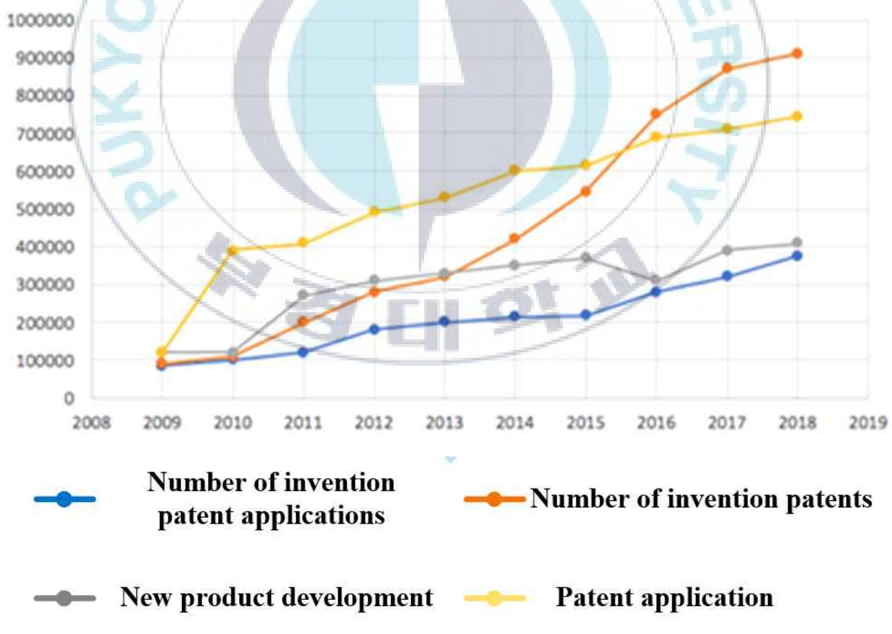
As a whole, introducing overseas technological input strength in acquisition modes of the Chinese manufacturing industry has been reduced, while the core technological input strength of gaining target enterprises through overseas M & A has been increased. Relative to the pure introduction of overseas technologies, it is advantaged with mastering technologies, talents and capital to gain core technologies of target enterprises, enhancing independent innovation capacity, and saving time and costs. However, purchasing domestic technologies still has remained fewer changes. Perhaps, the inadequate domestic technological innovation of the Chinese manufacturing industry in current days can't satisfy the needs of technological innovation in domestic enterprises.

The Chinese manufacturing industry has had lower digestion and technological transformation expenditure input strength, showing that enterprises have little technological digestive expenditure and lack the necessary attention. Moreover, due to insufficient innovation input strength of the Chinese manufacturing industry and weak R&D foundation, technological digestive capacity has been worse and can't completely integrate with new technologies, so it is not good for enterprises to do technological innovation.

2.3 The Output Status of the Technological Innovation in Chinese Manufacturing Enterprises

Innovation output is an achievement that enterprises spend research input and introduce technologies for digestion based on certain innovation capacity. It can be used to measure the technological innovation capacity of enterprises. Figure 7 shows the total patent application quantity, patent application quantity for invention, the number of patents for invention, and new product development number of enterprises in the Chinese manufacturing industry. Figure 8 reveals the proportion of new products' sales revenues in main business incomes. Figure 9 represents relevant indexes of new products' amount of exports, comprehensive patent application quantity, new products' sales revenues, and new products' amount of exports to measure the innovation output of the Chinese manufacturing industry.

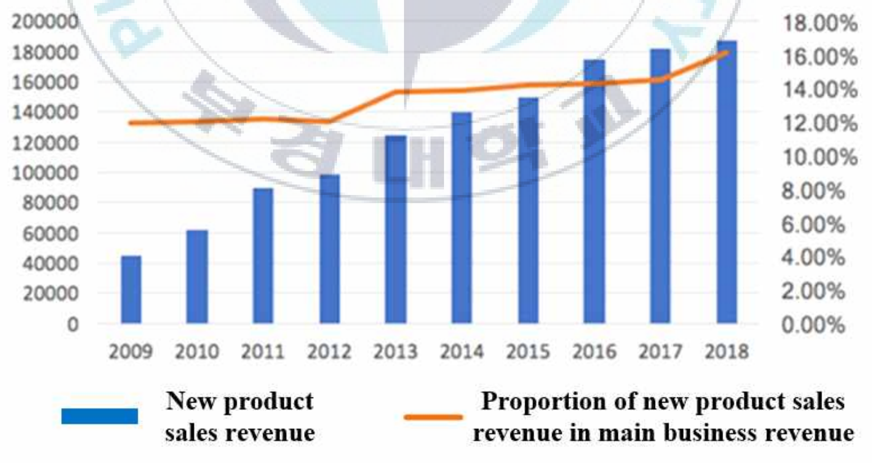
The patent index: The total patent application quantity of the Chinese manufacturing industry in 2009 reached 11200 items, including 2700 items of patent application quantity for invention. The latter accounted for 23.89% of the latter. In 2018, total patent application quantity realized 684400 items, including 273900 items of patent application quantity for invention, which accounted for 40.02% of total patent application quantity. The proportion of patent application quantity for invention in total patent application quantity was increased year by year. Moreover, the average increasing rate of patent application quantity for invention and total patent application quantity respectively reached 36.90% and 30.77%. The former had a faster speed than the latter, showing that relative to utility model and appearance design, manufacturing enterprises pay much attention to patents for invention and enterprise technology innovation. The number of new product development in 2009 and 2018 respectively realized 54800 items and 385600 items with an average annual increase rate of 14.08%. Except for negative growth in 2016, growth in other years remained 25% below, showing the relatively stable growth. The number of patents for invention was increased to 748400 items in 2016 from 6100 items in 2009 after ten years of development, increased by 122 times with the average annual increase rate of 37.98%, indicating that technological innovation of the Chinese manufacturing industry has shown the rapid growth trend.



The data source: the Technological Statistical Yearbook of Chinese Industrial Enterprises and Chinese Technological Statistical Yearbook

[Figure 7] Patent Application and New Product Development in the Chinese Manufacturing Industry

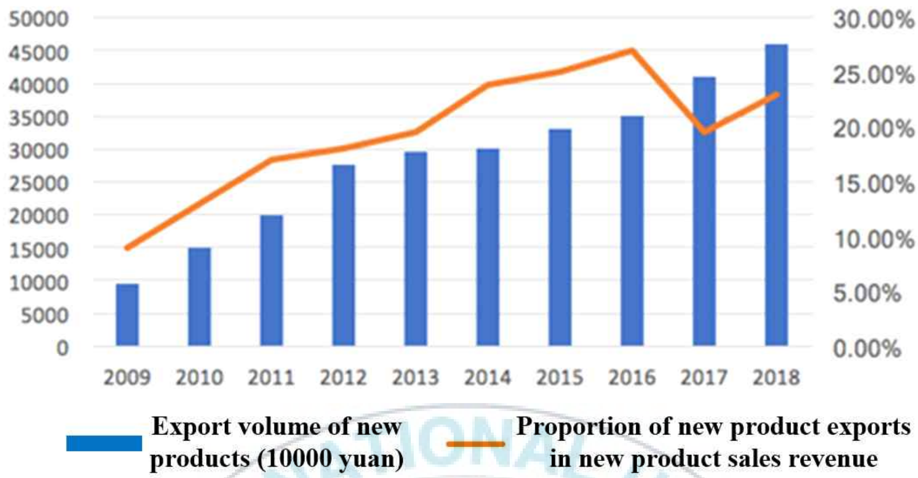
New products’ sales revenues and new products’ amount of exports: economic benefits brought by technological innovation in the manufacturing industry can be measured by new products’ sale revenues. Also, new products’ amount of exports can judge the competitive capacity of new products brought by technological innovation. Competition in products’ amount of exports in the international economy refers to the competition in technological innovation. New products’ sales revenues were increased to 17.28 trillion RMB in 2018 from 0.26 trillion RMB in 2009, showing the average annual increase rate of 22.55%. The trend figure shows that new products’ sales revenues in the Chinese manufacturing industry have been realizing steady-state growth. The proportion of new products’ sales revenues in the main business incomes of the Chinese manufacturing industry was increased to 16.5% in 2018 from 5.67% in 2009. Except for the heavy fluctuation of the proportion in 2010, other years have been realizing steady-state growth, showing the relatively stable growth trend of innovation output in the Chinese manufacturing industry.



The data source: the Technological Statistical Yearbook of Chinese Industrial Enterprises and Chinese Technological Statistical Yearbook

[Figure 8] New Products’ Sales Revenues

New products’ amount of exports in 2009 and 2018 respectively reached 549.503 billion RMB and 3267.47 billion RMB with the average annual increase rate of 18.95%but it showed negative growth in 2012. The proportion of new products’ amount of exports in new products’ sales revenues was rising year by year in 2015-2018, but it was decreased to 20% below in 2012. After that, the proportion was slowly rising because of the financial crisis in 2018. In this way, the demands of min trading nations for Chinese products have been dramatically reduced, resulting in an export reduction of new products in China. As a whole, new products’ amount of exports in the Chinese manufacturing industry has a lower proportion in the international market without competitive advantages due to weak technological innovation of the Chinese manufacturing industry. Technological innovation is an important factor for enterprises to remain stable advantages in international competition. However, the technological innovation of the Chinese manufacturing industry is weak and new products remain the bad situation in the fierce international competition, showing that the Chinese manufacturing industry still should constantly enhance self-technological innovation and reduce the gap with countries around the world.



The data source: the Technological Statistical Yearbook of Chinese Industrial Enterprises and Chinese Technological Statistical Yearbook

[Figure 9] New Products' Amount of Exports and Export Proportion in the Chinese Manufacturing Industry

To sum up, under the comprehensive role of increasing independent innovation input and introducing overseas technologies, innovation output of the Chinese manufacturing industry is present in the rising trend year by year, indicating that the technological innovation capacity of the Chinese manufacturing industry is gradually strengthened. Enterprises value self-technological innovation. Patent application lays particular emphasis on the technological innovation of patents for invention. Nevertheless, innovation output still has no competitive advantages in international competition. Relative to the international market, technological innovation capacity is also weak. Enterprise input for independent development is inadequate. In manufacturing enterprises, 85200 enterprises attended the R&D activity in 2018. In 2018, there were 353900 large and medium-sized industrial enterprises in the Chinese manufacturing industry, but only 24% of enterprises attended the R&D activities. At the end of 2018, 60861 manufacturing enterprises had scientific institutions, accounting for 17.19%. Less than one-quarter Chinese manufacturing enterprises could carry out independent innovation, resulting in weak self-foundation, weak technological digestion, and obstruction of enterprise technology innovation.

