



Faculty of Economics and Business

**Efficiency Performance of Industrial Innovation System of China Brand
Automobile**

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Efficiency Performance of Industrial Innovation System of China Brand
Automobile

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DECLARATION

I declare that the work in this thesis was carried out in accordance with the regulations of Universiti Malaysia Sarawak. Except where due acknowledgements have been made, the work is that of the author alone. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

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ABSTRACT

In 2009, China has become the largest automobile production and sales country in the world. However, China automobile industry presents a large but not strong situation, that is the market share of own brand automobile is not high, and the situation of relying on foreign brands and technology is still serious. Based on the innovation system of automobile industry, this study analyzes the problem of “large but not strong” of China automobile industry. The aim of this study is to investigate the efficiency performance of the innovation system of China automobile industry from 2001 to 2021. The DEA-VRS, DEA-CRS method and DEA-Malmquist index model were used to evaluate the innovation efficiency of China brand automobile industry. The technical efficiency, pure technical efficiency, scale efficiency, total factor productivity, comprehensive technical efficiency, and technological progress index are calculated, respectively. It also explores the determinants of innovation system’s efficiency. The conclusion of this study is that, from the perspective of 24 regions, there are obvious spatial imbalances in the efficiency development of China own brand automobile industry’s innovation system. From a national perspective, there is no significant upward or downward trend in the efficiency of the innovation system in the own brand automobile industry. The total factor productivity and comprehensive technical efficiency show no significant trend and do not exceed 1.0, while the technology progress index shows a fluctuating upward trend, with values higher than 1.0 throughout the entire sample period. In terms of influencing factors, there are several identical ones that have different impacts on efficiency and productivity, respectively. The policy recommendations of this study are that own brand automobile enterprises should strengthen technological research and development, choose the optimal

development model. The government should increase investment in the research and development of own brand automobile enterprises, establish scientific systems, promote the effective combination of industry, academia, and research, carry out top-level design to enhance the independent innovation drive of state-owned automobile groups.

Keywords: Automobile industry, China brand, Innovation system, Efficiency performance

Prestasi Kecekapan Sistem Inovasi Industri Automobil Jenama China

ABSTRAK

China telah menjadi negara pengeluaran dan pemasaran kereta terbesar di dunia pada tahun 2009. Walau bagaimanapun, industri automobil di China adalah industri yang besar tetapi ia tidak kukuh, iaitu syer pasaran kereta jenama nasional adalah tidak tinggi, dan kebergantungan kepada jenama dan teknologi asing adalah masih serius. Tiada jenama terkenal antarabangsa dan tiada syarikat multinasional automobil bertaraf dunia. Berdasarkan sistem inovasi industri automobil, kajian ini menganalisis masalah "besar tetapi tidak kuat" industri automobil di China. Matlamat kajian ini adalah untuk mengkaji prestasi kecekapan sistem inovasi industri automobil China dari tahun 2001 hingga 2021. Kaedah DEA-VRS, DEA-CRS dan model indeks DEA-Malmquist digunakan untuk menilai kecekapan inovasi industri automobil jenama China. Kecekapan teknikal, kecekapan teknikal tulen, kecekapan skala, jumlah faktor produktiviti, kecekapan teknikal komprehensif, dan indeks kemajuan teknologi dikira masing-masing. Ia juga meneroka pembolehubah penentu kecekapan sistem inovasi. Kesimpulan kajian ini adalah terdapat ketidakseimbangan spatial yang jelas dalam pembangunan kecekapan sistem inovasi industri automobil jenama China sendiri berdasarkan perspektif dari 24 wilayah. Dari perspektif negara, tiada trend menaik atau menurun yang ketara dalam kecekapan sistem inovasi dalam industri automobil jenama sendiri. Jumlah produktiviti faktor dan kecekapan teknikal yang komprehensif tidak menunjukkan trend fluktuasi yang jelas, dan nilai kecekapan tidak melebihi 1.0, manakala indeks kemajuan teknologi menunjukkan arah aliran menaik yang turun naik, dengan nilai yang lebih tinggi daripada 1.0 sepanjang keseluruhan tempoh sampel. Dari segi faktor yang mempengaruhi, terdapat beberapa

faktor yang serupa yang masing-masing mempunyai kesan berbeza terhadap kecekapan dan produktiviti. Cadangan dasar kajian ini ialah syarikat kereta jenama tempatan harus mengukuhkan penyelidikan dan pembangunan teknologi, memilih model pembangunan yang optimum. Kerajaan harus meningkatkan pelaburan dalam penyelidikan dan pembangunan perusahaan automobil jenama tempatan bagi mewujudkan sistem saintifik, menggalakkan gabungan industri, akademik dan penyelidikan yang berkesan, melaksanakan reka bentuk peringkat atasan untuk meningkatkan pemacu inovasi bebas kumpulan automobil milik kerajaan.

Kata kunci: *Industri automobil, Jenama China, Sistem inovasi, Prestasi kecekapan*

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LIST OF ABBREVIATIONS

BYD	Build Your Dreams
DEA	Data Envelopment Analysis
EV	Electric Vehicle
FAW	First Automobile Work
GAC	Guangzhou Automobile Group Co., Ltd
JAC	JiangHuai Automobile Co.Ltd
PTE	Pure Technical Efficiency
R&D	Research and Development
SAIC	Shanghai-Automotive-Industry-Corp
SE	Scale Efficiency
SFA	Stochastic Frontier Analysis
TE	Technical Efficiency
TFP	Total Factor Productivity
VIF	Variance Inflation Factor

CHAPTER 1

INTRODUCTION

1.1 Introduction

The automobile industry is an essential pillar of the national economy in many countries, which plays a significant role in social development with a long industrial chain, high correlation, comprehensive employment and large consumption. The share of automobile industry accounted for 20%, 13.1%, 9% and 10% of the gross domestic product (GDP) in Japan, India, Germany and China, respectively, in 2020 (Sabeti, 2020). Additionally, the number of workers in the automobile industry reached 36 million in 2022. The automobile industry creates not only direct jobs, but also employs additional jobs in other sectors. It was found that for each job completed in the automobile industry, four different jobs were created in another sector (International Labour Organisation, 2020).

Innovation refers to transforming production factors and conditions into a new mode through permutation and combination to reduce production costs and improve production efficiency. Schumpeter was the first to put forward five forms of innovation: product, technological, market, resource allocation and enterprise organisation innovation (Wang & Cao, 2012). Innovation is the soul of enterprise development; it is the eternal vitality of the development of the automobile industry; innovation, the development of the automobile industry will be complex. Enterprise innovation not only brings enormous benefits to enterprises, but also provides better products for consumers. At the same time, it can drive the development of relevant enterprises and jointly promote social prosperity and progress.

The development level and innovation ability of the automobile industry reflect a country's industrialisation level, comprehensive innovation ability and industrialisation complementation. The operation performance of the innovation system of the automobile industry directly affects the innovation performance and the international status of China's automobile industry. The essence of the industrial innovation system is a connection, which is to connect the innovation activities of enterprises and other secondary participants. Furthermore, it takes technological innovation as the core, forms integrated innovation ability, reduces the innovation cost of individual innovation activities and maximises the benefits. This is to promote the generation, flow, renewal and transformation of new technologies, or new knowledge in the industry and promote the formation of enterprise innovation ability and the improvement of industrial competitiveness. System efficiency evaluation is an essential content of industrial innovation system research, which helps to grasp the evolution process of industrial innovation ability and provides the basis for making related innovation policies.

1.2 Background of the China Automobile Industry

Since 2009, China has been the world's largest automobile manufacturer and automobile market. China's annual auto production accounts for more than 30% of the global automobile production (Statista Research Department, 2021). The market share of the top ten global automakers was at the same level as that of China's top ten automakers for the first time in 2017. Nearly 20% of the top ten global automakers' entire product is manufactured in China, as shown in Figure 1.1.



Figure 1.1: Market Share of the Automobile Production in China (2010 to 2017)

Source: Quest Trend Magazine (2019)

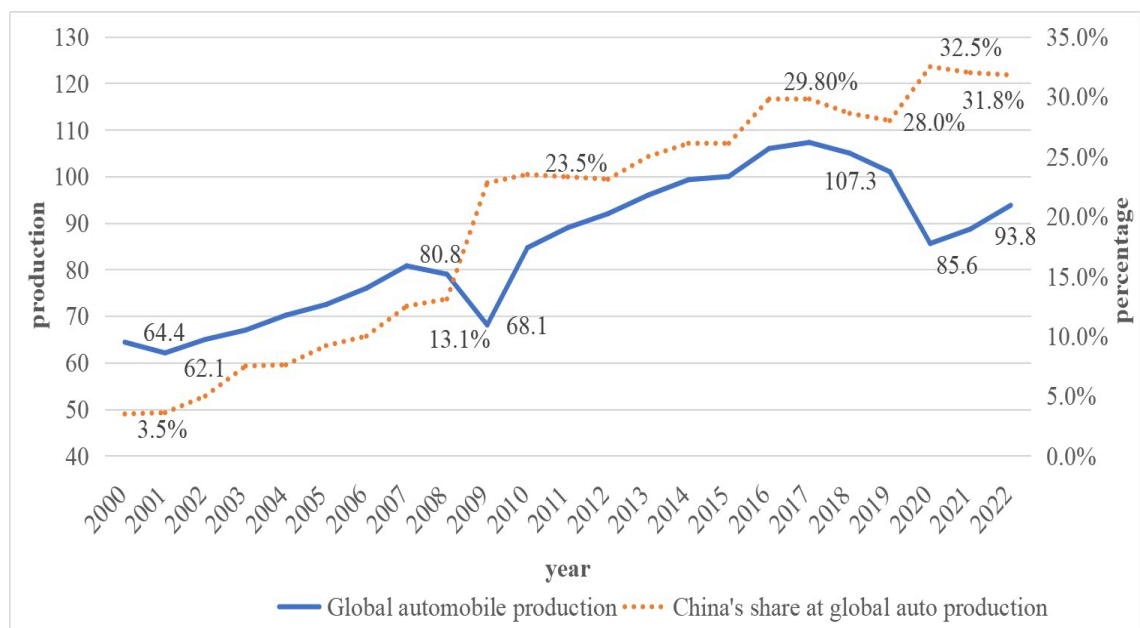


Figure 1.2: World Automobile Production (2000 to 2022) (Unit: '00, 000)

Source: Organization Internationale des Constructeurs d'Automobiles (OICA, 2023)

The importance of China for the world's auto production is evident. As shown in Figure 1.2, the global auto production increased by 45% from 2000 to 2022, whereby China's global auto production has grown 9-fold. In the 15 years from 2007 to 2022, the global auto production fell by 9.9% without China.

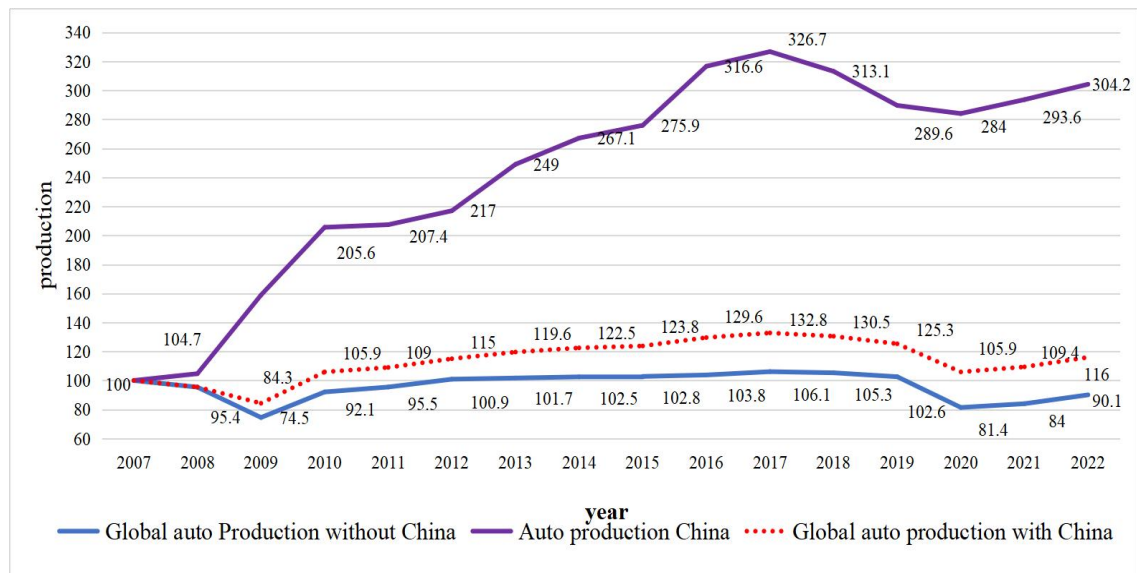


Figure 1.3: Automobile Production in China and Global (2007 – 2022) (Unit: '00, 000)

Source: Organisation internationale des Constructeurs d'Automobiles (OICA, 2021)

Based on Figure 1.3, the declined average annual rate of the world's automobile production was 0.7%. However, with China, the global auto production increased by almost 16% from 2007 to 2020, with an average annual growth rate of 1%. China's automobile production has increased 3-fold during the 15 years.

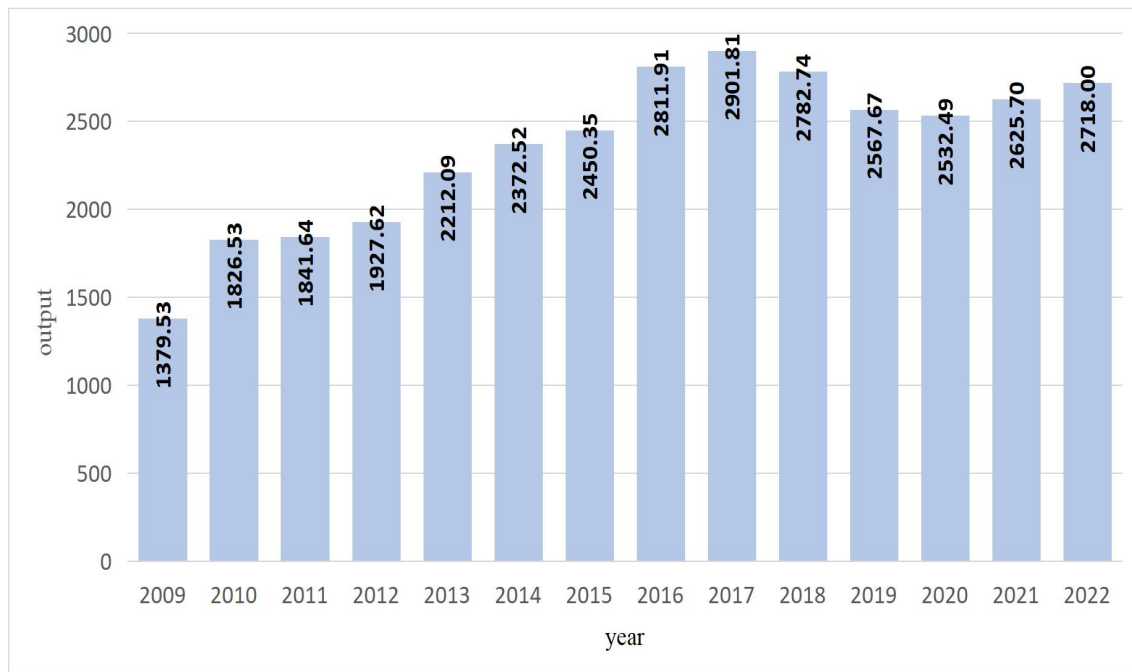


Figure 1.4: Output of China Automobile Industry from 2009 to 2022 (Unit: ' 000)

Source: National Bureau of Statistics (2023)

In the past decade, China's automobile industry has developed at high speed. As shown in Figure 1.4, the output of automobile industry has increased sharply from 13.8 million vehicles in 2009 to 27.2 million cars in 2022 (National Bureau of Statistics, 2023). Since 2009, China's automobile production and sales have been ranked first in the world for 14 consecutive years, which has made it the world's largest automobile producer. The leading own brand automobile corporations and their brands are presented in Table 1.1. The Build Your Dreams (BYD) vehicles, amongst which, was ranked 12th in the world's most valuable automobile brands ranking in 2023, as shown in Table 1.2.

Table 1.1: China Brand Automobile Corporations

Corporation	Main Brands
Shanghai Automotive Industry (Group)	Wuling, Shanghai Shenwo, Mingjue, Rongwei
Dongfeng Motor Co., Ltd	Dongfeng, EV NewEnergy, Shenglong, Chenglong, Huashen, Lantu, Fengshen, Fengxing, Xiaokang, Baolong, Longka
China First Automobile Group	FAW Jiefang, FAW Sedan, Red Flag, FAW Haima, FAW Pentium
BAIC Motor Group Co., Ltd	Jihu, Beijing, Futian, Ouake, Aoling, Wise Smurf, Xiangling, Ruiwo, General, Jixiang, Ouhui, Proko, Navigation, Foton
Guangzhou Automobile Industry Group	Trumpqi, Gonoe, Aion
Chang'an Automobile (Group)	Changan, Hafei, Changhe, Lufeng, Hafei, Dong'an, Chang'an star, Chang'an Xingguang, Chang'an Benben, Chang'an Jiexun, Chang'an Zhixiang, Chang'an Ruixiang
China Heavy Truck Group	Yellow River, Shandeka, Howao
Brilliance Auto	Brilliance Zhonghua, Brilliance Jinbei

Table 1.1 continued

Chery Automobile Co., Ltd	Chery, Kairui, Weilin, Ruiqi
Anhui Jianghuai Automobile Group	JAC, Ankai
BYD Co., Ltd	BYD
Geely Automobile Group	Geely

Source: China Association of Automobile (2021)

Table 1.2: World's Most Valuable Automobiles Brands

2023 rank	2022 rank	Brand	Country
1	3	Teda	United States
2	2	Mercedes-Benz	Japan
3	1	Toyota	Germany
4	5	BMW	Germany
5	6	Prosche	Germany
6	4	Volkswagen	Germany
7	7	Honda	Japan
8	8	Ford	United States
9	12	Hyundai	South Korea

Table 1.2 continued

10	11	Audi	Germany
11	9	Nissan	Japan
12	19	BYD	China
13	14	Lexus	Japan
14	13	Chevrolet	United States
15	10	Volvo	Sweden

Source: <https://carspiritpk.com/2023-worlds-most-valuable-automobiles-brands/>

The development of China’s automobile industry can be divided into the following four stages:

I. Initial Stage (1950-1965)

On 13 July 1956, the First Automobile Work (FAW) built the liberation truck, ending the history that China could not produce cars. On 5 May 1958, the first Dongfeng CA71 car was trial produced. The number of automobile manufacturers increased from one in 1953 to 16 in 1960. By the end of 1965, there were nearly 290,000 civil cars in China (Liang, 2009).

II. Growth Stage (1966-1980)

In 1969, the second automobile company was built in Hubei province to produce “Dongfeng” trucks, “Fukang” cars and later “Elysee” cars. The second automobile company has 20,000 sets of equipment and more than 100 automatic production lines.

Only 1% of the critical equipment is imported from abroad, which is another excellent progress in China's automobile industry. In 1976, the number of automobile manufacturers in China increased to 53. In 1980, 222,000 cars were produced, which was 5.48 times of 1965. The ownership of cars reached 1.69 million (Liang, 2009).

III. Cooperation Stage (1981-1999)

Since the reform and open policy, China's automobile industry has fully enjoyed the dividend brought by economic development. With the rapid growth of China's economy, the demand for automobiles has gradually increased. However, at the same time, because the level of China's automobile industry at that time could not meet the demand, China imported 640,000 cars from 1984 to 1987, with a total cost of 26.6 billion yuan. During the reform process, China introduced foreign capital and built joint ventures. SAIC Volkswagen was established in 1985, whereas FAW Volkswagen was established in 1991. Since then, several joint venture car enterprises have been established.

Through continuous cooperation with foreign auto factories and the introduction of advanced standards and systems, China's auto industry has formed a relatively complete industrial system. The sales volume of joint venture brands of the top auto groups in China accounts for more than 50%. For example, FAW has a deficient sales volume of its brands (Pan, 2020).

IV. High Speed Development Stage (Early 21st Century till Present)

China's automobile industry is advancing at a faster pace, with new models emerging, segments being continuously improved and vehicle technology constantly improving. In 2019, China's passenger car sales ranked first in the world, accounting for 33% of the global total sales (China Association of Automobile Manufactures, 2020).

Simultaneously, the pace of cooperation with foreign automobile giants is becoming more and more obvious, such as Volkswagen's sharing in JAC. Foreign auto companies are also deepening their layout in the Chinese market (Pan, 2020).

1.3 Problem Statement

China's automobile industry seems to be in a dilemma of being big, but not strong. From the perspective of market share, China is the largest country in automobile production and sales. However, the market share of own brand automobiles was only 35.7% in 2020 (National Passenger Cars Association, 2020), a 2.1% decrease from that of 2019 and most of the domestic market was occupied by foreign brands. The domestic sales volume of China own brand passenger cars only accounted for 38.4% of the total car sales volume in 2020, which is 0.9% less than in 2019 (Ministry of Industry and Information Technology, 2021), while the market shares of Japanese and American brand passenger cars increased in 2020.

The productivity level of China brand cars is relatively backward. In the primary supporting market of the domestic automotive industry, a large number of domestic independent component enterprises only accounted for 20% of the market share, foreign-owned enterprises accounted for 50% of the market share and Sino foreign joint ventures accounted for 30% of the market share. The competitiveness of China brand cars is mainly concentrated in the low-end market, while it lacks competitiveness in the middle- and high-end markets (Li, 2021). In recent years, China's national automobile enterprises have developed relatively rapidly, such as Chery, Geely, BYD, JAC and Lifan. However, presently, a large number of the own brand automobiles sold in China's domestic market are mainly concentrated in the field of low-end cars with displacement less than 1.6 litres.

In contrast, the cars sold in the middle- and high-end car markets are German, Japanese, American and Korean cars as well as other foreign brands or joint venture brands (Li, 2021).

The independent innovation capability of China brand automobiles is low. The proportion of invention patents amongst the various patents is relatively small (Sun et al., 2023). Most of the innovation are concentrated in areas, such as materials, new energy batteries and automotive electronic systems. The majority of enterprises in the domestic automotive industry still rely on intensive labour and traditional manufacturing models to participate in market competition (Yang, 2020). Furthermore, China brand automobile enterprises lack core technologies with independent intellectual property rights and the investment in science and technology R&D is insufficient, whereby their independent R&D ability is still fragile. Although the own brand automobile enterprise groups have made some progress in the construction of vehicle integration capacity and body development capacity, they still have many deficiencies in the development and application of new technologies, such as automobile electronic control technology and engine assembly development technology. For the sake of interests, multinational corporations have always firmly controlled the core technologies, such as vehicle, gearbox and engine, rarely carried out substantive R&D work in joint ventures and set very strict cooperation conditions in crucial equipment, technology transfer fees and other aspects (Liu & Huang, 2019).

The innovation efficiency of the automotive industry is not high. The efficiency calculation results of the technology research and development process in the automotive industry are not ideal, with an average annual decrease of 18.5% in recent years. The

prominent issue is that the efficiency of technological research and development is lower than the efficiency of technological transformation. Vehicle and new energy power parts enterprises have become new innovation growth poles in the automotive industry. However, the low technology transformation efficiency of vehicle manufacturing enterprises does not match their high technology research and development efficiency, which is the main constraint on innovation and progress in the entire automotive industry (Jin et al., 2023).

In foreign countries, automobile engines and other core parts are produced by automobile manufacturers themselves. However, many automobile manufacturers in China do not have enough funds and large-scale technical R&D teams, so it is not easy to realise self-supply of engines. The average proportion of R&D investment in revenue of 28 domestic listed automobile enterprises in 2017 was 2.55% (Hou, 2018). In terms of total amount, the R&D expenses of listed companies in China automobile industry in the first half of 2021 was 30.275 billion yuan. It is only nearly half of the R&D investment of the Volkswagen Group in the same period, but not half of the R&D investment expected by Toyota in the whole year (CAAM, 2021). In the 2021 global automotive manufacturer R&D investment ranking, only the SAIC Group was in the top 10, ranking ninth (CPCA, 2022). The insufficient investment in R&D resources directly leads to a limited degree of technological innovation, which restricts them from advancing towards high-end through independent research and innovation.

In terms of talent composition, the R&D personnel, middle and senior technicians of major brand automobile enterprises in the world accounted for more than 10% and 40% of the number of employees, respectively, while the number of talents of many automobile

enterprises in China are lower than this index (Liu & Huang, 2019). Talent is the primary resource for an industry's innovation performance. It will affect total factor productivity through innovative activities. The talents in China's automobile industry mainly include technical, R&D, sales and other functional management talents. The R&D and technical talents are the types of talents with the largest demand as well as the types of talents with the largest gap in recent years. According to a report on an in-depth investigation and future development trend of China's auto industry talent market from 2019 to 2022 released by Xinsijie Industry Research Centre, the gap of employees and talents in China's auto industry showed an expanding trend. The demand gap for employees increased from 1.7 million in 2016 to 1.98 million in 2018. The talent demand gap increased from 1.37 million in 2016 to 1.58 million in 2018. Nevertheless, foreign brand automobile enterprises have recruited a large number of talents in automobile R&D and sales in China. They have set up R&D centres to attract Chinese talents since they need to realise localisation management, which is uncondusive to Chinese automobile enterprises to retain talents. Moreover, the free trade zone carries out parallel import automobile business and the parallel import automobile dealers recruit many relevant talents in China presently. This resulted in shortage of technical R&D personnel and a decline in comprehensive quality of industry personnel, which seriously restricts the development, including the innovation efficiency and productivity of the own brand automobiles in China (Pan & Liu, 2016).

1.4 Research Questions

Based on the above-mentioned issues and discussions, this study has identified the following questions for further exploration:

- I. What is the efficiency level of the innovation system of China brand automobile industry?
- II. What is the productivity of the industrial innovation system of China brand automobile?
- III. Which factors affect the innovation system efficiency of China brand automobile industry?