3. Differences from previous research

3.1 Summary of previous research

Previous research of major domestic and overseas scholars is listed in the form of tables, which could make the summary of the research results clearer and more intuitive.

[Table 1] Summary of Previous Research

Previous research subjects	**Major domestic and overseas scholars**	**Previous research direction/content**	**Previous research outcomes**
Technological innovation	Schumpeter（2020）	Theory of technological innovation	1. The proposer of technological innovation theory 2. Put forward five definitions of innovation
	R. Solow（2013）	Two necessary conditions for technological innovation	1.The construction of new ideas 2. The implementation process of new ideas
	Glynn（2012）	From the perspective of time development	Technological innovation includes the whole process from technology to commercial products
	Musser（2021）	The discontinuity of technological innovation	Technological innovation should be characterized by new thinking and successful application
	Fu jiaji and Jiang Yanfu（2017）	The connection between technological innovation and market	Technological innovation is the market technology and management technology related to technology development and

			application
Technological innovation efficiency	Sharma and Thoinas（2007）	Regional technological innovation	the level of national innovation efficiency was investigated and the reasons for the formation of national differences were analyzed
	S.Rousseau and R.Rousseau（2009）	Regional technological innovation	The comparison of national innovation efficiency was investigated
	Wang（2020）	Regional technological innovation	DEA is used to study the technological innovation efficiency of different countries, and the reasons for the efficiency difference are obtained
	Gaylen（2017）	Research on technological innovation with enterprises as the research object	That size and market share of American firms are positively correlated with their innovation capability was found
	kihiro and Shoko（2020）	Research on technological innovation with enterprises as the research object	the technological innovation efficiency of Japanese enterprises was measured and its influencing factors were analyzed
	Oakey（2019）	Research on technological innovation with enterprises as the research object	The innovation strategies of small high-tech enterprises in the United States and The United Kingdom were analyzed. The results showed that the innovation of enterprises is mainly from inside, and external innovation resources are not important in general
	Dodgson（2014）	Research on technological innovation with	The innovation behavior of European small enterprises was investigated.

		enterprises as the research object	
	Michael（2018）	Research on technological innovation with enterprises as the research object	Dutch manufacturing enterprises are increasingly dependent on external innovation resources, and there is a positive correlation between R&D intensity and technology outsourcing scale
Evaluation of technological innovation efficiency	A.Charnes and W.W.Cooper（1997）	Non-parametric method	Data Envelopment Analysis (DEA), which includes DEA evaluation model based on multiple inputs and multiple outputs -- CCR model (1984)
	Andersen and Petersen（2020）	Non-parametric method	The establishment of super-efficiency DEA model overcomes the problem that the traditional data envelope can't completely sort multiple DMU when they are in the front at the same time
	Chi Renyong（1998）	Non-parametric method	differences of regional economic development in China was studied, holding that it is necessary to strengthen China's regional technological innovation ability and reduce the gap between the three regional economic development levels
	Xiang Benwu（2019）	Parametric method	The stochastic frontier analysis method was used to measure the technological innovation efficiency of Industrial industries in China. It was found that the technological innovation efficiency of industrial industries does not improve with the passage of time.
	Guo Yujin（2019）	Parametric method	The stochastic frontier method

			was used to analyze the impact of science and technology environment on regional technology innovation efficiency in China, and the situation of the eastern, central and western regions was investigated
	Xia Yeliang and Cheng Jia(2010)	Parametric method	The stochastic frontier analysis was used to analyze the effect of foreign investment on the technological innovation efficiency of Chinese industrial enterprises, and it was found that foreign-owned enterprises and foreign-controlled enterprises have better effects
Selection of technical innovation evaluation index	Tao Ye and Xu Long（2019）	index system mainly constructed by stages	The innovation process was divided into four stages: input, implementation, management and realization, and the index system is constructed respectively.
	Ma Jianfeng（2020）	index system mainly constructed by stages	The innovation process was divided into "technology research and development" and "technology application". According to the different periods of initial input, intermediate output, additional input and final output, a DEA series model with two stages and three periods is established
	Du Dong（2019）	index system mainly constructed by stages	It is considered that the design of the index system should be as concise as possible, intuitive and clear, so the input index including labor and capital, and the output index of the

			proportion of the output value of new products in the output value of all products are preliminarily established.
	Wu Cuihua（2012）	index system mainly constructed by stages	Technical indicators (high-tech conversion rate, technology and products, R&D investment level, etc.), economic indicators (new product development capacity, product share, financial income, etc.) and comprehensive indicators (staff quality and environmental factors) have been set up.
	Wang Weiguang（2017）	Input and output index system	Starting from the input-output ratio of industrial innovation, the selected indicators include R&D expenditure and R&D personnel.
	Sun Kai（2021）	Input and output index system	The innovation efficiency of Chinese provinces were evaluated, the total amount of R&D internal expenditure were selected as input index, and the transaction value of technology market and the number of three kinds of patents were selected as output index
	Li Qiang（2018）	Input and output index system	According to the data characteristics of listed SMEs, R&D expenditure and the number of technical personnel were selected as the input indicators of DEA model, and the single index of product net profit is taken as the output indicator to evaluate the innovation efficiency of listed SMEs.

	Yu Jiayu（2012）	Input and output index system	The innovation capability was evaluated by taking four capabilities including innovation guarantee, input, implementation and output as first-level indicators and subdividing them into 22 second-level indicators

3.2 Differences from previous research

In previous studies, from the perspective of research subjects, foreign researchers mainly study from different countries, regions and some industries, while Chinese scholars mainly focus on different regions, provinces and industries. In terms of research methods, non-parametric method (mainly DEA) and parametric method (mainly SFA) are the main methods. From the perspective of research content, scholars mainly adopt different methods to conduct modeling, select indicators and analyze results. Some researchers carried out empirical studies through regression analysis, gray correlation and other methods on the basis of evaluation. The difference between the prior study and this study lies in:

First, the determination of the evaluation object. The research of existing Chinese scholars mainly focused on the regions with strong innovation capacity in the central and eastern regions, or the provinces with relatively developed economy. Less research had focused on China's western and northern regions, which are now heavily promoted by Chinese policy and are also important manufacturing bases. This paper includes study on western China and northeast China, which is more comprehensive.

The second one is about the understanding of the evaluation content. Research on technological innovation of industrial enterprises mostly focused on the evaluation and improvement of innovation capability, or on the overall innovation efficiency, or on the comparison of efficiency differences between different regions, while there are few researches on the innovation efficiency by stages. This paper compares the difference of technological innovation efficiency in different regions.

The third point is relevant with the understanding of the choice of evaluation method. Through analyzing existing literature, it could be discovered that both parameter method and non-parameter method have their advantages and disadvantages. When evaluating innovation efficiency, parameter estimation and index weight assignment are not necessarily required in DEA method, which could avoid the impact of subjective factors and hence DEA is more suitable for complex systems of multiple inputs and outputs, but inevitably, it would be affected because of the ignorance of random error. While SFA method is mostly used in the evaluation of the relative efficiency of multiple inputs and single output. In consider of the volatility and complexity of the innovation process of enterprises, it is hard to represent outputs with one specific index. Therefore, it is more suitable to adopt DEA method in this paper.

Fourthly, most papers took technological innovation efficiency in each industry or region into consideration, but few of them considered which factor influence the technological innovation efficiency or failed to combine these two aspects. The efficiency and influencing factors of technological innovation in each region are considered together in this paper, which is more comprehensive.

III. Research design

1. Research model

The research methods used in this paper are data envelopment analysis and Tobit model. Data envelopment analysis (DEA) includes DEA-CCR model, DEA-BCC model and Malmquist index method. DEA method has its unique advantages: first, it is suitable for the effective evaluation of multiple inputs and multiple outputs; Second, the application of DEA method does not require dimensionless data processing; Third, there is no need for any weight assumption, which excludes many subjective factors.

Tobit model can explain the variation of technological innovation efficiency of large and medium-sized industrial enterprises in China in a better manner, so as to provide more complete decision-making information for technological innovation of large and medium-sized industrial enterprises in China. In this paper, Tobit model is used to test the influencing factors of technological innovation of large and medium-sized industrial enterprises.

1.1 The DEA-CCR Model

Assuming that there are n DMUs for evaluation with m input factors x_j(j=1,2,3…m) and s outputs y_{ir}(r=1,2,3…s)(x_j, y_{ir}≥0), so the relative efficiency index h_0(u,v) of the DMU O can be expressed as:

max

$$s.t.\frac{\sum_{r=1}^{s} u_r y_{or}}{\sum_{j=1}^{m} v_j x_{ij}} \leq 1$$

Among which, u_r, v_j≥0; i=1,2…, n; j=1,2…,m; r=1,2…,s

To clearly express the sentence, it can be changed as follows for antithesis:

$\min_{\theta} \theta$;

Among which, i=1,2…,n; j=1,2…,m; r=1,2…,s

θ is the efficiency value of the evaluation unit, between 0 and 1. When θ=1, it means the DEA of the DMU is valid; when θ<1, it means that the DEA of the DMU is invalid.