1.5 Objectives of the Study

The general objective of this study is to investigate the efficiency performance of the innovation system of China brand automobile industry from 2011 to 2021. This is by comparing and analysing relevant data from different provinces to explore the development direction and strategies of innovation in the automotive industry. Specific objectives are outlined below:

- I. To estimate the efficiency performance of industrial innovation system of China brand automobile.
- II. To assess the productivity of industrial innovation system of China brand automobile.
- III. To investigate the main determinants of efficiency performance of China brand automobile industrial innovation system, including the level of economic development, degree of openness, foreign direct investment and others.

1.6 Scope of the Study

This study selects data from 2011 to 2021, comprising 24 provinces or municipalities in China with own brand automobiles for analysis. After removing the data from provinces with several missing data and provinces without own brand cars, the study estimates the efficiency performance, assesses the productivity and investigates the determinants of efficiency performance of China brand automobile industry innovation system. Furthermore, the overall and provincial efficiencies of China brand automotive industry will be analysed. Data of R&D investment, total number of technical employees, number of patent applications, sales revenues are collected for the estimating efficiency. The level of economic development, degree of openness, foreign direct investment, degree of marketisation, financial support for science and technology are adopted to investigate the determinants of efficiency performance.

1.7 Significance of the Study

There is still a big gap between the technical level and innovation ability of China's automobile industry and the world's advanced level, and thus it is urgent to realise the transformation from large to strong. This study focuses on the innovation system of China brand automobile industry, which is based on the fact that the independent innovation is the source and driving force of the development of automobile industry. If the core of innovation is bypassed, it will be difficult for China's automobile industry to get deep development and the basic and strategic position of China's automobile industry in the national economy will be difficult to continue.

The characteristics of automobile industry decide that it is more suitable to be studied with the theory of industrial innovation system. On the one hand, the automobile

industry belongs to the typical technology intensive industry with active innovation and high technical complexity. Automobile products have high industrial precision, reliability, integration and complete set. The technical level of automobile industry reflects the manufacturing level and scientific and technological level of a country. The conclusion of this study can provide policy suggestions for the development of China brand automobile industry. Therefore, this research has an important practical significance. However, the automobile industry is highly related to and involves many sectors of the national economy. The innovation research of automobile industry needs to involve various types of innovation subjects and their interrelationships, which is more suitable for analysing from the perspective of innovation system. At the same time, because of these characteristics of the automobile industry, the analysis of its industrial innovation system has a certain universality, which can provide reference for other industries.

Additionally, from the existing literature, domestic research on the innovation system of automobile industry is less and the quantitative evaluation of innovation is limited. Therefore, research on the industrial innovation system of China brand automobile can also enrich the research results of academic field.

1.8 Organization of the Study

The contents of this research are categorised into five chapters. Chapter One narrates the study background, problem statement, significance as well as the study objectives and research questions. Chapter Two summarises the definition, theory and empirical study of the innovation system efficiency and factors affecting efficiency of industrial innovation system as the theoretical basis of the study. Chapter Three explains the study methodology, comprising the content that describes the research design, variable

definition, data source and processing, and analysis tools. The descriptive statistics of variables and the data analysis are presented in Chapter Four. Finally, Chapter Five provides the conclusion, recommendations, policy implications and limitations of the study.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter covers discussions on the development of industrial innovation system research from the perspectives of industrial innovation, industrial innovation system, analysis model and the evaluation of industrial innovation performance. Furthermore, it includes the evaluation of the innovation system productivity and efficiency, comprehensive evaluation of capability and efficiency, relationship amongst innovation, competitiveness and performance of enterprises, and factors affecting the efficiency of the industrial innovation system. Additionally, a summary and research gaps are drawn on the research status of industrial innovation system.

2.2 Operational Definition

2.2.1 Industrial Innovation

In 1912, Schumpeter clearly put forward the concept of innovation for the first time, whereby he believed that innovation establishes a new production function and summarised innovation into five new combinations (Schumpeter, 1912). Schumpeter's (1912) concept of innovation became an important theoretical basis for guiding innovation research in western countries and laid the second theoretical foundation for the theory of national innovation system. Schumpeter (1912) wrote the theory of economic development, put forward the theory of innovation, regarded economic development as the combination of implementing innovation and pointed out five specific contents of innovation. These included developing a new product, adopting a new production mode, opening a new

market, adopting a new method of controlling raw materials and semi-finished products, and realising a new organisation of the industry (Schumpeter, 1921). Although this innovation theory has some limitations, it opens a precedent for further research of the innovation system.

The concept of industrial innovation was first proposed by an economist, Freeman (1974). He mentioned that industrial innovation was a collection of various forms of innovation, involving all links in industrial economic activities, including technological development, product design, production and processing, enterprise operation, marketing and other forms of innovation. Through empirical research on multiple industries, he put forward that specific content of industrial innovation varied according to the industry. Additionally, he proposed that industrial innovation was a systematic concept. Freeman is the founder of industrial innovation theory. He published the first monograph on industrial innovation economics, which laid the foundation of industrial innovation theory. He believed that the core of national innovation was the industrial innovation (Freeman, 1974).

The research on the theory began to unfold one after another. Freeman (1974) believed that industrial innovation included the technology, skill, product, process, management and marketing innovations, and made empirical research on the innovation of many industries. The conclusion was that the content of industrial innovation was different in various industries, such as the content of industrial innovation in the chemical industry was mainly process innovation, while in the instrument industry was mainly product innovation, whereas in the power industry was mainly market innovation (Freeman, 1974).

The industrial innovation manual compiled by Dodgson and Rothwell (1994) is an internationally influential industrial innovation treatise. It collected and arranged the

achievements of theoretical and empirical research on industrial innovation in the form of a collection of papers. Dodgson and Rothwell (1994) put forward the “five generation theory” of innovation process. They believed that the comprehensive innovation model based on concurrent engineering (the fourth generation innovation process model) and the system synthesis and network innovation model based on network process (the fifth generation innovation process model) reflected the important characteristics and significance of the production innovation. The research of these scholars reflects the systematisms of industrial innovation and lays a foundation for the proposal of industrial innovation system theory.

Other scholars have also discussed the connotation of industrial innovation from different perspectives, which can be basically divided into two levels: narrow and broad.

Yan (1999) proposed that industrial innovation refers to the behaviour of different enterprises in a country's industry to carry out technological innovation through technical cooperation or forming strategic alliances. Moreover, it assisted the industry to achieve technological breakthroughs and improved technological capabilities, and finally made the development of a country's industrial structure mature gradually and formed corresponding competitive advantages in the world. Luo and Wu (2005) also agreed with this view and further elaborated on the form of cooperative innovation in industrial innovation. Specifically, several large enterprises in the industry take the initiative to jointly develop or take the lead in realising technological breakthrough by enterprises with the strongest technological ability and improve the industrial technological level as a whole in the form of knowledge learning and technology transfer. Wang (2015) held similar opinion that industrial innovation could be understood as the spatial agglomeration of many enterprises

centred on innovative technology; the coupling of technological innovation and enterprise agglomeration.

With technological innovation as the core, these scholars have expounded the connotation of industrial innovation in a narrow perspective, namely, enterprises, as the main body of innovation, carry out cooperative innovation, realise the industrialisation of invention and creation, and finally aim to improve the competitiveness of enterprises and industries.

Lu (2003) proposed that the industry also has its life cycle. If enterprises wanted to achieve long-term sustainable development, they should be able to change the existing industrial structure or create new industries. Therefore, Lu (2003) believed that industrial innovation was a process in which enterprises do not stick to the existing industrial structure and flexibly used various forms of innovation to change the solidified industrial structure or create new industries. Furthermore, Liang and Zhao (2016) posited that industrial innovation was a process in which enterprises could not be bound by the current industrial form, insight and conceive the future industrial form, accumulate their own core competence and lead industrial innovation. In fact, industrial innovation means to firmly grasp the general direction of industrial progress, aiming at the world's industrial frontier and top level, and making major breakthroughs in key core technology fields (Li & Lu, 2017). These scholars defined industrial innovation in a broad sense and emphasised the breakthrough of the existing industrial structure. Moreover, they believed that industrial innovation was an innovation process in which multiple participants in the government, enterprises and other industries change the existing industrial structure or cultivate new

industries through complex innovation behaviours and comprehensive utilisation of social resources.

In this study, industrial innovation is a process, whereby an industry evolves from a state of low technology and low added value to a state of high technology and high added value. It is a new development approach proposed for the development of traditional industries. The core of industrial innovation is the innovation of concepts and ideas. Industrial innovation includes multiple aspects, including not only conceptual ideas, but also institutional innovation and technological innovation in industrial development.

2.2.2 Industrial Innovation System

Baler and Breschi (1997) proposed the industrial innovation system concept. Based on the national innovation system, they posited that the industrial innovation system first had a certain knowledge and technology foundation, input factors and demand conditions. This outcome derived after referring to the definition of the network system of technological innovation activities by the technology system and taking the evolution theory as the generation principle of innovation activities. At the same time, the system included a series of institutions, organisations and individuals to interact through market or non-market activities to promote the generation and diffusion of innovative products. These participants had different learning processes, competitiveness, organisational structure, culture, objectives and behaviours. Under the constraints of institutional rules, they carried out interactive activities, such as communication, exchange and competition. With the evolution of various constituent elements, the industrial system could evolve.

Briefly, the industrial innovation system proposed by Malerba and Breschi (1997) referred to a network system composed of a series of institutions, organisations and individuals under certain knowledge and technology, input factors and demand conditions. Additionally, under the constraints and guidance of relevant institutional rules, in order to promote the generation and diffusion of innovative products through various types of connections. The national and regional innovation systems focused on the impact of institutional and cultural environment on innovation network. However, the industrial innovation system proposed by Malerba and Breschi (1997) believed that the relationship between various subjects in the system was mainly due to the interdependence of technology and it emphasised the technology flow in the industry and the impact of technology development on the dynamic evolution of industry.

Based on theoretical research of the national innovation system, Zhang (1999) proposed that there were not only enterprises and research institutions that directly carried out knowledge production or technology development, but also institutions and organisations that supported and assisted technological innovation activities. The network system formed by these institutions was the industrial innovation system. Zhang (1999) believed that the industrial innovation system was not limited by national boundaries and its definition of industry could be cross-border or even cross-regional. This definition highlighted the networking of industrial innovation system.

Liu (2000) emphasised the networking of industrial innovation system and expounded the connotation of industrial innovation system through the construction of network structure. The network structure of industrial innovation system was composed of nodes and the connection relationship between nodes. Enterprises, research institutions,

intermediaries and users who participated and assisted in technological innovation activities in the industry constituted the nodes in the industrial innovation system network. There was interaction between different nodes and the main forms of connection were business cooperation and technical exchange. The more nodes in the industrial innovation system network, the closer the connection relationship between nodes, which means that there is sufficient cooperation and exchange in the industry and the more mature the conditions for innovation.

Zhang (2003) suggested that the industrial innovation system had the following connotation: industrial innovation system was a network system driven by market demand under policy regulation and certain environmental protection, which promoted innovation activities in the industry and improved industrial competitiveness through innovative technology supply.

Based on the concepts derived from industrial innovation system, Weber and Rinkel (2017) identified the cross patterns of changes in different industries. Furthermore, they analysed the impact of these patterns on innovation policies, including the transformation from products to systems and services, fuzzy boundaries between departments, demand integration between departments and cross departments, and management of interaction between departments.

Within the whole industry, the industrial innovation system, based on the strategic objectives of technological innovation and industrial upgrading, such as innovation subjects, education departments, relevant government departments and corresponding financial intermediaries, formed an industrial innovation connection network through the connection of industrial chain. Additionally, the system took improving industrial

technology as the core, reduced the development, diffusion and realisation costs and risk coefficient of industrial innovation, and promoted the innovation ability and competitiveness of the whole industry (Luo, 2018).

Results of the abovementioned research highlighted the systematic and networking of industrial innovation system, emphasised the connection and interaction between industrial participants and put forward that innovation activities were not isolated, but related to environmental factors, such as the knowledge and technology status, policy and system. The goal of industrial innovation system was to promote the occurrence of innovation activities and the diffusion of innovation achievements in the industry, and finally enhance industrial competitiveness.

In this study, the industrial innovation system refers to a series of organisational structures, policy measures, technological innovation platforms and talent support established at different levels to promote industrial innovation. The essence of the industrial innovation system is connection, which links the innovation activities of enterprises and other secondary participants (universities, research institutions, intermediary service institutions, financial institutions, users and suppliers, and the government), with technological innovation as the core. This establishes the integrated innovation capabilities, reducing the innovation costs of individual innovation activities, maximising benefits, promoting the generation, flow, and updates, transformation of new technologies or knowledge within the industry, promoting the formation of enterprise innovation capabilities and the improvement of industrial competitiveness.

2.2.3 Regional Innovation System

Cooke et al. (1997) defined the regional innovation system as a collective order based on micro institutional regulation. The character of the regional innovation system is a universal association, collaboration and trust dependency. Pekkarinen and Harmaakorpi (2006) argued that promoting multi participant innovation in RIS (regional innovation system) is crucial for reducing transaction costs, correcting market failures and reducing risks, enabling participants to increase productivity. Cooke (1997) classified regions into two different situations based on the degree of autonomy or dependence of actors and intermediaries on central government policies and investments. Additionally, he pointed out the importance of acknowledging these differences in analysing the configuration and function of RIS. Similarly, Fritsch and Graf (2011) stated that the macroeconomic environment at the regional level plays a crucial role in the success of RIS, and thus focusing solely on a region as a geographic space is insufficient. According to Inkinen and Suorsa (2010), intermediary agencies played a crucial role in a country and RIS, particularly in innovation policies, by linking the internal and organisational aspects of IS (Innovation System), as they focus on technology transfer, funding intellectual development and commercialisation of products and services. Cooke (2005) redefined RIS as a knowledge generation and development subsystem that interacts with global, national and other regional systems.

2.3 Theories of Industrial Innovation System

2.3.1 Innovation System

Since the emergence of innovation theory, research on innovation activities was mainly based on the enterprise level. It was not until the 1980s that the theoretical circle

gradually realised that innovation was not a single subject and began to study innovation from a systematic perspective (Zeng, 2002). Existing studies believed that the innovation system is a network system composed of institutions participating in innovation activities and various resources needed for innovation, which was committed to the development and diffusion of innovation. The innovation system consisted of three parts: the main body of innovation activities, the environment of innovation activities and the connection relationship between the main bodies. The function of the innovation system was to produce technical knowledge, products and services and economic benefits (Zhang, 2013).

Freeman (1987) first studied the innovation theory from a systematic point of view. When studying the Japanese economy, he found that the system and innovation environment had an important impact on the country's innovation activities. Furthermore, he proposed that the national innovation system was a network system composed of the interconnection of different institutions and organisations, which promoted the generation, exchange, improvement and diffusion of technological innovation through the interaction between institutions, and finally achieving the goal of improving national competitiveness. Freeman made clear the importance of this network relationship to the innovation system, and put forward that the operation of the industrial innovation system directly affected the national innovation system. In 1996, the Organisation for Economic Cooperation and Development (OECD) defined the national innovation system. This concept referred to the network system formed by the connection of various institutions and departments of ownership in a country. Various organisations connected and cooperated with each other to realise knowledge transfer and technology diffusion in the process of interaction and finally improved the country's technological level and innovation ability. At the same time, OECD believed that an enterprise's ability to communicate and integrate with various

external knowledge sources (such as other enterprises, users, universities and research institutions) and its ability to coordinate internal knowledge sources (such as R&D, production and sales) determined its innovation ability (OECD, 1997). Research of national innovation system focused on the impact of a country's system and policy on the network structure, which composed of different institutions and the efficiency of knowledge transfer in the network.

Edquist and Hommen (1999) stated that innovation policies could be divided into the demand side orientation and supply side orientation. Similarly, the theory of innovation process could be divided into the linear theory or system oriented theory. There are important similarities and logical connections between these two classifications. On the one hand, the linear perspective of the innovation process supports the supply side orientation of innovation policies. On the other hand, from the perspective of theoretical and policy relevance, the systemic perspective of innovation has produced a more effective perspective on demand.

2.3.2 Technical Systems

An American economist, Carlsson (1987) presented the concept of technical system, which was similar to the national innovation system, but using the technology field rather than the national boundary to define the research scope. He defined technical system as an institutional network interacting in a specific technical field under a specific institutional environment, committed to the generation, diffusion and application of technology. The technical system focused on the micro characteristics, such as the generation, diffusion and utilisation of technology, while the national innovation system emphasised the macro national policy and system. Based on the theory of national innovation system, technical

system theory improved the theoretical basis of industrial innovation system. Hubka and Eder (1988) stated that the technical system (together with humans, information and management systems, and the activity environment) applied the effects required to achieve the required transformation to the operating objects. The technical system is the main means to achieve transformation.

Eder (2016) briefly introduced Hubka's technical system theory. It describes the commonalities of all engineering equipment, regardless of their physical principles of action. This theory is based on the General Transformation System (TrfS) and could be used to demonstrate engineering in the context of social, economic and historical development. The life-cycle of a technical system consists of seven main TrfS, each of which is composed of further specific products of TrfS. From this theory of technical systems, Hubka (1988) derived a methodology as a voluntary guide for system design engineering, to be applied when empirical intuitive methods are proven ineffective. This engineering design method is different from other artistic designs. This method is suitable for novel design problems and redesign that developed some educational aspects to demonstrate the scope of knowledge required for engineering design. The operator of TrfS is also TrfS - as demonstrated by observing the management system throughout the technical system (TS) life-cycle.

2.3.3 Evolution Theory

In the late 19th century, an economist, Marshall (1890) proposed that the idea of Darwinian evolution could be used to compare and study the law of economic development. Nelson and Winter (1982) believed that economic equilibrium is temporary, not long-term, and should not be treated in a static way. The explanation of technological

changed in the economic system should adopt the viewpoint of evolution theory and regarded economic change as a complex evolutionary system. There were differences amongst members in the system, which was similar to species diversity in biology. This diversity was the basis of system evolution and screening process. At the same time, members themselves had “persistence” and “heterogeneity”, corresponding to “heredity” and “variation” in evolution. The result of evolution had both randomness and causality. Under the action of internal pressure and external environment, the system screened the characteristics of members. This process was similar to the process of natural selection. The technical track retained through system screening was more adaptable to the competitive environment and would be maintained and continued by the participants of economic activities for a long time. Evolution theory had become a new angle to analyse and understand the deep dynamic factors of economic development.

Evolution theory emphasised changes in the system and adaptation to the new environment, but the real economic activities were affected by policies and institutions, which were difficult to be compared with the evolution theory. The innovation system research attached importance to the impact of policy-making on economic activities, but it was difficult to reveal the essence of economic change. Therefore, they could learn from each other and integrate dynamic evolution analysis and formal system research to explore the driving force of economic development (Liu, 2013).

Compared to the static equilibrium of neoclassicism, the theory of evolutionary economics emphasises more on dynamic, open, and systematic study of organisational evolution and technological change (Veblen, 1898). Nelson and Winter (1982) proposed the concept of “convention” based on bounded rationality and knowledge dispersion, and

they believed that organisational evolution is more a result of “convention” rather than rational selection. It is through continuous learning, searching and selection that enterprises achieve technological innovation. Furthermore, it drives the evolution of organisations. However, Pavitt (1984) found through a systematic analysis of over 2,000 major innovation practices in Britain since 1945 that there were differences in the technological sources and directions of technological change amongst different types of enterprises. The conclusion of this study coincides with the randomness of technological evolution in evolutionary economic theory, providing an empirical basis for understanding the diversified behaviour of enterprises and their dynamic relationship with technology and industrial structure. Additionally, it provides a reference for research on the direction of technological change in industrial innovation systems.

2.4 Analysis Model of Industrial Innovation System

In the definition of industrial innovation system, Malerba (1997) stated that the industrial innovation system could be composed of three dimensions: knowledge and technology foundation, participants and network, and system and rules. At the same time, the establishment of this industrial innovation system should also have a potential or existing market demand. Therefore, Malerba (1997) believed that the industrial innovation system was composed of six parts: industry related knowledge and technology, enterprises, other participants, linkage, systems, and rules and market demand. Through the observation of each part, industrial innovation could be effectively analysed and compared.

Li (2009) added boundary and requirement modules on the basis of Malerba's (1997) three-dimensional analysis framework. Li (2009) also proposed that the industrial innovation system included a variety of participants, in which enterprises were the core

participants in innovation activities. Participants formed a participant network through connection and cooperation, and the industrial innovation environment would have an impact on participants as well as the relationship amongst participants.

Considering the networking and systematisms of industrial innovation, Zhang (2006) built an industrial innovation system model based on Rothwell and Zegveld's (1985) innovation policy classification system and Carlsson's (1995) technology system. Rothwell and Zegveld (1985) classified policy tools into three types based on their direct and indirect effects: supply, demand and environmental. This classification method is widely used in policy areas, such as technology, innovation, entrepreneurship and employment, and emerging industries. Carlsson (1995) stated that a technology system is a network of agents that interact and participate in the generation, dissemination and utilisation of technology within a specific institutional infrastructure, or set of infrastructure in a specific economic/industrial field. Zhang (2006) proposed that the industrial innovation system should be a positive feedback system, which could evaluate and reflect its own industrial innovation. Therefore, he believed that the industrial innovation system was mainly composed of the policy, technology, environmental and evaluation systems. The technology system was the basis and centre of these systems, whereas the policy and environmental systems composed of political, economic and cultural background that had an important impact on industrial innovation activities (Chen, 2008).

Li (2007) discussed the conditions and process of industrial innovation from the dynamic mechanism of technological innovation. She proposed that the innovation process in an industry first originated from various types of technological innovation. After the technological development matured and met the conditions of large-scale production,

product innovation was carried out. Following a series of product development processes, such as development, trial production and improvement, it was successfully commercialised and pushed to the market to realise market innovation. At the same time, new technologies and products were diffused, industrial clusters were gradually formed, and relevant enterprises and research institutions gathered in regions with similar geographical locations to carry out further innovation activities, and finally formed a market and complete industrial innovation.

Wang (2019) proposed that the research level should be clarified and the level definition of country, industry and region should be clarified. The industrial innovation system model should be constructed from the industrial level, with industrial technology as the core and enterprises as the innovation subject. Simultaneously, interaction between the innovation subject and other participants and the regulatory effect of the system on the behaviour of relevant subjects should also be considered, and attention should be paid to the cultivation of industrial innovation environment. Wang (2019) believed that the essence of industrial innovation was technological innovation within the industry. Therefore, industrial technology was the core of the industrial innovation system. Around the development of industrial technology, it also needed the guidance of industrial objectives as well as support and cooperation from three aspects: industrial environment, industrial structure and industrial policy.

2.5 Evaluation of Industrial Innovation Performance

Presently, the performance evaluation of innovation system is mainly carried out from two aspects. Some scholars understood the performance of innovation system as the operation ability of innovation system, and comprehensively evaluated the whole

innovation system. Furthermore, some scholars paid attention to the operation efficiency of the innovation system and evaluated the relative performance of innovation system from the perspective of the efficiency of transforming innovation input into innovation output. A few scholars tried to integrate the ability and efficiency evaluations to establish a comprehensive performance evaluation.

2.5.1 Evaluation of Innovation System Capability

Zhang (2003) proposed that the evaluation index system could be established from four aspects: policy system, technical capacity, environmental impact and innovation output results of the industrial innovation system. Additionally, Xie (2009) evaluated the industrial innovation system from the perspective of industrial innovation ability. Based on Zhang's (2003) research, Xie (2009) proposed to evaluate the industrial innovation ability from five aspects, which included the economic benefits brought by industrial innovation, effectiveness of policy role in industrial innovation activities, level of industrial technology, support of auxiliary institutions for innovation activities and level of industrial innovation cooperation.

You and Chen (2009) proposed that industrial innovation activities should be studied from the perspective of dynamic evolution. It was believed that the industrial innovation system has the characteristics of dissipative structure, which means that the industrial innovation system keeps exchanging manpower, materials and information between the system and the environment and amongst the subjects within the system. From the process perspective, he divided this dissipation behaviour into four aspects, such as innovation input, innovation production, innovation output and environmental function,

and established the evaluation index system of industrial innovation system according to these four aspects.

Herman (2003) started from the national innovation system, qualitatively analysed the industrial innovation system and set up a specific index system from four aspects: technical characteristics, organisational structure of innovation chain, institutional environment and industrial characteristics. From the perspective of knowledge flow, OECD evaluated the national innovation system from four aspects that included the institutional alliance, talent flow, industrial clusters and emergence of innovative enterprises (OECD, 1996). Duar and Zheng (1994) proposed to evaluate the national innovation system from three aspects, such as the scale, flow direction and operation results. The scale reflected the degree of centralisation in the industry; the ownership or control of innovation achievements by large scientific research institutions and innovative enterprises in the industry. The flow direction mainly reflected the flow direction of human resources in the industry. The operation results were the technological achievements of industrial innovation, including patents and scientific papers. Wang (2000) believed that the operation performance of the national innovation system was comprehensively determined by a country's innovation resource status and innovation resource allocation ability. With reference to the international competitiveness evaluation system, a national innovation performance evaluation system was established to evaluate the resource status and resource allocation ability of the national innovation system from three aspects: capital, human resources and knowledge. Carlsson (1991) proposed to evaluate the technology system from the perspective of economic competitiveness and established the evaluation index system from four aspects: strategic ability, organisation and coordination ability, technical ability and learning ability.

Based on the above-mentioned scholars' research results, it could be found that to evaluate the performance of the innovation system from the perspective of the operation ability, the industrial innovation system was generally directly evaluated on the basis of the industrial innovation system analysis model. Furthermore, the established evaluation index system contained more qualitative indicators.

2.5.2 Evaluation of Innovation System Efficiency

It is a common quantitative research method to select appropriate indicators to establish an evaluation system to evaluate the innovation output and performance of the industrial innovation system. For the number of patent applications, Breschi and Malerba (1995) put forward indicators, such as the production concentration (CR4), Herfindahl index, cross period Spearman rank correlation coefficient and cross region Spearman rank correlation coefficient to study the characteristics of the Technological Paradigms in different industries. Caniels (2009) adopted such indicators as the total amount and intensity of R&D, number and intensity of patent applications, number and proportion of employees with various degrees, and number and intensity of relevant technology alliances in his research. Li (2008) constructed the performance evaluation index system of industrial innovation system, involving a total of 40 indicators at several levels, such as innovation personnel input, capital input, technology introduction and innovation output.