1.2 The DEA-BCC Model

The CCR model is the most classical DEA model, which is established under the precondition of the constant returns to scale. Such an assumption often disagrees with reality. For this reason, Bankeretal (1984) added variable returns to scale on the basis of the CCR model and came up with the BCC model, which not only conforms to the actual production experience, but also can inspect the technological effectiveness and scale effectiveness of the DMUs. The concrete form is stated as follows:

$$\min\left[\theta - \epsilon\left(e^{T}s^{-} + e^{\wedge T}s^{+}\right]\right.$$

$$\sum_{j=1}^{n} \lambda_j x_j + s^{-} = \theta x_0$$

$$\sum_{j=1}^{n} \lambda_j y_j - s^{+} = y_0$$

$$\sum \lambda_j = 1$$

$$\lambda_j \geq 0, j = 1, 2 \ldots n$$

$$s^{+} \geq 0, s^{-} \geq 0, \theta \ \ unlimited$$

Among these, θ is the effective value of evaluation units. s^+ and s^- stand for slack variables and the combinational ratio between the original DMUs and correspondingly constructed DMUs. The efficiency value (TIE) solved by the CCR model can be decomposed into the product of scale efficiency(SE) and pure technical efficiency(PTE), namely technological efficiency= pure technical efficiency x scale efficiency. The pure technical efficiency is the efficiency value solved by the BCC model. The returns to scale of DMUs can be judged according to: As >1, it means decreasing returns to scale; as =1, it means returns to scale can reach the optimal earnings; as <1, it means increasing returns to scale.

1.3 The Malmquist Index Method

The Malmquist index was proposed by Malmquist in 1953. Caves et al.,(1982) first used the DEA to construct the Malmquist index measurement efficiency change or productivity. Hence, the technological innovation efficiency change index in manufacturing enterprises studied in this thesis (CTIEC) can be expressed as:

$$TIEC_t^{t+1} = M_t^{t+1} = \left[\frac{D^t(x^{t+1}, y^{t+1})}{D^t(x^t, y^t)} + \frac{D^{t+1}(x^{t+1}, y^{t+1})}{D^{t+1}(x^t, y^t)} \right]^{\frac{1}{2}}$$

According to the study of Fare et al., (1994), the technological innovation efficiency change index can be decomposed into the technological efficiency change EFFCH index and technological progress index TECHCH to further figure out the source for efficiency changes:

$$TIEC_t^{t+1} = M_t^{t+1} = \frac{D^{t+1}(x^{t+1}, y^{t+1})}{D^t(x^t, y^t)} * \left[\frac{D^t(x^{t+1}, y^{t+1})}{D^{t+1}(x^t, y^t)} + \frac{D^t(x^t, y^t)}{D^{t+1}(x^t, y^t)} \right]^{\frac{1}{2}}$$

Among these, EFFCH represents the “pursuit” effect of the DMUs for the production frontier. If EFFCH>1, it shows the DMUs below the frontier tend to the frontier, while if EFFCH<1, it means to keep away from the frontier; TC represents the movement of the production frontier. If TC>1, it means relocation of the production frontier (with technological innovation); if TC<1, it means ingression of the production frontier (with technological progress). When technological efficiency change (EFFCH) remains variable returns to scale, it can be further decomposed into pure technical efficiency change (PTEC) and scale efficiency change (SEC).

$$EFFCH = \frac{D^{t+1}(x^{t+1}, y^{t+1}|V)}{D^{t}(x^{t}, y^{t}|V)} * \frac{D^{t+1}(x^{t+1}, y^{t+1}|C)}{D^{t}(x^{t}, y^{t}|C)} + \frac{D^{t}(x^{t}, y^{t}|V)}{D^{t+1}(x^{t+1}, y^{t+1}|V)}$$

The front item is pure technical efficiency change (PTEC). The second item is the scale efficiency change (SEC). As PTEC<1, it means a reduction of pure technical efficiency, vice versa; as SEC>1, it means an increase of scale efficiency, vice versa. Under the precondition of variable returns to scale, the total factor productivity index can be decomposed into:

$$TIEC_t^{t+1} = M_t^{t+1} = PTEC * SEC * TECHCH$$

In other words, the technological innovation efficiency change index is composed of the pure technical efficiency change index, scale efficiency change index and technological progress index.

1.4 Tobit Model

As the value of technological innovation efficiency in this paper is between 0 and 1, the range, as a dependent variable, is limited, so it is inappropriate to use the least square method for regression at this time. Therefore, Tobit model, an econometric model with limited dependent variables, can be used for regression analysis. Tobit model is the extension of Probit model, which was proposed by Tobin in the estimation of the dependent variable relation of limit value. This model is an econometric model proposed for dependent variables with partial continuous distribution and partial discrete distribution, also called interception regression model. The specific form of Tobit model is as follows:

$$Y_i = \begin{cases} X_i\beta + \mu_i, when\ X_i\beta + \mu_i > 0 \\ 0, others \end{cases}$$

Where I = 1,2,3..., is the restricted dependent variable, is the explanatory variable, and is the unknown parameter vector .

2. Research hypothesis

Abundant achievements of manufacturing technological innovation research have been made by domestic and foreign scholars. According to the theoretical research basis in chapter 2 and model constructed in last section in this chapter, this section proposes hypothesis from two aspects including technological innovation efficiency and external environment of technological innovation efficiency mainly based on region factors.

2.1 Research Hypothesis of region factors impacts on technological innovation efficiency

The eastern part of China includes the Yangtze River Delta region (Shanghai, Jiangsu, Zhejiang), Guangdong, Shandong, Fujian and other large provinces. These provinces have large populations, are close to the sea and have developed economies. For years, the eastern region has contributed half of China's GDP. It is the large number of manufacturing enterprises in the eastern region behind this rapid economic development that made great contributions to China's economic take-off. Central China region includes Henan, Shanxi, Hubei, Anhui, Hunan, and Jiangxi Provinces, which were vital gain base. However, nowadays, due to the middle area location, inconvenient traffic condition, as well as the weak connection with outside world under this globalization situation, economic development of these provinces has been tepid, with only few manufacturing enterprises. Western China region includes Sichuan, Yunan, Guizhou, Xizang, Chongqing, Shanxi, Guangxi and other areas. Under the impact of China’s policy of developing western China vigorously, some manufacturing enterprises started to set factories in western region considering of the low land price and low labor price, which leads to the take- off of the economy. Northeast China generally refers to Heilongjiang, Jilin and Liaoning provinces. Northeast China region was once a heavy industry base of China, providing a large number of production tools and industrial equipment, which were mainly steel, for the development of Chinese manufacturing industry. However, due to the situation of overcapacity, coupled with the implementation of China's supply-side structural reform, manufacturing enterprises in northeast China are facing the important task of transformation. Based on this reality, hypothesis 1, hypothesis 2 and hypothesis 3 are proposed.

H1: In terms of comprehensive technological innovation efficiency, Eastern China > Western China > Central China > Northeast China

H2: In terms of utilization rate of technical resources, Eastern China > Western China > Central China > Northeast China

H3: In terms of the scale of manufacturing industry, eastern China > Western China > central China > Northeast China

2.2 Research hypothesis of the impact of external environment on technological innovation efficiency

(1) Research hypothesis on the influence of manufacturing enterprises to industrial enterprises in technological innovation efficiency

Manufacturing enterprises are part of industrial enterprises, which also include mining, electricity, heat, water and other industries. For a long time, manufacturing has been the pillar of the national economy, and it plays a crucial role in the development of the country, especially in the process of poverty alleviation. Meanwhile, the manufacturing industry has also solved most of the country's employment problems. Most of the manufacturing enterprises are labor-intensive and can absorb more working-age workers. Therefore, the greater the proportion of manufacturing enterprises in industrial enterprises, the greater the impact on the national economy and national life, as well as the impact on technological innovation. Based on this, hypothesis 4 is proposed.

H4: The proportion of manufacturing enterprises in industrial enterprises is positively correlated with technological innovation efficiency

(2) Research hypothesis on the influence of proportion of state-owned enterprises on technological innovation efficiency

Manufacturing enterprises can be divided into state-owned manufacturing enterprises and private manufacturing enterprises according to the ownership of means of production. State-owned manufacturing enterprises usually only need to complete the targets and tasks issued by the state, and there is no specific requirement for innovation. A good example could be manufacturing enterprises in northeast China, most of which are state-owned manufacturing enterprises. Under the environment of technological progress and innovation, manufacturing enterprises in northeast China have not kept pace with time and thus have fallen behind manufacturing enterprises in other regions. However, private manufacturing enterprises are facing fierce competition in the market and must keep competitive all the time, so they have to improve their technological innovation ability. Based on this, hypothesis 5 of this paper is proposed.

H5: The proportion of state-owned enterprises is negatively correlated with technological innovation efficiency

(3) Research hypothesis of the impact of the degree of opening to the outside world on the efficiency of technological innovation

China's manufacturing enterprises are of large size, but lag behind the world's leading level in terms of technology. Manufacturing enterprises should develop toward high-end and advanced manufacturing enterprises, adhere to opening up, learn from foreign advanced manufacturing technology and management, and improve their own system construction. Based on this, this paper proposes hypothesis 6.

H6: There is a positive correlation between the degree of openness and the efficiency of technological innovation

(4) Research hypothesis of the impact of higher education development level on technological innovation efficiency

In the early stage of the development of China's manufacturing industry, it gradually changed from handicraft industry to machine manufacturing. Therefore, the laborers working in manufacturing enterprises are generally not highly educated. Under the influence of the new era and new technology environment, more highly educated talents are needed for manufacturing enterprises, so as to provide suggestions for manufacturing enterprises to catch up with the world's leading pace and get rid of excess capacity. Based on this, this paper proposes hypothesis 7.

H7: There is a positive correlation between the development level of higher education and technological innovation efficiency

(5) Research hypothesis of the impact of policy support on technological innovation efficiency

To achieve the leading position, manufacturing enterprise need to continuously improve the level of information, automation and intelligence, which requires a lot of capital and talent support. If the country can offer policy support, such as providing preferential policies in taxation, developing more matching talents and providing financial support, manufacturing enterprises can integrate into advanced technologies and upgrade to advanced manufacturing. Based on this, this paper proposes hypothesis 8.

H8: There is a positive correlation between policy support and technological innovation efficiency..