Carlsson (2002) presented the performance measurement indicators of the technology system, including three levels: the generation of knowledge (such as number of patents, scientists and engineers), diffusion of knowledge (number of collaborators, number of technology transfer licenses, etc.) and application of knowledge (some

production and operation performance indicators, etc.), which could also be used for reference in the research of industrial innovation system.

Guan and Liu (2003) proposed in the measurement research on the regional innovation system that could be regarded as a decision transformation unit, so that the system operation process could be simplified and understood as the process of transforming the innovation resource input of the region into innovation output. They set up an index system from two aspects of innovation input and output and studied the transformation efficiency of regional innovation system according to the input and output. This enabled them to evaluate and compare the innovation performance of different provinces and cities in China.

Data envelopment analysis (DEA) is an effective research tool to evaluate the efficiency of input and output. In recent years, it has been widely used in the efficiency evaluation of the national and regional innovation systems. At the national level, a typical DEA model with seven variables, namely, two inputs, three outputs and two adjustments, proposed by Nasierowski and Arcellus (2003) for the national innovation system. The model analyses the innovation efficiency and R&D production capacity of different types of national innovation systems. Chinese scholars mostly utilised the DEA method to study the efficiency of regional innovation system. Yu (2005) applied the G^2GS^2 model to evaluate the efficiency of technological innovation in 30 provinces (cities, districts) in China for four years. Ren (2006) applied the C^2R model to evaluate innovation efficiency in central China and compared it with Beijing, Shanghai and other eastern regions. Li (2016) presented a DEA evaluation method based on weight constraints, evaluated the

efficiency of China's strategic emerging industries' innovation system, analysed its evolution characteristics and put forward corresponding policy suggestions.

Xu and Li (2023) adopted the slack-based measurement model to evaluate the sustainable innovation efficiency in China. Wang et al. (2023) employed the global super efficiency efficiency-based measure model to estimate the green innovation efficiency of cities in China. Shaturaev (2023) combined multiple methods, such as synthesis, statistical analysis, mathematical methods and others to evaluate the efficiency of investment project using indicators of production, growth rate, volume of investment, number of new jobs, etc.

2.5.3 Comprehensive Evaluation of Capability and Efficiency

Li (2008) comprehensively evaluated the efficiency performance of industrial innovation system from two aspects. On the one hand, he analysed the overall operation and evolution of industrial innovation system by evaluating the comprehensive operation of industrial innovation system. On the other hand, by evaluating the technical, scale and comprehensive effectiveness of the industrial innovation system's operation, he analysed the operation efficiency of industrial innovation system. When evaluating the operation capacity, Li (2008) set up an index system from four aspects: resource input, implementation capacity, structural adjustment and achievement output. Whereas, when evaluating the efficiency of industrial innovation system, he mainly set up evaluation indexes from two aspects: input and output.

Lu (2009) also took regional innovation capability and regional innovation efficiency as the research object. He divided regional innovation capability into four aspects: innovation investment, achievement performance, supporting conditions and

development potential, and established the evaluation index system of regional innovation capability from these four aspects. At the same time, he established a regional innovation efficiency index system from two aspects of input and output. Finally, the regional innovation capability measurement model and regional innovation efficiency measurement model were established and the interaction between them was analysed.

2.5.4 Evaluation of Productivity

Productivity refers to the efficiency performance in the process of transforming raw materials into products, which is the output per unit of input, i.e., the ratio of output to input (Mamgain, 2011). The productivity can be obtained by dividing the total amount of products and services by the total amount of resources consumed. The increase in productivity is due to an increase in capital or labour efficiency. Research on the role of productivity in economic growth began with the concept of aggregate production function proposed by Douglas and his assistants in the 1930s. Subsequently, Tinbergen (1942) further developed the concept proposed by Douglas by adding a time trend term to the capital and labour input functions to represent the magnitude of production efficiency.

Solow (1957), a famous American economist, made a quantitative study of the total factor productivity for the first time. An American economist, Dennison used the concept of weights to classify various input factors in detail and then synthesised the total input index using weights, further developing the “Solow Residual”. Lovell et al. (1977) proposed the stochastic frontier production function. Since then, the gradually developed stochastic frontier production function allows the existence of technical inefficiency and decomposes the change of total factor productivity into the movement of the production possibility boundary and the change of technical efficiency. Furthermore, several

researchers conducted a large number of empirical studies using the stochastic frontier production function method, mainly involving the relationship between output and technical efficiency, total factor productivity, which makes this method increasingly perfect (Schmidt, 1980; 1986; Kumbhakar, 1988; 1990; Bauer, 1990; Kalirajan, 1993).

Based on the variable scale financing model, Fare et al. (1994) divided the change of production index into scale efficiency change, technological progress change and pure technical efficiency change. Ray and Desli (1997) proposed the RD hierarchical model. Bloch and Tang (1999) measured the rate of technological change using an endogenous model, compared the rate of technological change with TFPG, and calculated TFPG using traditional methods. Chamarbagwala et al. (2000) concluded that for a country, its development stage, labour force level and capital technology all have an impact on productivity.

The calculation methods of total factor productivity include parametric and nonparametric methods. The parametric method is to measure the total factor productivity based on the assumption of a certain production function. It is divided into C-D function method, algebraic exponent method and transcendental logarithmic production function method. Nonparametric methods include the index method, DEA and DEA-Malmquist index method (Wang, 2023).

2.6 Innovation Efficiency

2.6.1 Efficiency Theory

Efficiency theory has always been an important theory in economics. Adam Smith (1776) emphasised the division of labour efficiency theory and competition efficiency

theory in his economic works. He believed that labour efficiency had a wide range and could be effectively provided through division of labour. Freedom of competition belongs to the category of competitive efficiency. Although it has not been clearly defined, later generations generally believe that this is one of the initial research results of competitive efficiency. Competitive efficiency is one of the effective means to achieve self-iteration of economic ecology and optimal allocation of social resources.

In later classical economics, Pareto allocation efficiency was used as a substitute for efficiency research. Pareto allocation efficiency is mainly divided into overall and local analysis, and local equilibrium refers to the efficiency equilibrium of a certain field or region, believing that the market can be separated and independent. Furthermore, overall equilibrium focuses on examining the balance of efficiency from the perspective of the economy as a whole, believing that overall unity is a fundamental characteristic of the market (Pareto, 1906). These two theories represent scholars, such as Wallace and Marshall. Additionally, some scholars have divided the efficiency of technological innovation, considering not only the simple input-output ratio, but also the minimum actual production value generated by a certain input under other unchanged conditions, which is technological efficiency. On the premise of keeping other conditions unchanged, the impact of production scale on economic output constitutes the study of scale efficiency.

The earliest research on innovation efficiency was conducted by scholars on the innovation efficiency of large science and technology parks, evaluating the history and development process of large technology parks in the United States from a qualitative perspective and concluding that there were related economic agglomeration effects. Although the research method has certain shortcomings, this approach has certain

inspirational significance for future generations to study on innovation efficiency (Link & Scott, 2003). To date, there has been a lot of research on the evaluation system of innovation efficiency for enterprises, mainly focusing on output oriented quantitative analysis, including relevant innovation output indicators and economic benefit output indicators of enterprises. The main representative systems include the evaluation systems proposed by innovation associations in the United States and Europe.

2.6.2 Efficiency Measurement Models for Innovation System

The mainstream measurement methods for the innovation system efficiency mainly include parametric and nonparametric methods. Amongst which, the parametric method is mainly represented by stochastic frontier approach (SFA). The idea of this estimation method originated from a study by Aigner et al. (1977). The nonparametric method is represented by DEA, which can be traced back to a study by Farrell (1957) and the DEA model was proposed by American operations researchers (Charnes et al., 1978). Since their proposal, the method and model have been widely used in different industries and departments and have many advantages in dealing with the relationship between multiple indicators of input and output. It compares and analyses the relative efficiency of various input-output combinations of decision-making units (DMUs) by establishing mathematical programming models, in order to evaluate each DMU effectively and non-effectively. It can also refer to the relatively effective DMU to adjust the non-effective DMU to different degrees and directions to achieve an effective state. It is based on the idea of mathematical programming and uses convex analysis and linear programming as tools to calculate the distance model between DMU and production frontier (Cooper et al., 2007). The production frontier calculated by this method is not random, but fixed. Specifically, the

basic idea of DEA is to take the set of DMUs that is composed of research samples as a comprehensive evaluation group of research, input the multi-input and multi-output variables of many DMUs, estimate the effective production frontier according to the observed values of multiple input-output variables and evaluates the comprehensive effect of DMUs on this basis (Zhou & Yu, 2008). This method does not need to know the specific form of production function in advance and is suitable for efficiency calculation under the condition of multi-input and multi-output.

The first model of DEA was proposed by Charnes et al. (1978) and is commonly named after them as the CCR or C²R model. It can comprehensively evaluate the technical and scale effectiveness of DMU simultaneously. Since it is set under the condition of constant returns to scale, it is also known as the constant returns to scale (CRS). To overcome the limitation of CRS, Charnes et al. (1985) proposed the C2GS2 model, which can be used in situations where returns to scale are variable, also known as the variable return to scale (VRS) model. Banker and Morey (1986) proposed a “one-stage method” to introduce the DEA model by considering the impact of uncontrollable variables on efficiency as input or output terms, respectively. Banker (1996) compared the efficiency research results of 130 financial institutions from 21 countries, using five different cutting-edge methods. The efficiency estimation of nonparametric (DEA and FDH) studies is similar to that of parametric frontier models (SFA, DFA, and TFA), but nonparametric methods typically produce slightly lower average efficiency estimates and seem to have greater discreteness than the results of parametric models. Avkiran (2001) conducted an empirical study on the efficiency and overall performance of 36 Australian universities in 1995 using the C²R model and BC2 model, respectively. Sufian (2016) followed Simar and Wilson’s (2007) two-stage programme to analyse the efficiency of Malaysian banking

industry. In the first stage, the bootstrap DEA method was used to calculate the efficiency of a single bank from 1999 to 2008. Then, the bootstrap regression was used to test the impact of origin on the bank's efficiency, while the potential impact of contextual variables was controlled.

The random frontier parameter analysis (SFA) method was invented by foreign scholars Aigner and Lovell. Stochastic frontier analysis (SFA) is based on the method of econometrics to establish a specific production function model to estimate the parameter value and technical efficiency value of the research object (Aigner et al., 1977). The production frontier calculated by this method is not fixed, but random. Specifically, this method needs to clarify the specific expression of the production function in advance and estimate the parameters of the frontier production function. According to the current research literature, the Col Douglas Function and Translog Function are the two most widely used function forms in the research of SFA. It could be concluded that the SFA method needs to assume the form of production function in advance, and some random errors are allowed. Unlike nonparametric methods, the core of SFA method is to construct specific functions, accurately estimate the parameters of the production function located on the frontier surface, and then calculate the size of innovation efficiency.

By comparing SFA and DEA, it could be seen that SFA needs to determine the specific form of production function and assumptions should be made according to the changes of production units during the model construction. If the assumptions are inappropriate or the setting of function model is unreasonable, the estimation results will be affected, and SFA cannot deal with the efficiency problem of multi-input to multi-output. Although DEA is sensitive to outliers, it does not need to determine the specific

function form of input and output, which can effectively avoid the wrong conclusion caused by the wrong use of function form. Considering this study is to measure the efficiency of the innovation system of China brand automobile industry, on the one hand, the efficiency of the innovation system is affected by multi-input and multi-output and DEA can study the problem of multi-input and multi-output. On the other hand, this study only needs to consider the impact of the interaction between various input factors of economic subjects on the innovation efficiency, which is in line with the setting principle of DEA method. Therefore, this study selects the DEA method to evaluate the efficiency of China brand automobile industry's innovation system.

2.6.3 Efficiency in Transport

Costa and Markellos (1997) measured the performance of public transportation services based on the concept of production efficiency. A new nonparametric method based on multi-layer perceptron neural network has been proposed. MLP, along with DEA and modified least squares (COLS) were used to develop the annual efficiency comparison indicators for the London Underground from 1970 to 1994.

Somogyi (2011) reviewed the application of DEA in transportation sectors, including airports, ports, railways and urban transportation. Emphasis was placed on the inputs and outputs selected from DEA models used in different fields.

Sami et al. (2013) measured the technical efficiency of 64 public road operators in 18 countries and investigated the degree to which various factors affect the efficiency level of these companies. The SFA analysed samples from 2000 to 2011 over a period of 12 years. The empirical results indicated that operating profit, investment and enterprise scale

had a significant impact on technological efficiency. The results showed that the technical efficiency level of public road operators was between 0.46 and 0.95. Large operators with strong investment capabilities were more technically efficient than small operators. Additionally, operators in developed countries were more efficient in technology than those in developing countries.

2.7 Relationship among Innovation, Competitiveness and Performance of Enterprises

2.7.1 Relationship between Innovation and Competitiveness of Enterprises

Innovation is the key to the development of industrial economy and the promotion of competitiveness (He, 2012). As one form of innovation, technological innovation helps to create the advantage of low product cost. In the era of knowledge economy, the basis of high-quality products is technological innovation.

The term “competitiveness” was proposed by Philip Selznick (1957) to describe the relevant skills of enterprises in executing strategies. Subsequently, different scholars mainly focused on studying competitiveness in different dimensions and fields, providing different understandings. Fan (1998) believed that the concept of competitiveness could ultimately be understood as the concept of “cost”, which referred to how a company could provide customers with the same quality of products at a lower cost. Zhang (2001) believed that competitiveness is the strength exhibited by market participants in the process of competing for competitive objects and its essential feature is the gap between competing entities. Huang (2017) stated that competitiveness is the manifestation of a certain gap in competitiveness between the two parties participating in competition.

Only through continuous technological innovation can companies develop high-quality products that occupy a leading position in the international market and obtain the advantage of market competition. A basic performance of technological innovation in improving the international competitiveness of products is to reduce the product cost and make it obtain the cost advantage, so as to realise the core value of products and obtain the core competitiveness (Chen, 2021).

Additionally, technological innovation is an effective way to open up the market. The degree of acceptance and sales status of any product in the market should go through the process of “birth - growth - maturity - decline”. When the market of a product develops to a certain extent, there will be a situation of oversupply, resulting in maturity. Only through continuous technological innovation can companies provide new products to the market. Due to its new functions and characteristics, the market value of this new product is higher than the previous commodities and easier to meet the needs of consumers. This is to grasp the initiative of international market competition and establish the core competitiveness of international trade (Shen & Peng, 2022).

Technological innovation helps to improve the resource use efficiency and added value of enterprises. One of the main characteristics of the international competitiveness of enterprises is value, whereby it helps enterprises to realise the core values concerned by customers. Through technological innovation, enterprises use advanced production technology, improve and update services, produce more products with less investment, increase the added value of products and obtain more benefits.

Xia and Wang (2015) stated that the level of technological innovation, strength of ability and speed of development of enterprises are mainly reflected in the demand for the

improvement of core competitiveness as well as the technical means, financial support and innovation atmosphere of R&D and innovation. The promoting effect of enterprises' core competitiveness on technological innovation is realised by further strengthening the functions of the above aspects. That is the core competitiveness of enterprises that provides strong demand power for technological innovation. The need to enhance the core competitiveness of enterprises is often the growth point of technological innovation, which determines the direction, focus and breakthrough choice of technological innovation development. Therefore, this promotes the progress and development of technological innovation to be a strong driving force or demand force for the continuous development of enterprise technological innovation to a higher level (Luo & Deng, 2012).

The core competitiveness of enterprises provides advanced technical means for technological innovation. On the one hand, enterprises with a high level of core competitiveness generally have a higher level of R&D capability and the production and processing capability of materialising R&D achievements into products. This kind of enterprise has the ability to independently or jointly develop and produce higher-level technical equipment, instruments and meters required by the enterprise's technological innovation, so as to make the enterprise's technological innovation at a higher level and make new breakthroughs and development. On the other hand, enterprises with higher core competitiveness generally have the advantage of high comprehensive benefit level and more special expenses for R&D equipment. Such enterprises have the ability to purchase the equipment, instruments and meters needed for technological innovation at home and abroad in order to ensure the effective implementation of technological innovation at a high starting point (Xia & Wang, 2015).

The core competitiveness of enterprises provides more financial support for technological innovation. Generally, enterprises with a high level of core competitiveness not only have product advantages, market advantages, comprehensive benefit advantages and management decision-making advantages, but also the advantages of enterprise development funds. This is to provide more financial support for technological innovation, make technological innovation at a higher starting point and level, achieve new breakthroughs and R&D achievements, and improve the ability of enterprise technological innovation. Additionally, core competitiveness of enterprise creates a good innovation atmosphere for technological innovation. In enterprises with a higher level of core competitiveness, all kinds of personnel at all levels are driven by innovation (Xia & Wang, 2015).

In recent years, Porter's "Diamond Model" is often applied when analysing industrial competitiveness (Porter, 1990). He believed that industrial competitiveness was formed by four main factors: production factors, domestic market demand, related and supporting industries, enterprise strategy, enterprise structure and competition in the same industry, as well as two auxiliary factors such as government's behaviour and opportunity. Amongst which, the first four factors are the main influencing factors of industrial competitiveness, which constitute the main framework of the "Diamond Model". The four factors influence each other and form an entirety, which jointly determines the level of industrial competitiveness. Porter's model can be explained by the industrial innovation system theory to a great extent. They all emphasise on the system's elements and interaction amongst them. Moreover, the elements in Porter's model are included in the theory of industrial innovation system to a great extent.

2.7.2 Relationship between Innovation and Industrial Innovation System

Liu (2000) pointed out that innovation had different levels from the perspective of technological innovation. At the national level, it is the national innovation system, whereas at the regional level, it is the regional innovation system. Furthermore, at the industrial level, it is the industrial innovation system. The key to the operation of industrial innovation system is to establish a cooperative innovation network.

Industrial technological innovation, industrial organisational innovation and industrial management innovation constitute the core of industrial innovation. Therefore, the industrial innovation system should include three subsystems: industrial technology innovation subsystem, industrial organisation innovation subsystem and industrial management innovation subsystem. Each subsystem is composed of several contents and has specific functions (Table 2.1).

Table 2.1: Composition and Function of Industrial Innovation System

Item	Technological innovation system	Organizational innovation system	Management innovation system
System content	Product innovation Process innovation	Organizational innovation of a single enterprise	Innovation of management system; Innovation of management means; Innovation of management content

Table 2.1 continued

System function	Provide competitive new products; Improve technical level	Division and combination of enterprises	Ensure operation, increase efficiency, improve benefit
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Source: Zhang (2003)

Zhang and Hu (2006) deepened the definition of industrial innovation system and believed that industrial innovation system was a network system driven by market demand, guided by policy regulation, guaranteed by a good domestic and international environment, centred on the supply of innovative technology and aimed at realising specific industrial innovation. Concurrently, the industrial innovation system model was constructed, including four subsystems: industrial innovation technology system, industrial innovation policy system, industrial innovation environment system and industrial innovation evaluation system.

2.7.3 Relationship between Innovation and Performance

Baker and Sinkula (2002) stated that innovation would positively affect performance of enterprises. Godswill (2018) agreed that innovation had a significant positive impact on firm performance, whereby the size of the firm takes an important role.

The sustainability of technological innovation has a positive impact on an enterprise's performance to a certain extent. However, when the sustainability of innovation exceeds a certain degree, it will have a negative impact on enterprise performance, and thus there is an inverted "U" relationship between them. The synergy

between input sustainability and output sustainability of innovation does not have a significant positive impact on enterprise performance. Diversification intensity has a positive regulatory effect on the relationship between “innovation input sustainability and enterprise’s performance”, but it has no significant regulatory effect on the relationship between “innovation output sustainability and enterprise performance” (He & Zhang, 2017).

2.8 Factors Affecting Efficiency of Industrial Innovation System

2.8.1 Financial Support for Science and Technology

For different industries, the government’s role in innovation activities is different, but its main function is to solve the obstacles in the process of system operation and optimise the whole system (Zhang, 2011). The government mainly plays the functions of direct investment and indirect guidance in the industrial innovation system, guides and supports the industrial innovation behaviour, reduces the obstacles of other innovation subjects in the innovation process and makes the industry have sustainable innovation ability and power. Government direct inputs usually includes the government direct investment, project subsidies and other national financial funds. Especially in the industry early stages of development, the government can inject a great deal of financial funds to give birth to and cultivate a new market environment. For example, the government can provide investment for technological innovation and infrastructure with high risk or no return in the short term, provide the driving force for subsequent innovation for enterprises and escort the innovation of cultural enterprises. Government indirect guidance means that the government guides other subjects to participate in innovation investment by formulating relevant fiscal, tax and financial policies. Additionally, it creates a favourable

external environment for the innovation and development of cultural industry, clears away the obstacles of various subjects in innovation activities, and subsequently encourages and promotes enterprises to innovate continuously (Wang, 2015).

2.8.2 Economic Growth

Industrial innovation and economic growth are inextricably linked. The two are driven by each other, and thus innovation is a key component of the government's political agenda (Hsu et al., 2014). Economic indicators have an impact on industrial innovation at different levels: companies, states and countries (Pece, 2015). Ulku (2004) concluded that there was a strong positive correlation between industrial innovation (patent stock) and per capita GDP in countries, while only OECD countries with large markets, including G-7, Australia, the Netherlands, Spain and Switzerland could increase innovation through investment in R&D. Marques and Lopes (2021) analysed the causal relationship between long-term per capita economic growth and innovation. They found that there was a two-way causal relationship between innovation and per capita economic growth.

In some cases, the per capita economic growth leads to industrial innovation, which supports the demand relationship according to the innovation growth hypothesis. In other cases, it is industrial innovation that regulates the per capita economic growth level and supports the supply leading hypothesis of the innovation growth relationship. Sometimes, industrial innovation and per capita economic growth are interdependent. In this case, both are self-reinforcing. Additionally, industrial innovation and per capita economic growth are independent of each other. Both are neutral and support the neutral hypothesis of the innovation growth relationship (Maradana, 2017).

2.8.3 Degree of Openness

Taking China's top 100 multinational corporations as the research sample, Sun (2015) used the structural equation model to analyse the relationship between degree of enterprise internationalisation and innovation efficiency. The degree of enterprise internationalisation was divided into two dimensions, namely, the breadth and depth of enterprise internationalisation. The empirical results showed that improvement of the breadth of enterprise internationalisation was conducive to the improvement of enterprise innovation efficiency, and subsequently promoted the growth of enterprises. However, the improvement of the depth of enterprise internationalisation did not significantly promote the innovation efficiency of enterprises.

Xiao (2022) pointed out that the implementation of internationalisation strategy would help enterprises improve their innovation efficiency. This was consistent with the theoretical description and empirical analysis results of previous scholars, whereby by entering the international market, enterprises could get more innovative resources and turn innovative resources into higher innovation output with the help of the broad space of the international market. The moderating effect of a company's market position on the relationship between its internationalisation level and innovation efficiency is insignificant. As a leading enterprise in the industry, the technology manufacturing and production process did not need to be greatly changed to meet the consumption needs of foreign fixed customers since the enterprise was unwilling to spend more energy and capital on R&D and innovation. Therefore, the positive effect of the degree of internationalisation on the innovation efficiency of the enterprise was not obvious.

2.8.4 Foreign Direct Investment

Foreign direct investment (FDI) has a significant positive impact on industrial innovation system efficiency. Increasing the proportion of FDI in GDP will help to increase the number of patent applications. This conclusion is consistent with the existing research that FDI has the knowledge spillover effect of promoting innovation. Moreover, FDI not only makes up for the shortage of domestic capital, increases the total amount of capital and enriches R&D funds, but also helps to improve the innovation ability of the host country through technical guidance, patent authorisation and licensing (Dong, 2016).

Qayoom and Ruchi (2016) studied the spillover effect of FDI and its impact on the innovation efficiency of domestic enterprises in India's manufacturing industry. They concluded that FDI had a moderate impact on the innovation efficiency of enterprises in the same industry. However, statistically, the impact of supply sector on enterprise innovation efficiency seemed to be strong.

Li (2017) focused on the impact of FDI on regional innovation efficiency in China. The empirical results showed that FDI did have a significant positive impact on innovation efficiency, but on the whole, the improvement effect of FDI on innovation efficiency in the eastern region was not as obvious as that in the central and western regions.

2.8.5 Degree of Marketisation

The degree of marketisation (MAL) generally reflects the position and role of market mechanism in promoting economic activities, such as technological innovation. The improvement of marketisation degree represents the enhancement of market power and the improvement of market competition environment in economic activities. The

reduction of government intervention, vigorous development of various economic entities of ownership, and increase of fierce competition in product market and factor market will significantly enhance the internal driving force of enterprises to carry out technological innovation activities. Improvement of the market legal system environment also protects the economic value and expected income of technological innovation achievements of enterprises. In a healthy market environment, enterprises will devote more energy to technological innovation activities, constantly accumulate innovation experience and improve innovative organisation and management methods. Therefore, it is not difficult to understand why the degree of marketisation variable has a significant positive impact on the technical efficiency of innovation (Feng, 2011).

Yang (2020) conducted a research on the influence of marketisation degree on regional innovation efficiency in China. She found that from a national perspective, the improvement of China's regional marketisation had a positive role in promoting regional innovation efficiency. The lower level of factor marketisation in the central and western regions could not promote the improvement of innovation efficiency and the higher level of factor marketisation in the eastern region can promote the improvement of innovation efficiency to a certain extent. The improvement of product marketisation level can promote the improvement of innovation efficiency in the east, central and western regions.

2.8.6 Scale of Enterprises

Wakasugi and Koyata (1997) showed that large enterprises had a stronger willingness to innovate and R&D output would increase with the expansion of scale. However, the defects of large enterprises in flexibility and information accessibility were easy to lead to low efficiency of innovation activities, making the enterprise scale

irrelevant or even negatively related to innovation (Rogers, 2004). Furthermore, some studies believed that compared with high-tech industries, the scale effect of innovation activities was more prominent in low-tech enterprises and industries (Pla-Barker, 2007). Specifically, there is a linear positive correlation (Hamberger, 1965) between enterprise scale and a single index of innovation as well as nonlinear relationships, such as inverted U-shaped (Scherer, 1965) and “~” shaped (Sun, 2016). The inverted U-shape, amongst them, is the most common conclusion: before the maximum point of the function, innovation ability of enterprises enhances with the increase of scale. Once the critical value exceeded, innovation will be subject to the adverse impact of scale expansion.