3. Selection of variations

3.1 The Selective Principles of the Technological Innovation Efficiency Evaluation Index

Constructing the index system is the precondition of evaluation. The evaluation index system is the organic integrity of multiple evaluation indexes with interrelation and role according to a certain hierarchical structure. Constructing a reasonable index system is very important for evaluation results. Too many indexes will make calculations redundant and complicated with repeated information to obstruct results. Too fewer indexes make information incomprehensive and lack of representativeness. It is easy to result in one-sidedness. There is no uniform academic standard and paradigm for the construction of the index system, but should refer to the specific situation. Generally speaking, the following principles should be observed:

(1) Scientificity and simplicity: the index system must reveal features and status of evaluation objects. It is scientific and reasonable and conforms to objective laws and evaluation purposes. It not only should scientifically summarize basic features of technological innovation in industrial enterprises, but also should provide valuable information and the basis for enterprises. Moreover, indexes shouldn't be miscellaneous. The key is whether the role of evaluation is obvious. Concise and straightforward indexes can effectively save time costs, so that the evaluation activity can be developed and implemented successfully. In this thesis, on the basis of studying previous references, the author selects indexes from different perspectives, tries to use the refined index system to evaluate in a real, objective and scientific manner.

(2) Representativeness and differentiation: input and output factors of technological innovation efficiency are numerous and complicated. The index selection should reveal the characteristics of research objects in a better manner. Even if indexes are reduced, it still can ensure the reliability and credibility of evaluation results. Also, indexes also should have a difference. Each other should make a comparison. Indexes without representativeness and differentiation, on the one hand, increase redundancy of the index system. On the other hand, the authenticity of evaluation results is affected, but can't objectively and accurately reveal the actual situation.

(3) Operability and quantization: not all indexes are suitable for using as an evaluation basis. It is necessary to consider data acquisition and operability, effective approaches to data acquisition and convenience. Moreover, as selecting indexes, it is essential to consider whether data can conduct quantitative processing. Indexes that can conduct quantitative processing should be convenient for mathematical calculation and analysis. In the process of constructing the index system, the approaches of data acquisition come from all kinds of statistical yearbooks, showing strong representativeness. However, unavailable indexes will be removed to ensure that all index data will conduct quantitative processing for calculation.

3.2 Selection and detection of dynamic evolution analysis indexes

(1) Selection of dynamic evolution indexes

In this thesis, the author studies the technological innovation efficiency status of Chinese manufacturing enterprises from the following perspectives: input and output are used to reveal the technological innovation efficiency status of manufacturing enterprises. The index selection principles and problems to be noticed should be considered as a whole. Therefore, the author determines to use the combination of the qualitative method and quantitative method to select the relevant input-output index. The qualitative basis is the study of existing references and theoretical analysis. During the analytical process of existing references, the author finds that personnel input and capital input in technological innovation input indexes generally are required, while the frequency of selecting patent application quantity and industrial output of new products in technological innovation output indexes is also maximum. Meanwhile, in theoretical analysis, the author analyzes the connotation and production function of technological innovation efficiency. Such content shows the reference for selecting indexes. In the quantitative analysis, the author conducts the correlation analysis for preliminarily selected indexes to ensure the high relevance between the selected indexes.

After considering authority and availability of index data, the author combines with the specific situation of technological innovation in Chinese industrial enterprises and selects the input indexes as follows on the research basis of overseas and domestic scholars, including Wu Yanbing(2006), Guan Jiancheng, et al.,(2003), and Bai Junhong et al.,(2008, 2009, 2010).

The full-time equivalence of researchers shows the sum of converting full-time personnel and non-full-time personnel in R&D into the full-time personnel according to the workload. It actually reveals the number of personnel in R&D.

The development expenditure of new products reveals the expenses for developing new products spent by enterprises. It is an important index for enterprise technology innovation input.

Other technical activity expenditures refer to enterprise expenses for technological transformation, technological introduction, digestion and purchasing of domestic technologies. It is another important index for enterprise technology innovation input.

The output index selection: the number of new product development items is the direct index to measure enterprise technology innovation output, including extensive innovation of enterprises; Gayle (2001) considers the patent application quantity as an important index to measure enterprise technology innovation achievements. Patents are important achievements for enterprise technology innovation. If there are more patents, enterprise technology innovation capacity will be stronger. Liu Xielin, Chen Mao(1995), and Liu et al., consider the industrial output of new products as another crucial index of innovation output, which is the purpose of technological innovation, showing the paramount achievement of enterprise technology innovation.

When the DEA is used for studying data, the sample size should be twice of indexes, so 30 Chinese provinces and areas are chosen as research objects in this thesis. It is suitable to select 6 input-output indexes. The data source of this thesis comes from the Chinese Technological Statistical Yearbook of each volume in 2009-2018.

(2) Detection of dynamic evolution indexes

To provide convenience for comprehensive comparison, the author studies the regional difference of Chinese R&D efficiency from the perspectives of the Eastern Region, the Central Region, and the Western Region. According to the division criteria of the Eastern Region, the Central Region, and the Western Region in the Chinese Statistical Yearbook, the Eastern Region contains Beijing, Tianjin, Hebei, Shanghai, Jiangsu, Liaoning, Guangdong, Shandong, Fujian, Hainan and Zhejiang. The Central Region includes Hubei, Hunan, Henan, Anhui, Jiangxi, Shanxi, Inner Mongolia, Jilin, and Heilongjiang. The Western Region gets involved in Ningxia, Xinjiang, Guangxi, Chongqing, Sichuan, Guizhou, Yunnan, Shaanxi, Gansu, and Qinghai.

Due to the particularity of scientific activities, there is a "time lag" between input and output. The author refers to the study of Furman et al.,(2002) and determines the time lag of each index as 1 year, namely the input of 2009 corresponds to the output of 2010, and so on. Table 1 shows the descriptive statistical feature of the input-output variables.

[Table 2] The Descriptive Statistical Feature of the Input-output Variables

Variables	Units	Quantity	Maximum	Minimum	Mean	Standard Deviation
y_1	PCS	150	24434	34	4044	4471
y_2	PCS	150	43554	5	3932	697
y_3	Tens of million Yuan	150	112343	100	15443	19878
x_1	Man-year	150	256545	85	32432	38798
x_2	Tens of million Yuan	150	7200	14	941	1342
x_3	Tens of million Yuan	150	5434	5	1356	1908

There is a precondition as using the DEA model for data to study, namely whether input-output variables can satisfy "isotonicity". In other words, when the DMU input is increased, the corresponding output also should be increased. Hence, Pearson's correction is used for verification. The analytical results are shown in Table 2. Under the circumstance of no less than 0.05 of the significant level, input-output variables have a significant positive correlation. By analyzing the analytical results of Pearson's correlation coefficient, it can be observed that the same data meet the conditional requirements of "isotonicity". The DEA model can be used for modeling.

[Table 3] Pearson's Correlation Coefficient between Input and Output of Samples

Variables	x_1	x_2	x_3	y_1	y_2	y_3
x_1	1.000					
x_2	0.734**	1.000				
x_3	0.896**	0.897**	1.000			
y_1	0.887**	0.792**	0.816**	1.000		
y_2	0.906**	0.876**	0.918**	0.816**	1.000	
y_3	0.817**	0.543**	0.825**	0.838**	0.902**	1.000

3.3 Selection of influencing factor variables of technological innovation efficiency

Since there are many factors affecting the technological innovation efficiency of large and medium-sized industrial enterprises, when selecting variables, the authority and availability of index data and the specific situation of the current development of Chinese industrial enterprises are taken into account, and previous research results are referred. Variables are selected as follows:

(1) Industrial structure refers to the proportion of large and medium-sized industrial enterprises in the added value of industrial enterprises of each province.

(2) Proportion of state-owned economy refers to the proportion of large and

medium-sized state-owned industrial enterprises of each province in regional large and medium-sized industrial enterprises.

(3) Level of opening-up refers to the proportion of import and export value of large and medium-sized industrial enterprises in output value of large and medium-sized industrial enterprises by region.

(4) The development level of higher education refers to the number of students in institutions of higher learning per 100,000 people in each province.

(5) Policy orientation is expressed by the proportion of local science and technology appropriations in the total regional scientific research funds. The data are from China Statistical Yearbook and China Statistical Yearbook of Science and Technology.

IV. Empirical analysis

1. The Dynamic Evolution Analysis of the Technological Innovation Efficiency in Manufacturing Enterprises

1.1 The Technological Innovation Efficiency Evaluation of Manufacturing Enterprises Based on the BCC Model

Based on the innovation input and output index data of the manufacturing industry in each Chinese province and area in 2018, DEAP2.1 software and the DEA-BC model are used to calculate technological innovation efficiency in each province and area. The results are stated in Table 3.

[Table 4] Empirical Results of Technological Innovation in the Manufacturing Industry of Each Chinese Province and Area in 2018

Areas	Overall efficiency (CR)	Pure technical efficiency (VR)	Scale efficiency (SC)	Returns to scale
Beijing	1	1	1	-
Tianjin	0.669	0.676	0.989	drs
Hebei	1	1	1	-
Shanxi	0.809	0.813	0.995	drs
Inner Mongolia	0.672	0.683	0.983	irs
Liaoning	0.804	0.804	1	-
Jilin	1	1	1	-
Heilongjiang	0.879	0.954	0.922	drs
Shanghai	1	1	1	-
Jiangsu	0.848	1	0.848	drs
Zhejiang	1	1	1	-
Anhui	0.843	0.881	0.957	drs
Fujian	0.792	0.853	0.929	drs
Jiangxi	0.97	1	0.97	irs
Shandong	0.776	1	0.776	drs
Henan	0.884	1	0.884	drs

Hubei	0.706	0.833	0.847	drs
Hunan	0.935	0.982	0.952	drs
Guangdong	0.782	1	0.782	drs
Guangxi	0.734	0.816	0.899	irs
Hainan	1	1	1	-
Chongqing	1	1	1	-
Sichuan	0.599	0.76	0.788	drs
Guizhou	0.939	1	0.939	irs
Yunnan	0.915	0.982	0.932	irs
Tibet	1	1	1	-
Shaanxi	1	1	1	-
Gansu	0.692	0.965	0.718	irs
Qinghai	0.545	1	0.545	irs
Ningxia	0.515	1	0.515	irs
Xinjiang	0.506	1	0.506	irs

Notes: irs represents the increasing returns to scale; drs stands for decreasing returns to scale; - means constant returns to scale

(1) Analysis of Technological Efficiency

(a) Analysis of overall efficiency

It can be observed from Table 3 that the overall efficiency values in the Eastern Region, the Central Region, the Western Region, and the Northeast in 2018 respectively reached 0.866 ,0.883 ,0.880, 방0.832, 0.636 ,0.615, 0.882, 0.728, 0.651, 0.670, 0.621, 0.546. Through the analysis, the overall efficiency value in the Eastern Region was higher than the other three major regions for two consecutive years, showing that the cultural manufacturing industry in the Eastern Region has had relatively good innovation efficiency, but it still should be improved. The overall efficiency values in the Central Region, the Western Region and Northeast remained the continuous declination stage. In 2018, their efficiency respectively realized 0.615, 0.651 and 0.546. The overall efficiency was lower, showing that these three regions were not ideal in overall technological innovation development. The entire level of the cultural manufacturing industry in each Chinese area was lower. By making a comparison on the overall efficiency values of four major regions, it can be observed that overall efficiency values in four major regions were present in the state of the Eastern Region> the Western Region> the Central Region> Northeast. Moreover, the overall efficiency of the cultural manufacturing industry in each region had a great difference. Hypothesis 1 is verified.

Based on the Eastern Region, the overall efficiency value in Zhejiang Province and Shanghai Municipality was 1, reaching the valid DEA. Though Jiangsu Province was not valid, it also reached 0.848, showing that the innovation level of the cultural manufacturing industry among them has reached the optimal state. Innovation input resources could be fully and reasonably used (Jiangsu was not valid, but the efficiency value remained the high and stable level). The overall efficiency value in Jilin Province in 2018 reached 1, showing that resource allocation in these several years was gradually reasonable, making technological innovation efficiency lift. Innovation efficiency in Heilongjiang remained 0.8-1 state level, indicating that the innovation efficiency level of the cultural manufacturing industry still should be promoted. The overall efficiency values in Tianjin and Inner Mongolia were lower and only reached 0.669 and 0.672 in 2018, directly pulling down the overall technological innovation efficiency level in the Eastern Region. According to the Central Region, overall efficiency in Anhui and Jiangxi was invalid in2018, but the efficiency values continuously remained the higher level, showing that the resource utilization rate of both provinces was relatively higher, but it still had advancement. The overall efficiency values of Shanxi, Henan, Hubei and Hunan in 2018 basically remained about 0.8, indicating that the resource utilization rate in most provinces and cities in the Central Region was lower, seriously pulling down the overall technological innovation level in the Central Region. From the perspective of the Western Region, the Western Region faced the same problem with the Central Region. In other words, innovation input resources of the cultural manufacturing industry in most provinces and cities in the region obtained scientific and reasonable allocation, resulting in the lower overall technological innovation efficiency in the region. According to the

Northeast, the overall efficiency of Jilin Province in 2018 reached the valid DEA state, but the overall efficiency values in Liaoning and Heilongjiang were lower, directly taking down the average level of technological innovation efficiency of the cultural manufacturing industry in the Northeast.

As a whole, the mean overall efficiency value of the cultural manufacturing industry in 31 provinces and cities of the Chinese four major regions in 2018 was 0.749, showing the low-efficiency value. In 2018, the efficiency value reached 1, namely the overall efficiency of 9 provinces and cities remained a valid state, accounting for 29% of total samples. The “U” development trend was present as a whole. 10 provinces and cities showed overall efficiency between 0.8 and 1, accounting for 32% of total samples. It was present in the constant downtrend. In 2018, 12 provinces and cities remained 0.588 of overall efficiency, accounting for 39% of total samples and showing the constant rising trend. No provinces and cities remained 0.5 below of overall efficiency in 2018. It can be observed from the above-mentioned analysis that overall technological innovation efficiency in the Chinese cultural manufacturing industry was general. Provinces and cities with an efficiency value of less than 0.8 were continuously rising. More than 50% of provinces and cities have less than 0.8 of the efficiency value every year. Hence, technological innovation efficiency in the Chinese cultural manufacturing industry still has had a great space for advancement.

(b) Pure technical efficiency analysis

In 2018, pure technical efficiency in the Eastern Region, the Central Region, the Western Region, and the Northeast respectively reached 0.907, 0.853 and 0.971, which were higher than the overall efficiency value in the same period. Through the analysis, it can be observed that the mean pure technical efficiency in the Northeast showed the rising trend and it would continue rising. In 2018, it reached 0.912, which was higher than the other three major regions, showing relatively good pure technical efficiency of the cultural manufacturing industry in the Northeast and relatively high resource utilization rate. Also, the mean pure technical efficiency in the Western Region was continuously reduced with a small amplitude. Moreover, the efficiency value was higher than 0.8 for three consecutive years, showing a relatively stable technological level, but it still should be improved. As a result, it is necessary to reasonably allocate resources, enhance the technological efficiency level, and make it realize optimization. Before 2018, mean technological efficiency in the Central Region and the Northeast was on a declining curve. And the efficiency value in 2018 was lower than 0.8, indicating the lower technological efficiency level and great upside potential. It can be seen from the above-mentioned analysis that except for the Northeast, pure technical efficiency in the other three major regions showed the continuous downtrend in 2018, showing the annual expenditure input strength before 2018 was generally higher than expenditure input strength in 2018. Hence, it is judged that expenditure input strength has had a significant impact on technological efficiency. By further analyzing the pure technological efficiency value in four major regions, it can be observed that the technological efficiency values in four major regions showed the state of the Eastern Region> the Western Region> the Central Region> the Northeast. Moreover, the cultural manufacturing industry of each region had a great difference in the pure technical efficiency value. Hypothesis 2 failed to pass the verification. The reason is that northeast China, as an old-line industrial manufacturing region, still retains a certain capacity of technology transformation, a large volume and abundant resources, which can make the investment of funds more effective.

(c) Scale efficiency analysis

In 2018, the pure technical efficiency values in the Eastern Region, the Central Region, the Western Region, and the Northeast respectively reached 0.953, 0.969 and 0.905, which were higher than the overall efficiency values and pure technical efficiency in the same period. By analyzing Table 3, the scale efficiency value in the Northeast in 2018 was 0.961, which was higher than other three major regions, showing that the production scale of the cultural manufacturing industry in the Northeast was relatively good, but it still should effectively integrate, allocate resources, and make the production scale benefit reach the optimization. The scale efficiency values in the Central Region and the Western Region remained the continuous declination trend in 2018, reduced to 0.848 and 0.763, showing the high falling range(the mean scale efficiency in the Northeast had the rising trend in 2018, but it was decreased to 0.821 in 2018 from 0.936 with the falling range of 12.29%, showing the high amplitude). Therefore, it showed that the unreasonable phenomenon in the Central Region, the Western Region, and the Northeast in 2018 was increasingly severe, directly pulling down the technological innovation efficiency level. As a result, it is essential to scientifically and reasonably adjust the production scale, allocate resources, enhance its resource utilization rate, and increase the scale efficiency, so as to increase technological innovation efficiency. Furthermore, by further analyzing the scale efficiency values in four major regions, it can be found that in 2018, the scale efficiency values in four major regions showed the state of the Eastern Region> the Central Region> the Northeast> the Western Region. Moreover, it had the same feature with overall efficiency and pure technical efficiency in the cultural manufacturing industry of each region, namely the scale efficiency values of the cultural manufacturing industry in each region had a great difference. Hypothesis 3 fails to pass the verification. Although manufacturing enterprises in the western region continue to make strength, there are still a large number of manufacturing enterprises in the central region, and the stock effect still exists.

(2) Analysis of returns to scale

By analyzing returns to scale, the author further studies the scale status of the cultural manufacturing industry in each province and city of China and dissects the reasons for lower scale efficiency, see results in Table 4.

[Table 5] Analytical Results of Returns to Scale in the Manufacturing Industry of Each Region in China in 2018

	The number of provinces and cities(PCS)			Proportion (%)		
Returns to scale	Ascending	Invariable	Descending	Ascending	Invariable	Descending
The Eastern Region	3	7	2	12	28	8
The Central Region	4	4	3	16	16	12
The Western Region	1	1	1	4	4	4
The Northeast	2	1	2	8	4	8
Total	10	13	8	40	52	32

According to Table 4, 3 provinces and cities remained the ascending returns to scale of the cultural manufacturing industry in the Northeast of China in 2018, 7 provinces and cities remained the invariable stage, as well as 2 provinces and cities kept the descending stage. In the Central Region, 4 provinces and cities remained the ascending and invariable returns to scale of the cultural manufacturing industry, while 4 provinces and cities kept the descending stage. One province and city respectively remained three stages of returns to scale in the cultural manufacturing industry in the Western Region in 2018. Returns to scale of the cultural manufacturing industry in each province and city of the Northeast evenly distributed in three stages in 2018. Through the further analysis of returns to scale in the cultural manufacturing industry of each region, it can be found that in 2018, the Northeast had more provinces and cities remaining in the invariable stage, while the Central Region, the Western Region, and the Northeast had more provinces and cities in the descending stage of returns to scale, indicating that the technological innovation efficiency level of the cultural manufacturing industry in the Northeast was higher than other three major regions.

As a whole, according to returns to scale in the Chinese manufacturing industry in 2018, it can be seen that 10 provinces and cities remained the ascending stage, accounting for 40% of the proportion. For provinces and cities in such a state, it is essential to enlarge resource input, allocate in a reasonable manner, use resources, and make resources develop the maximum benefits. 13 provinces and cities kept the invariable scales to return, occupying 52% of the overall proportion. Provinces and cities in such a state reached the optimal returns to scale. 8 provinces and cities had the descending returns to scale, occupying 32 of the overall proportion. It can be seen that provinces and cities in the descending state occupied a high proportion in 2018. Such provinces and cities had a relatively high production scale in the cultural manufacturing industry. Hence, it is necessary to focus on adjusting the capital structure and enhance profitability, so as to strengthen returns to scale.

(3) Efficiency analysis

This thesis combines with the DEA efficiency judgment principle and divides the empirical analytical results into 3 categories. The detailed results see Table 5.