With the limitations of a single index, more scholars begin to pay attention to the innovation efficiency at the industrial level, but there are still a few special studies on enterprise scale and innovation efficiency. Some scholars empirically found that there was a linear positive correlation between enterprise scale and innovation efficiency (Zhu, 2006), and some research results believed that the two were negatively correlated (Xiao, 2014). Affected by factors, such as R&D stage and index selection, the direction and intensity of the impact of enterprise scale on innovation efficiency are not fixed.

Whether it is a single innovation index or efficiency index, for the purpose of simplifying research methods or intuitively displaying results, the above studies regarded the change of the relationship between enterprise scale and innovation capability as a continuous process. In fact, there are often discontinuous jumps in the action process of enterprise scale on innovation (Li & Zhang, 2014). The model setting of continuous function not only ignores the structural mutation that may occur at the turning point of the

relationship between the two, but also fails to explain the heterogeneity of the impact of different enterprise scale on innovation, which is far from reality.

2.8.7 Growth Ability of Enterprises

The growth ability of a company can reflect its development prospects and potential. A company with good growth potential and good operating performance indicates that it has a good financial condition and capital accumulation ability, can effectively respond to enterprise risks and provide a good innovation environment for the company. The stronger the growth ability of an enterprise, the higher its ability to optimise resource allocation, which is conducive to improving innovation efficiency (Tong and Xie, 2018). Guo (2021) demonstrated through theoretical and empirical methods that the growth power of enterprises played a positive moderating role between innovation investment and long-term performance of enterprises. It would subsequently affect the industrial innovation system.

2.9 Research on Innovation System of China's Automobile Industry

In the past two decades, the automobile industry has gradually become the focus of theoretical circles and relevant government departments in China, and the proposal of automobile industry innovation system can be traced back to 2000. Hu (2007) proposed to formulate and implement the national automobile innovation project, focusing on the technological innovation and industrial innovation of China's automobile, whereby the State Council will directly lead and organise the government, industry, university and research union. Additionally, they will mobilise the national scientific and technological forces and effective resources to tackle key problems and key breakthroughs through

strong financial support and scientific organisation and management.

Chen (2007) put forward the preliminary idea of establishing a national innovation system for the auto industry. He believed that this system was generally a coordinated organisation of government, industry, university and research cooperation. It was an open network that fully introduces the innovation and application of knowledge and made it industrialised on the basis of inheriting and carrying forward the technological innovation system. The system was organised and coordinated by the government, with FAW, Dongfeng and SAIC as the core to attract the participation of relevant enterprises, universities and scientific research institutions. The funds needed for the implementation of the innovation system should be raised through multiple channels and the establishment of special funds and introduction of venture capital mechanism could be considered.

Although Hu and Chen (2007) did not directly cite the theory of industrial innovation system and thought about the innovation of automobile industry from the perspective of building management tools, their basic ideas are consistent with the theory of industrial innovation system in many specific aspects. In terms of academic research, Zhang (2003) proposed the innovation and development objectives, directions, strategies and measures of China's automobile industry from the perspective of industrial innovation system. Furthermore, he decomposed the industrial innovation system into three subsystems: technological, organisational and management innovations. Liang (2009) applied the Malerba's theory to analyse the evolution of China's automobile industry. Pang (2009) studied the technological innovation of China's automobile industry from the perspective of industrial chain. Zeng (2010) constructed the model framework of China's automobile industry innovation system from the perspective of improving the ability of

independent innovation. Using the theoretical framework of industrial innovation system (SSI), Gao (2019) comprehensively used the research methods of patent retrieval and analysis, literature collection and expert interview to investigate the development of China's new energy vehicle industry innovation system and the obstacles encountered, namely system failure, from the four dimensions of knowledge and technology, actors and their networks, infrastructure and system.

2.10 Innovation Policy in China

In July 1994, the State Council officially issued China's first automobile industry policy, which established for the first time the policy of introducing, digesting and absorbing advanced foreign technologies, and subsequently developing their own brand automobiles. The concept of industrial technology innovation policy was proposed in the 1994 version of the automotive industry policy, which clearly stated that the goal of industrial technology innovation policy is to promote technological progress and independent innovation in the automotive manufacturing industry (Xu & Ouyang, 2017).

In 2004, the new "Automobile Industry Development Policy" for the first time merged the automobile industry policy with the consumption policy (National Development and Reform Commission, 2004). Compared with the policy in 1994, the new policy proposed a brand strategy to encourage and support domestic automobile manufacturing enterprises to independently develop products with core competitiveness, while guiding and encouraging related enterprises to develop energy-saving and environmentally friendly and new fuel vehicles. In 2009, China issued the "Automobile Industry Adjustment and Revitalisation Plan", which clearly proposed to encourage the "four major groups" of China's automobile manufacturing enterprises to restructure

nationwide and support the “four small groups” to implement regional mergers and acquisitions (Zhang, 2009).

In 2006, China issued the National Medium- and Long-Term Plan for Scientific and Technological Development (2006-2020). This plan clearly stated “the ability to independently innovate, promote economic and social development through science and technology, and ensure national security has significantly enhanced, providing economic support for the comprehensive construction of a moderately prosperous society” (www.gov.cn, 2006). The overall goal of scientific and technological development is to significantly enhance the comprehensive capabilities of basic science and cutting-edge technology research, obtain a number of scientific and technological achievements with significant impact in the world, enter the ranks of innovative countries and lay the foundation for becoming a strong country in science and technology by the middle of this century. In 2015, the “Made in China 2025” document clearly stated that the country needs to improve the manufacturing innovation system that is enterprise-led, market-oriented and combines government, industry, academia, research and application. China will deploy innovation chains around the industrial chain, allocate resource chains around the innovation chain, strengthen key core technology research and development, accelerate the industrialisation of scientific and technological achievements, and improve innovation capabilities in key links and areas (State Council, 2015). At the same time, the Chinese government has also introduced a series of targeted supportive technology innovation policies, including both direct R&D subsidies and indirect corporate tax incentives.

Since 2008, the Chinese government departments have been providing preferential treatment to various aspects of research and development of new technologies for high-

tech industry enterprises. Firstly, support enterprises in technological innovation. Research and development expenses incurred by enterprises for the development of new technologies, products and processes, which comply with the Enterprise Income Tax Law and relevant regulations are allowed to be subjected to additional deductions when calculating taxable income. Secondly, support enterprises in promoting the transformation of scientific and technological achievements. The portion of annual technology transfer income not exceeding 5 million yuan obtained from the transfer of ownership and non-exclusive licensing rights of resident enterprises for more than five years (inclusive) shall be exempt from corporate income tax. The portion exceeding 5 million yuan will be subject to a 50% reduction in corporate income tax (Ministry of Finance and State Administration of Taxation, 2015). Additionally, the government provides maximum tax incentives for the expenses incurred by enterprises in providing high-tech talent training. Finally, support the development of high-tech enterprises. Certified high-tech enterprises shall be subject to corporate income tax at a reduced rate of 15%.

The research results of scholars indicated that industrial technology innovation policies could to some extent promote the establishment of independent research and development awareness and R&D investment in automotive enterprises, thereby enhancing the innovation efficiency and international competitiveness of China's automotive manufacturing industry. However, the coefficient of R&D subsidies is relatively small, indicating that the government's R&D subsidies and tax incentives for the automotive manufacturing industry are still insufficient, technological progress and innovation capabilities are weak and transformation of R&D achievements is ineffective.

In addition to national policies, several provinces and cities in China have also introduced policies for the development of the automotive industry. The Action Plan for Developing Strategic Pillar Industry Clusters in Automobile Industry in Guangdong Province (2021-2025) proposed to adhere to innovation leadership and seize the forefront of emerging automotive technology innovation. Accelerate the research and development of traditional fuel vehicle power systems, core components of new energy vehicle power, software ecosystems and other fields to enhance the technological innovation capabilities of automotive enterprises. The Implementation Plan for Accelerating the Development of the New Energy Vehicle Industry in Shanghai (2021-2025) stated that by 2025, the industry scale will be leading domestically and significant breakthroughs will be made in core technology research and development. The ability of networked and intelligent applications has significantly improved, infrastructure supporting facilities continue to be optimised and policy systems continue to be improved. To accelerate the innovative development of the automotive industry in Hubei province, the province has formulated an implementation plan for the transformation of the automotive industry (2023-2025) and by 2025, Hubei will build an important new energy vehicle production base in China. The independent and controllable ability of key core technologies in key areas and the level of industrial security guarantee will significantly increase.

2.11 Chapter Summary

Through the comprehensive analysis of literature, it could be seen that after nearly two decades of development, the research content is constantly enriched and the research angles are becoming more diverse. However, there are still some deficiencies in the existing research, which can be summarised as follows.

Firstly, the application of industrial innovation system theory to the research of developing countries is still incomplete. Although the relevant research has made some necessary amendments, it still lacks a theoretical framework of industrial innovation system suitable for developing countries (especially China). For developing countries, environmental background of industrial development, role of non-enterprise innovation subjects, such as government, universities and industry organisations, demand of domestic market and role of multinational corporations showed different characteristics from developed countries.

Secondly, the research on industrial innovation system is not very abundant. Generally, the domestic industry, academia and government management departments regard the industrial innovation system more as a policy management tool than a scientific theory, and thus the corresponding academic research is less. Although there is extensive research on the innovation system in China, the proportion of industrial innovation system is very low.

Thirdly, currently, the industrial innovation system is mainly a qualitative analysis and the corresponding quantitative research is less. Some quantitative methods that have been widely used in the research of other innovation systems have not been widely used in the research of industrial innovation system for various reasons.

CHAPTER 3

RESEARCH METHODOLOGY

3.1 Introduction

This study explores the efficiency, productivity and determinants of China brand automobile industry innovation system. From the perspective of industrial innovation system theory, the efficiency of industrial innovation system is jointly affected by macro external factors and internal factors of enterprises. The macro external factors, amongst which, can be further divided into market macro environment and government support.

The objective of this study is to measure the efficiency of industrial innovation system of China brand automobile. Based on the comparison of methods, this study tests how the macro external factors and enterprise internal factors affect the efficiency of innovation system of China brand automobile. This chapter first selects and constructs the efficiency evaluation model of China brand automobile industry innovation system and the econometric empirical model of determinants, then selects and defines the input-output variables and determinant variables of the innovation system efficiency and finally introduces the data sources and data processing of quantitative econometric analysis.

3.2 Research Philosophy

The study adopted positivism philosophy with quantitative method to achieve the research objectives. Positivism refers to the statistical and generalisable approach based on the observation of larger samples through hypothesis research. It mainly used to explain social phenomena or causal relationships (Greener, 2008). Positivism originates from the philosophical ontology of realism, which means that reality is real and understandable, and

things themselves have inherent fixed and repeatable laws. Positivism defines theory as a proposition that connects abstract concepts, which is also a widely used definition. The positivist theory focuses on seeking explanations for reasons and supporting causal relationships, emphasising the generalisation and universality of the theory. This type of research makes scientific research more objective and verifiable. Deductive approach was employed and secondary data was collected in this study for the research.

This section covers the innovation system of China brand automobile industry. Firstly, it briefly introduces and selects the efficiency evaluation model, whereby the model will be introduced in detail, which is DEA. Furthermore, it subsequently constructs the Tobit model, which is the innovation system determinant model of efficiency of China brand automobile industry.

3.2.1 Data Envelopment Model

Data envelopment analysis (DEA) is an interdisciplinary field of mathematical economics, management science and operations research, developed by Charnes et al. (1978) using linear programming to evaluate the relative effectiveness of organisational units. The basic principle is to estimate a nonparametric segmented efficient production frontier and then compare other decision units (DMUs) with the efficient frontier to determine its efficiency. Compared to the least squares method and the stochastic frontier method, DEA has prominent advantages in handling multiple inputs and outputs, which is more in line with the ideas of this study. It has been applied to performance research in some service industries, including banking (Angelidis & Lyroudi, 2006), nursing (Hsu & Hu, 2007), and insurance (Mahajan, 1991). DEA includes two classical models, the

constant returns to scale (CRS) and variable returns to scale (VRS), both were designed by Rolf et al. (1994).