[Table 6] Analytical Results of the DEA Efficiency in 2018

	Valid DEA		Weakly valid DEA		Invalid DEA	
Efficiency	Quantity	Proportion	Quantity	Proportion	Quantity	Proportion
The Eastern Region	6	67	1	11	2	22
The Central Region	3	33	2	22	4	46
The Western Region	2	20	4	40	4	40
The Northeast	0	0	0	0	3	100
Total	11	35	7	23	13	42

DEA effectiveness means that innovation activities meet the necessary conditions of technology effectiveness and scale effectiveness. As can be seen from table 5, the number of provinces and cities in China's manufacturing industry reaching DEA effectiveness in 2018 was 11 respectively. The reason may be that the investment intensity of Shanxi Province and Anhui Province has decreased, but the innovation output has been improved. In 2018, the number of provinces and cities with DEA effective in China's manufacturing industry reached 11. According to the original data, the innovation input of Shanghai, Fujian, Shandong and Jiangxi provinces and cities increased to varying degrees, the innovation output also increased, the resources were reasonably allocated, the DEA was effective, and the innovation input of Guangxi and Chongqing provinces and cities increased, However, the innovation output has decreased, indicating that the innovation input resources have not been reasonably allocated, resulting in the decline of technological innovation efficiency.

DEA weak efficiency means that the manufacturing industry in various provinces and cities is in an effective state without considering the return of scale, and the resource allocation is also more reasonable. By observing table 5, it can be found that in 2018, the manufacturing industry of provinces and cities in Northeast China was not in the DEA weak effective stage, while the number of provinces and cities in the other three regions in the DEA weak effective stage was 7 respectively. Overall, the number of provinces and cities with weak and effective DEA in China's manufacturing industry is in the stage of fluctuation and rise. According to the analysis of table 5, the provinces and cities with weak DEA efficiency in 2018 are in the stage of decreasing scale, indicating that all provinces and cities in the region should not blindly increase innovation investment, but pay attention to the rational allocation of invested resources to maximize their utility.

DEA ineffectiveness means that innovation activities can neither meet the conditions of technical effectiveness nor scale effectiveness. In 2018, the number of provinces and cities in the eastern, central, Western and northeast regions with manufacturing industry in DEA invalid state was 2, 4, 4 and 3 respectively. The manufacturing industry in Northeast China is in the state of DEA invalidity. Overall, in 2018, 13 provinces and cities in China's manufacturing industry were in DEA invalid state, accounting for 42% of the total, indicating that nearly half of the 31 sample provinces and cities were in DEA invalid state every year, that is, there is still much room to improve the innovation efficiency level of manufacturing industry in various regions and provinces of China..

1.2 The Technological Innovation Efficiency Evaluation of Manufacturing Enterprises Based on the Malmquist Index

In this thesis, the author uses the Malmquist index model, utilizes DEAP2.1 software, and measures the technological efficiency index(EC), technological progress index(TC), pure technical efficiency index(PTE), scale efficiency index(SE) and total factor productivity (TFP) of the cultural manufacturing industry in each Chinese region from 2009 to 2018. To comprehensively reveal the dynamic variation change of technological innovation efficiency in the cultural manufacturing industry of each region, the author conducts the comparative analysis for the Malmquist index and results in 2009-2014 and 2015-2018. The results are stated in Table 6, Table 7, Table 8 and Table 9.

[Table 7] Malmquist Index and Results of Technological Innovation in the Cultural Manufacturing Industry in the Eastern Region of Each Year

Years	Technological efficiency (EC)	Technological Progress(TC)	Pure technical efficiency(PTE)	Scale efficiency(SE)	Total factor productivity (TFP)
2009-2014	1.038	0.912	1.098	0.992	0.923
2015-2018	0.991	1.100	0.943	1.028	1.098
Mean	1.115	1.006	1.021	1.010	1.011

[Table 8] Malmquist Index and Results of Technological Innovation in the Cultural Manufacturing Industry in the Central Region of Each Year

Years	Technological efficiency (EC)	Technological Progress(TC)	Pure technical efficiency(PTE)	Scale efficiency(SE)	Total factor productivity (TFP)
2009-2014	0.762	1.056	0.921	0.876	0.789
2015-2018	0.923	1.234	0.989	1.023	1.231
Mean	0.843	1.145	0.955	0.950	1.010

[Table 9] Malmquist Index and Results of Technological Innovation in the Cultural Manufacturing Industry in the Western Region of Each Year

Years	Technological efficiency (EC)	Technological Progress(TC)	Pure technical efficiency(PTE)	Scale efficiency(SE)	Total factor productivity(TFP)
2009-2014	0.875	1.223	0.932	0.923	0.965
2015-2018	0.963	1.234	1.005	0.932	1.136
Mean	0.919	1.229	0.969	0.928	1.051

[Table 10] Malmquist Index and Results of Technological Innovation in the Cultural Manufacturing Industry in the Northeast of Each Year

Years	Technologica l efficiency (EC)	Technological Progress(TC)	Pure technical efficiency(PTE)	Scale efficiency(SE)	Total factor productivity(TFP)
2009-2014	0.923	0.723	0.733	1.223	0.653
2015-2018	0.921	1.021	1.132	0.854	0.932
Mean	0.922	0.872	0.933	1.039	0.793

According to the computed results in Table 6, Table 7, Table 8 and Table 9, the total factor productivity in the Eastern Region and the Western Region had the same change trend during the research period. Both of them kept the downtrend in 2009-2014, but showed the rising trend in 2015-2018. Moreover, the amplitude of fluctuation in the former was less than the latter. Consequently, the total factor productivity in the Eastern Region and the Western Region was slowly rising in the entire research period. The total factor productivity in the Central Region and the Northeast was continuously reducing in 2009-2018 and had a higher falling range in 2015-2018, resulting in the rapid reduction of the total factor productivity in the research period. Based on the dynamic analytical results of Malmquist, during 2015-2018, technological progress in the Eastern Region was first reduced and then increased, but technical efficiency was first increased but then reduced. The falling range was less than the rising range, indicating that the overall innovation output capacity of the manufacturing industry in the Eastern Region had a good R&D capacity for new technologies, resulting in continuous rising of the total factor productivity during the research period. It can be found from Table 7 and Table 8 that during 2015-2018, technological efficiency and technological progress in the Central Region and Western Region revealed the same development trend. The former was continuously reducing in 2015-2018. In 2015-2018, the falling range was even up to 20.8%and 12.4%, leading to the dramatic reduction of the total factor productivity in those years, while the latter was continuously rising. In 2009-2018, the rising range was up to 24.7% and 24.5%, so that the total factor productivity in those years could be recovered, implying that overall innovation output capacity of the manufacturing industry in the Central Region and the Western Region was insufficient, showing lower utilization rate of existing technologies. However, the development capacity for new technologies was constantly enhancing. Based on Table 9, it can be seen that the technological efficiency and technological progress of the manufacturing industry in the Northeast were on a declining curve during the period of 2009-2018. The falling range of technological progress was up to 28.8%, resulting in a dramatic reduction of the total factor productivity in those years. In 2015-2018, technological efficiency kept the declining stage, while technological progress was promoted. Nevertheless, the falling range of the former was greater than the rising range of the latter, so that the total factor productivity was present in the slow downtrend during the research period. According to pure technical efficiency and scale efficiency decomposed by technological efficiency, in 2009-2018, pure technical efficiency and scale efficiency in the Eastern Region didn’t have the same change trend. The former was first increased and then reduced, while the latter was first decreased and then increased. However, the amplitude of variation was lower and an upward trend was maintained as a whole. In 2009-2014, pure technical efficiency and scale efficiency in the Central Region realized the synchronous development and showed the continuous declination trend. Both of them interacted, resulting in a dramatic reduction in technical efficiency. In 2015-2018, pure technical efficiency and scale efficiency could be recovered. In 2009-2018, pure technical efficiency in the Western Region was first reduced and then increased, while scale efficiency was continuously decreased. Pure technical efficiency in the Northeast was first decreased and then increased, while scale efficiency was first increased and then reduced, implying that in 2015-2018, innovation resource utilization rate in the Northeast was relatively high, resulting in the promotion of pure technical efficiency, while scale efficiency was continuously reduced, showing the production operation scale still should be perfected.

1.3 The Influence Factor Analysis of Technological Innovation Efficiency in Manufacturing Enterprises

EViews software is used by using the proportion of state-owned economy, open-door to the outside world, higher education development level, and policy orientation as independent variables, and technological innovation efficiency values of the whole country and three major regions as dependent variables. The Tobit regression results are stated in the Table. According to the regression results in the Table, the following data can be obtained:

[Table 11] Regression results of factors affecting technological innovation efficiency of manufacturing enterprises from 2009 to 2018

Variables	The whole country	The Eastern Region	The Central Region	The Western Region
Industrial structure	0.005956*	-0.004321	-0.001153	0.028121*
	(2.001327)	(-1.378678)	(-0.089121)	(2.951563)
Proportion of state-owned economy	-7.25e-05	0.000532**	0.001762***	2.73e-05
	(-0.156227)	(2.084540)	(1.507631)	(0.025121)
Open-door to the outside world	0.003421	0.032756*	0.0132212	0.102215
	(0.752346)	(2.678576)	(0.167324)	(0.647391)
Higher education development level	1.32e-05**	6.43e-07	1.62e-06	0.000206***
	(2.019436)	(0.412121)	(0.544327)	(1.988652)
Policy orientation	-0.010531**	-0.000438	0.009601	-0.002187
	(1.029641)	(0.0258765)	(0.514751)	(1.131287)
Constants	0.960631*	0.698761*	0.514273	0.5142682**
	(11.99286)	(12.768272)	(4.007878)	(2.856534)
F	36.8937	6.987638	24.76451	10.11567
R	0.765280	0.609810	076340	0.842121

Notes: *** represents the significant correlation at 0.01(both sides)

(1) The structural influence on technological innovation efficiency shows a significant positive correlation, implying that if manufacturing enterprises have a higher proportion in industrial enterprises, it will be better for enterprise technology innovation. Manufacturing enterprises will spend more capital on technological innovation relative to small-sized manufacturing enterprises. Moreover, the former is more proficient in the utilization of new technologies, so new products developed will be easier to be recognized by the market. Technological innovation efficiency will be higher. The

coefficient in the Eastern Region and the Central Region is significantly negative, showing the slow development of manufacturing enterprises in the Central Region. Technological innovation efficiency is reduced because of the flourishing tertiary industry in the Eastern Region and Central Region. Manufacturing enterprises start transferring to the west. The Western Region welcomes the transfer period of manufacturing enterprises. It is essential to take full advantage of human capital to promote the great development of the regional economy. Hypothesis 4 is verified.

(2) The proportion of the state-owned economy is negative, but it is not significant, showing that the proportion of state-owned enterprises has no facilitation to the technological innovation efficiency of national manufacturing enterprises. The coefficient in the Central Region is significantly negative, indicating that state-owned enterprises have lower technological innovation efficiency of manufacturing enterprises in the Eastern Region and the Central Region. It is essential to change the development mode and positively explore the structural reform of state-owned enterprises. State-owned enterprises are significantly positive in the Western Region, implying that state-owned manufacturing enterprises in the Western Region can use self-capital and talent advantages to become the mainstay of technological innovation in regional enterprises. Hypothesis 5 is verified.

(3) Open-door to the outside world is significantly positive in each region, indicating that regional manufacturing enterprises frequently contact with foreign countries. The market competitiveness is stronger and technological innovation capacity is more prominent. Manufacturing enterprises must constantly take part in the international market, compete with transnational corporations, and constantly broaden the overseas market, so as to stand on the new period. With the constant increase of openness in China, domestic enterprises develop towards the overseas market, but they face strong pressure that foreign enterprises constantly capture the Chinese market. Facing such a situation, only by constantly refining the “internal power”, reinforcing independent innovation and

learning the overseas advanced technological and managerial experience can enterprises attend the international market competition. Hypothesis 6 is verified.

(4) Higher education development level has a significant positive influence on technological innovation efficiency of manufacturing enterprises, implying that high or low regional education level causes a great impact on the technological innovation of manufacturing enterprises. Higher education provides intelligent support for the technological innovation of manufacturing enterprises. Due to too high educational expenditure input in the Eastern Region, the technological innovation efficiency of manufacturing enterprises is higher than the Central Region and the Western Region. As a result, the state should enlarge expenditure input of colleges in the Central Region and the Western Region and create conditions for college development in the Central Region and the Western Region. At the same time, the Central Region and the Western Region should strengthen infrastructure construction of higher education, strongly introduce high-level scholars and professors, and positively attend the national major scientific projects. Hypothesis 7 is verified.

(5) From the national perspective, policy orientation is significantly positive, indicating that the Chinese government constantly enlarges scientific research capital support strength and strongly facilitates technological innovation of manufacturing enterprises. However, from the regional perspective, the coefficient in the Eastern Region and the Western Region is negative, showing that the scientific capital of the government can't promote manufacturing enterprises because of blind input of local governments for scientific research capital and abuse of scientific research expenditure in enterprises. For this reason, the government should reinforce the supervision management of scientific research capital use of enterprises. Furthermore, enterprises ought to enhance the utilization efficiency of scientific research expenditure and improve the problem hat scientific research expenditure input is disproportional to innovation output. Hypothesis 8 is verified.

2. Hypothesis verification results

[Table 12] Regression results of factors affecting technological innovation efficiency of manufacturing enterprises from 2009 to 2018

	Research hypothesis	Hypothesis verification results
Hypothesis 1	In terms of comprehensive technological innovation efficiency, Eastern China > Western China > Central China > Northeast China	The hypothesis passed the verification. The hypothesis is true.
Hypothesis 2	In terms of utilization rate of technical resources, Eastern China > Western China > Central China > Northeast China	The hypothesis did not pass the verification. The hypothesis is false.
Hypothesis 3	In terms of the scale of manufacturing industry, eastern China > Western China > central China > Northeast China	The hypothesis did not pass the verification. The hypothesis is false.
Hypothesis 4	The proportion of manufacturing enterprises in industrial enterprises is positively correlated with technological innovation efficiency	The hypothesis passed the verification. The hypothesis is true.
Hypothesis 5	The proportion of state-owned enterprises is negatively correlated with technological innovation efficiency	The hypothesis passed the verification. The hypothesis is true.
Hypothesis 6	There is a positive correlation between the degree of openness and the efficiency of technological innovation	The hypothesis passed the verification. The hypothesis is true.
Hypothesis 7	There is a positive correlation between the development level of higher education and technological innovation efficiency	The hypothesis passed the verification. The hypothesis is true.
Hypothesis 8	There is a positive correlation between policy support and technological innovation efficiency	The hypothesis passed the verification. The hypothesis is true.

V. Conclusions and Policy Suggestions

1. Conclusions

This paper conducts qualitative and quantitative research on the technological innovation efficiency of China's manufacturing industry from two research perspectives of region and subsector. Firstly, the background, purpose and significance of this paper are introduced. Secondly, the concept and classification of manufacturing industry, the theoretical basis of technological innovation and the existing research results of manufacturing industry and technological innovation efficiency domestically and overseas are summarized. Then, the development status of manufacturing industry is analyzed. Next, the index system of technological innovation efficiency of manufacturing industry is constructed, and empirical methods and data sources are introduced. The DEA-BCC model and DEA-Malmquist index model are used to conduct empirical research on technological innovation efficiency of China's four major regional manufacturing industries and 16 sub-sectors of manufacturing industry. Finally, the empirical research results are analyzed, and relevant conclusions are put forward, so as to propose targeted countermeasures and suggestions. This paper uses forefront of technology innovation theory as the basis of the theory, through investigation of the relevant theories and research methods of technological innovation performance evaluation of enterprises, the non-parametric DEA method is determined to be adopted. Technological innovation efficiency status of Chinese manufacturing enterprises is analyzed from horizontal region difference analysis and vertical dynamic evolution analysis perspectives, so as to research and evaluate technological innovation efficiency of Chinese manufacturing industry in an objective and fair way. Conclusions summarized from these two perspectives are as follows:

Firstly, technological innovation development of the manufacturing industry in Chinese four major regions was not synchronous and the technological innovation efficiency level was lower as a whole. The DEA-BCC model was used to measure technological innovation efficiency of the manufacturing industry in 31 provinces and cities of the Chinese four major regions, it can be found that in 2009-2018, the innovation efficiency value in the Eastern Region was present in the rising trend as a whole, while other three regions showed the continuous downtrend and had the lower efficiency values. Particularly, in the Northeast, the efficiency value was less than 0.7 for consecutive three years. In three years of 2009-2018, the mean technological innovation efficiency of the Chinese manufacturing industry respectively reached 0.839, 0.749 and 0.712, revealing the continuous downtrend and the lower efficiency values. It showed the overall innovation efficiency level in the Chinese manufacturing industry should be enhanced.

Secondly, technological innovation efficiency in the manufacturing industry of each Chinese province and city had a great difference. From the regional perspective, the innovation efficiency value of the manufacturing industry in the Eastern Region was higher in 2009-2018, while except for 2014, the innovation efficiency values of the cultural manufacturing industry in other three major regions were lower than 0.7, showing that technological innovation efficiency in each region had a great difference. Especially for the Eastern Region and the Northeast, the difference value was up to 0.334. In 2018, the difference values between maximum and minimum of innovation efficiency in provinces and cities of four major regions respectively reached 0.475, 0.747, 0.619, and 0.687, indicating that technological innovation efficiency between provinces and cities of each region had a great difference, especially for the Central Region.

Thirdly, innovation input resources of the Chinese manufacturing industry couldn’t obtain a reasonable allocation. In 2018, only 6, 1, 1, and 3 provinces and cities of the manufacturing industry in 31 provinces and cities of four major regions reached the valid

DEA. The efficiency value of 1, 1, 3 and 2 provinces and cities was less than 0.8, remaining the lower efficiency value. By analyzing 13 provinces and cities with the invalid DEA in 2018, it can be found that the manufacturing industry of each province and city had redundant innovation expenditure and personnel and insufficient innovation output, indicating that resource input and allocation were unreasonable, innovation expenditure and personnel couldn't be fully used, and utilization rate was lower, resulting in unsatisfactory innovation output. Eventually, the technological innovation efficiency of the cultural manufacturing industry was pulled down.

Fourthly, the technological innovation efficiency of the Chinese manufacturing industry had a good rising trend, but it still should be promoted. From the regional perspective, by measuring the dynamic innovation efficiency of the Chinese manufacturing industry through the Malmquist index model, the total factor productivity in the Eastern Region and the Western Region during 2009-2018 was present in the rising trend. 12 provinces and cities among 25 of them in the four major regions showed the rising trend in the total factor productivity, indicating that innovation efficiency of the cultural manufacturing industry in nearly half of Chinese provinces and cities was dynamically developing. As a whole, the technological innovation efficiency level of the Chinese manufacturing industry might be not very high, but the efficiency value in nearly half of provinces and cities and most of the market segments was constantly developing, showing the good technological innovation development trend of the Chinese cultural manufacturing industry. However, the technological innovation efficiency level of the cultural manufacturing industry in provinces and cities of each region still should have a great space for advancement.

The Tobit model was applied to analyze the influence factors of technological innovation efficiency of manufacturing enterprises, stated as follows: (1) Enterprise structure caused the significantly positive correlation on technological innovation efficiency, indicating the higher proportion of manufacturing enterprises in national enterprises, the better technological innovation of enterprises; (2) Proportion of state-owned economy had the negative national coefficient, but it was insignificant, indicating that the higher proportion of state-owned enterprises couldn't facilitate overall technological innovation efficiency of manufacturing enterprises; (3) Open-door to the outside door was significantly positive to each region, indicating the more contact between manufacturing enterprises and foreign countries, the stronger market competitiveness and the more prominent technological innovation capacity; (4) Higher education development level caused the significant positive impact on technological innovation efficiency of manufacturing enterprises, implying that high or low regional education level had a great impact on technological innovation of manufacturing enterprises. Higher education provided intelligent support for technological innovation of manufacturing enterprises; (5) From the national perspective, policy orientation was significantly positive, showing that the Chinese government could constantly enlarge the support for scientific research capital and promote technological innovation of manufacturing enterprises.

2. Suggestions

After entering the 21st century, the Chinese government has proposed to construct "the autonomous innovative country", trying to encourage enterprises to change the economic development mode through technological innovation and technological progress, abandon the "extensive" economic development mode in the past, and enhance resource utilization efficiency. On the basis of the empirical analysis, the author proposed the policy suggestions for technological innovation of large and medium-sized industrial enterprises.

(1) Reinforce the basic research and promote innovation talent team construction

Nowadays, the primary cause for the reduction of technological innovation efficiency in Chinese manufacturing enterprises is attributed to the technical setback. Hence, each region should enlarge basic research input. For a long time, basic research is difficult to gain economic benefits in a short time and it can't receive the deserved attention all the time. Moreover, it is difficult to apply for scientific research funds, especially for enterprises that pursue the current benefits. However, from the long-term perspective, basic research not only takes the lead in the technological competition of enterprises, but also can promote the technological progress of the entire society. Talents are subjects of innovation. Technological innovation only can be achieved by talents. Enterprises should reinforce cooperation with colleges and scientific research institutions, and realize the combination of "industry-university-research cooperation". Talent cultivation of scientific research institutions doesn't mean to run a school by closing a door, but should realize mutual cooperation, especially for extensive cooperation with enterprises, conduct technological development and personnel training through multiple channels, fully develop the role of high-level innovation personnel, support technological innovation capacity of enterprises, constantly enhance the technological level and economic benefits of enterprises, and establish the complementary, mutually support and mutually beneficial partnership with enterprises. Institutions of higher education, scientific research institutions and enterprises should undertake the heavy burdens of innovation talent construction, effectively find out, cultivate, use and gather excellent scientific research talents, and constantly improve the overall quality of scientific research personnel. Meanwhile, it is urgent to reinforce technological innovation management talent cultivation of enterprises. Particularly, the role of advanced management talents in enterprise innovation is never inferior to scientific research personnel.

(2) Reasonably allocate resources and coordinate with regional balance development

Low scale efficiency restrains enhancement of the technological innovation efficiency level of the manufacturing industry. Lower technological innovation efficiency of manufacturing enterprises is not attributed to the number of resource input, but should contribute to resource quality and reasonable allocation. Yearly R&D capital and personnel input lack of systematic and effective planning. Resource input has blindness. In resource input, it not only should increase the input of technological innovation R&D capital, but also should pay attention to cultivation and introduction of scientific talents and promote the increase of resource input on the basis of looking for the suitable input structure, for fear that any resource will restrain innovation activities. Due to low resource utilization efficiency, some areas even have redundant innovation resources, while some areas obviously have insufficient innovation input. Hence, each regional government ought to regulate innovation input of manufacturing enterprises, but can't directly intervene in enterprise decision-making. From the national perspective, areas with redundant innovation resources can lead innovation resources to insufficient areas through governmental guidance.

Moreover, China has unbalanced regional development. The Eastern Region, the Central Region and the Western Region have the obvious technological innovation efficiency difference in manufacturing enterprises, while the Eastern Region obviously takes the lead in the Central Region and Western Region. For this reason, the Eastern Region should remain advantages and drive the technological innovation efficiency of manufacturing enterprises in the Central Region and the Western Region to realize the leap increase under the precondition of stably enhancing enterprise technology innovation efficiency. The Central Region and Western Region should take full advantage of the late-mover advantage of technological choices. By purchasing, imitating and learning the developed technologies and managerial experience in the Eastern Region, enterprise technology innovation efficiency can be further enhanced, so as to realize the fundamental transformation from progressive innovation to independent innovation. Only by destroying the regional barrier and constantly increasing regional circulation of innovation resources can it reduce the technological innovation efficiency gap between regions.

(3) Make innovations on the organizational structure and introduce the market competition system

Large and medium-sized manufacturing enterprises have more capital for technological innovation relative to small-sized manufacturing enterprises. The former has the great innovation talent team strength and becomes more proficient in using new technologies. New products developed are easier to be recognized by the market. Also, technological innovation efficiency should be higher. Through this thesis, it can be found that state-owned enterprises in the Eastern Region and the Central Region have the poor technological innovation performance, showing that the current system of state-owned enterprises has certain constraint for self-technological innovation, so it is essential to positively explore the structural reform of state-owned enterprises and release technological innovation potential of state-owned enterprises. The “tangible hand” o the government should develop maximum efficiency. However, promoting enterprises to carry out technological innovation activities doesn’t mean that the government intervenes in enterprise management too much. Such a suggestion in essence hopes the government to help enterprises with innovation conditions to implement technological innovation activities more conveniently. During the process of regional independent innovation, on the one hand, the local governments can guide the development direction of regional independent innovation by formulating policies. On the other hand, the government should focus on perfecting the market competition mechanism and fully develop the intangible role of the market. It can’t excessively support enterprises, but should overcome the local protectionism thought. For enterprises that can’t keep up with the times, it is essential to firmly reform enterprises and eliminate them as appropriate.

(4) Optimize the technological innovation environment and reinforce intellectual property protection

Independent innovation is more than the behavior of individuals, but a system of social behavior. The leading role of the government is even crucial. Also, empirical results prove the promotion of governmental research input on independent innovation efficiency. During the process of regional independent innovation, the local governments can guide the development direction of regional independent innovation by formulating policies. For example, it can formulate the industrial policy, guide and supervise enterprises to enlarge technological innovation input strength in the corresponding industry field, adjust the tax structure and policy, implement tax reliefs of developing new products, allow enterprises to rapidly depreciate equipment, and expand innovation capital accumulation. Differing from technological innovation features of different industries and all kinds of categories, it is necessary to formulate the corresponding preferential policy and encourage bank or fiscal appropriation to provide concessional loans for enterprise technology innovation. The excessively strict intellectual property protection policy undoubtedly will affect the technological introduction activity of high-tech enterprises and delay the cultivation of technological innovation capacity because enterprise technology innovation activities will be restrained of various patents in multiple aspects. However, if the strict intellectual property protection policy is not implemented, it inevitably will cause two serious consequences: firstly, the scientific-technological activities of innovators will be seriously restrained. Under the circumstance, innovators can't fully protect their rights, resulting in affecting their enthusiasm for innovation activities. Secondly, technological transfer activities out of regions will be dramatically reduced because external innovators will refuse to transfer the high-tech industry to China for the imperfect intellectual property of China. Therefore, it is essential to further sound the patent system of China, for the sake of promoting the extensive application of technologies and remaining the powerful motivation for innovators.

3. Shortcomings and Prospects

To begin with, as applying the DEA method to measure the technological innovation efficiency of manufacturing enterprises, the author referred to previous research achievements in the index selection, but it was still affected by subjective factors. Moreover, data in this thesis came from the Chinese Technological Statistical Yearbook, so the index selection should consider data availability, but only could select relevant data indexes in the yearbook. Similarly, the index selection process of influence factors for technological innovation efficiency also has had the same problem.

Besides, the author in this thesis applied the quantitative method. However, due to the complexity of the enterprise technology innovation process, if qualitative and quantitative methods can be combined to analyze the technological innovation of enterprises, it will be more accurate and convincing. Furthermore, limited by the subject background and time, the author couldn’t deeply propose policy suggestions. The DEA method used in this thesis is a classical model, but only uses the input and output for evaluation without considering the middle process. For further study and input-output combinations in each stage, the author will learn the network DEA model and deeply evaluate technological innovation efficiency.

According to an analysis of research shortcomings, the author should further discuss the technological innovation activities of the Chinese manufacturing industry. As for the data selection of research object samples, sample data of more years should be used in the future for perfect statistics. The empirical results can fully reveal the development trend of technological innovation efficiency in the Chinese manufacturing industry. Besides, it is necessary to fully combine with specific features of research objects, select more indexes to measure technological innovation efficiency of the manufacturing industry, scientifically and systematically construct the index system, and finally choose a suitable method to supplement data(or supplement deficient sample of provinces and cities), so that the number of provinces and cities to be studied will be more complete to more accurately study and evaluate the overall technological innovation efficiency level of the Chinese manufacturing industry and eventually put forward more targeted, scientific and effective suggestions to enhance technological innovation efficiency of the Chinese manufacturing industry.

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Research on the Technological Innovation Efficiency Evaluation of Chinese Manufacturing Industry Based on the DEA Model

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Abstract

At present, under the condition that enterprises gradually become innovative subjects, knowledge production often comes from enterprises. Manufacturing enterprises become the important constituent parts of regional technological innovation and are subjects of technological innovation in the manufacturing industry. The technological innovation level of manufacturing enterprises represents the high or low national innovation capacity to a large extent. Hence, under the circumstance, it has the important practical significance to do scientific measurement for the technological innovation efficiency of manufacturing enterprises in each Chinese province and area and propose countermeasures for improvement.

On the basis of reading lots of domestic and overseas references and research results of experts, the author in this thesis summarizes the research status of the domestic and overseas technological innovation efficiency evaluation theories and methods. With the theoretical foundation of the non-parametric DEA method, the author investigates the technological innovation efficiency status of manufacturing enterprises in each Chinese province and rea from two aspects, including the horizontal regional difference and longitudinal dynamic evolution, and also utilizes the Tobit model to analyze influence factors of the technological innovation efficiency.

To begin with, the author analyzes the status of Chinese manufacturing enterprises to reflect on the necessity of carrying out the technological innovation efficiency evaluation, summarizes the domestic and overseas technological innovation efficiency evaluation theories and existing evaluation methods, and proposes the course research significance, research ideas, and innovative points. Next, the author constructs the technological innovation efficiency evaluation index system of manufacturing enterprises and applies Pearson's relevant analysis to do correlation verification on data. Also, the author uses the DEA-BCC model to do the horizontal static measurement on the technological innovation efficiency in each province and area, investigates the difference in the East Area, the Central Area and the West Area, and applies the DEA-Malmquist index method to analyze the dynamic changes of the technological innovation efficiency in each province and area. At last, the author utilizes the Tobit model to analyze influence factors of the technological innovation efficiency, so as to show the extensive application value to provide the targeted policy advice for the technological innovation efficiency of Chinese manufacturing enterprises.

Keywords: Large and medium-sized industrial enterprises; the technological innovation efficiency; DEA; Malmquist index method; Tobit model