3.2.2.1 CRS Model

The constant returns to scale (CRS) model is used to measure technical efficiency (TE) under the assumption that the return to scale is constant. Suppose m innovative enterprises are selected, and K input and M output data are selected for each enterprise. For the i -th company, K and M are represented by x_i and y_i , respectively. The goal of DEA is to construct a nonparametric envelope front according to data points and compare the relative position of observable data and production front. For all sample companies, the ratio of output to input $a'y_i / b'x_i$ can be obtained, where b represents $K \times 1$ Input weight matrix and a represents $M \times 1$. The output weight matrix, mathematical programming can be used to solve the problem of selecting the optimal weight.

$$\begin{aligned} & \text{Max}_{a,b} (a'y_i / b'x_i) \\ \text{s.t. } & a'y_j / b'x_j \leq 1, j = 1, 2, \dots, m \\ & a, b \geq 0 \end{aligned} \quad \text{Equation 3.1}$$

The efficiency of the i -th company is maximised and the constraints restrict the efficiency of all other companies to be less than or equal to 1. Assuming $b'x_i=1$, then Equation 3.1 is transformed into Equation 3.2:

$$\begin{aligned} & \text{Max}_{c,b} (c'y) \\ \text{s.t. } & b'x_i=1 \\ & c'y_j / b'x_j \leq 0, i = 1, 2, \dots, m \\ & c, d \geq 0 \end{aligned} \quad \text{Equation 3.2}$$

Changing a sign into c is called the multiplier form of linear programming. Assuming that λ represents for $N \times 1$ constant vector, d represents a scalar and Equation 3.2 is transformed into the binary form of linear programming to obtain Equation 3.3:

$$\begin{aligned}
 & \min_{d, \lambda} d \\
 & \text{s.t. } -y + Y\lambda \geq 0 \\
 & dx_i - X\lambda \geq 0 \\
 & \lambda \geq 0
 \end{aligned}
 \tag{Equation 3.3}$$

where, X represents input, Y means output, λ represents linear combination coefficient of decision-making unit, d represents efficiency score of the i-th innovative sample enterprise, $d \leq 1$, if $d=1$, it means that the i-th enterprise is on the frontier of efficiency, which means that the technology is efficient.

3.2.2.2 VRS Model

The variable returns to scale (VRS) model is a measure of efficiency under the changes in returns to scale. Through this model, the technical efficiency measured from the CRS model can be divided into two parts: the scale efficiency (SE) and pure technical efficiency (PTE) of each DMU. PTE indicates the distance between the sample enterprise and production frontier when the scale reward changes, while SE represents the gap between the production frontier when the scale reward is fixed and the scale reward changes, that is, the production ineffectiveness caused by the scale reward changes. If the technical efficiency of CRS and VRS of a specific enterprise is different, it proves that the company has scale efficiency. The model form is to add convexity constraint $m_i = 1$ to Equation 3.3 to get Equation 3.4, where m1 represents all $N \times 1$ Matrix.

$$\min_{d,\lambda d}$$

$$\text{s.t. } -y_i + Y\lambda \geq 0$$

$$dx_i - X\lambda \geq 0$$

Equation 3.4

$$M'_i = 1$$

$$\lambda \geq 0$$

The CRS model is the most basic DEA model proposed by Charnes, Cooper and Rhodes, also known as the CCR model. To simply judge the effectiveness of DMU, Charnes and Cooper introduced the concept of non-Archimedean infinitesimal quantity to solve the model by using the simplex method of linear programming to once judge the DMU. When using the constant scale reward model to evaluate efficiency, it should be assumed that each DMU is located at the optimal production scale, otherwise, the measured efficiency value will include the impact of scale effect. Additionally, to measure the PTE level of production units, Banker et al. (1984) proposed a variable return to scale (BCC) model. Under the assumption of variable returns to scale, possible productive collection T_v may be set as follows:

$$T_v = \left\{ (X, Y): X \sum_{i=1}^n \lambda_i X_i, Y \sum_{i=1}^n \lambda_i Y_i, \sum_{i=1}^n \lambda_i = 1, \lambda_i \geq 0, 1 \leq i \leq n \right\} \quad \text{Equation 3.5}$$

Model of PTE evaluation based on T_v (after relaxation variables SA and SB and perturbation ε are added, amongst which, relaxation variables SA and SB refer to new variables introduced under an inequality constraint, which can transform the inequality constraint in the original problem into an equality constraint) is:

$$(D_{\varepsilon}^V) \left\{ \begin{array}{l} \min \quad [\theta_v - \varepsilon(e_1^T SA + e_2^T SB)] \\ \text{s.t.} \quad \sum_{i=1}^n \lambda_i X_i + SA = \theta_c X_o \\ \sum_{i=1}^n \lambda_i Y_i - SB = Y_o \\ \sum_{i=1}^n \lambda_i = 1 \\ \lambda_i \geq 0, i = 0, 1, 2, \dots, n, SA \geq 0, SB \geq 0 \end{array} \right. \quad \text{Equation 3.6}$$

Then, when the solution is θ_v^* , λ^* , SA^* , SB^* , the following conclusions are obtained: (i) If $\theta_v^*=1$ and $SA=SB=0$, and thus DMU0 is valid. (ii) If $\theta_v^*=1$, DMU0 is weakly effective. (iii) If $\theta_v^* < 1$, DMU0 is invalid. In the equation, θ represents efficiency.

As mentioned above, the efficiency value measured by the CRS model includes SE and PTE. The VRS model examines the PTE level of production units. Then, the relationship amongst TE θ_c , PTE θ_v and SE θ_s is:

$$\theta_c = \theta_v * \theta_s, \theta_s = \theta_c / \theta_v \quad \text{Equation 3.7}$$

The DEA models of CRS and VRS were carried out respectively to get θ_c and θ_v and used to calculate the level of scale efficiency. When $\theta_c = \theta_v$, the scale efficiency of the production unit is 1.0, whereby the production is at the optimal scale. Otherwise, the scale efficiency of the production unit will be lost. There are also two reasons for the loss of scale efficiency, namely, too small scale and too large scale. The former means the enterprise is too small to meet the minimum scale required by the industry. The latter means the expansion of enterprise scale exceeds a certain limit and the increase in product output is smaller than the expansion of production scale.

3.2.2.3 Malmquist Index

The Malmquist index was first proposed by Malmquist (1953). Caves et al. (1982) first applied the index to the measurement of productivity changes and subsequently combined it with DEA theory established by Charnes et al., which has become increasingly widely used in productivity measurement.

With reference to technology T^t in period t , the Malmquist index based on output can be expressed as:

$$M_0^t(x_{t+1}, y_{t+1}, x_t, y_t) = d_0^t(x_{t+1}, y_{t+1}) / d_0^t(x_t, y_t) \quad \text{Equation 3.8}$$

Similarly, taking the technology T^{t+1} in $t+1$ period as a reference, the Malmquist index based on output can be expressed as:

$$M_0^{t+1}(x_{t+1}, y_{t+1}, x_t, y_t) = d_0^{t+1}(x_{t+1}, y_{t+1}) / d_0^{t+1}(x_t, y_t) \quad \text{Equation 3.9}$$

To avoid the difference that may be caused by the randomness of period selection, Caves et al. (1982) used the geometric mean as the Malmquist index to measure the productivity change from period t to period $t+1$, following the construction method of Fisher's ideal index. When the index is greater than 1, it indicates that total factor productivity increases from t period to $t+1$ period.

$$M_0(x_{t+1}, y_{t+1}, x_t, y_t) = \left[\frac{d_0^t(x_{t+1}, y_{t+1})}{d_0^t(x_t, y_t)} \times \frac{d_0^{t+1}(x_{t+1}, y_{t+1})}{d_0^{t+1}(x_t, y_t)} \right]^{1/2} \quad \text{Equation 3.10}$$

In Equation 3.10, (x_{t+1}, y_{t+1}) and (x_t, y_t) represent the input and output vectors of period $(t+1)$ and period t , respectively; d_0^t and d_0^{t+1} , respectively, represent the distance functions of period t and period $(t+1)$ with reference to the technology T^t of period t .

The Malmquist index obtained from the above treatment had good properties. It could be decomposed into two parts. The first part is the Technical Efficiency Change Index (EFFCH) under the assumption of CRS, which measures the catching up of production possibility boundaries by each DMU from period t to period $t+1$. The second part is the Technical Progress Index (TECH), which measures the movement of technological boundaries between period t and period $t+1$. The decomposition process is as follows:

$$M_0(x_{t+1}, y_{t+1}, x_t, y_t) = \frac{d_0^t(x_{t+1}, y_{t+1})}{d_0^t(x_t, y_t)} \left[\frac{d_0^t(x_{t+1}, y_{t+1})}{d_0^{t+1}(x_{t+1}, y_{t+1}|C)} \times \frac{d_0^t(x_{t+1}, y_{t+1})}{d_0^{t+1}(x_t, y_t)} \right]^{1/2} \quad \text{Equation 3.11}$$

According to Fare et al. (1994), the Technical Efficiency Change Index (EFFCH) could be further decomposed into Pure Technical Efficiency Change Index (PECH) and Scale Efficiency Change Index (SECH), respectively, represented as follows:

$$Ech = \frac{d_0^{t+1}(x_{t+1}, y_{t+1})}{D_0^t(x_t, y_t)} = \frac{SE_0^{t+1}(x_{t+1}, y_{t+1})}{SE_0^t(x_t, y_t)} \times \frac{d_0^{t+1}(x_{t+1}, y_{t+1}|V)}{d_0^t(x_t, y_t|V)} \quad \text{Equation 3.12}$$

where,

$$M_0(x_{t+1}, y_{t+1}, x_t, y_t) = TFPch = Tch \times Sech \times Pech = Tch \times Ech \quad \text{Equation 3.13}$$

Technical efficiency is the product of pure technical efficiency and scale efficiency and total factor productivity (TFPch) is the product of technical efficiency and technical progress. Compared with the DEA analysis of simple cross-sectional data, the Malmquist index analysis peels off the factors of technological progress. Therefore, the PTE of cross-sectional data includes technical progress and management level, while PTE in the Malmquist index analysis only reflects the management level, and thus the results are more accurate.

It could be seen that using the Malmquist index to measure innovation efficiency could not only decompose the TFPch index into technical efficiency change index and technical progress index, which is conducive to further analyse the reasons for the change of innovation efficiency of China brand automobile industry. However, it also studies the cross period change of innovation efficiency of China brand automobile industry in many regions (Dong et al., 2014), whereby the innovation efficiency of the dynamic panel data of China brand automobile industry can be calculated.

Based on the above analysis, on the one hand, this study utilised the DEA-CRS and VRS model to calculate the efficiency of China brand automobile industry's innovation system, compared and analysed the efficiency of own brand automobile industry innovation system in different regions of China. On the other hand, it used the DEA-Malmquist index to calculate the dynamic efficiency of own brand automobile industry innovation system in different regions of China (Figure 3.1).

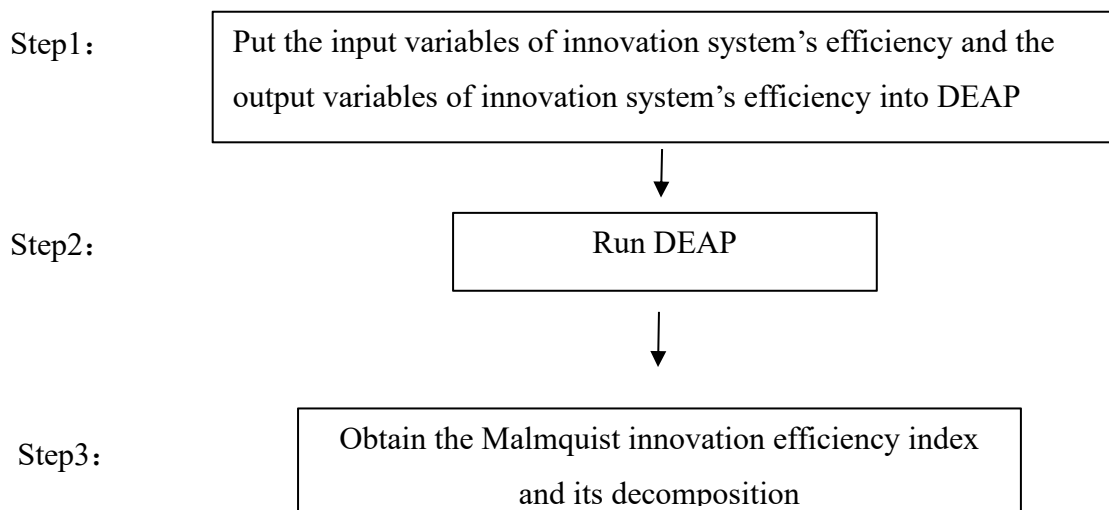


Figure 3.1: Steps of DEA Malmquist Innovation Efficiency Measurement

3.2.2 The Tobit Model

After calculating the innovation system efficiency of China brand automobile industry, this study constructed the corresponding measurement model and made a quantitative analysis on the determinants of the innovation system efficiency with the panel data of innovation efficiency. However, because multiple DMUs in the measurement results of comprehensive innovation efficiency may be at the efficiency boundary of DEA, the value of innovation efficiency of the explained variable was between 0 and 1.0. The lower limit was 0, the upper limit was 1.0 and the part greater than 1.0 would also be truncated to 1.0, which belonged to truncated data and the innovation efficiency became a restricted dependent variable. If the ordinary least square method (OLS) is used for linear regression analysis of panel data, its nonlinear term will be included in the disturbance term to make the disturbance term related to the explanatory variable. Finally, there will be bias and inconsistency in the estimated parameters, resulting in the deviation of the estimation results. In view of this limitation, an American economist, James Tobin (1958) proposed the Tobit model. The Tobit model is a statistical model used to deal with truncated data. It can effectively handle the situation where the value range of the observed variable is limited. It can avoid the disadvantage that the value of the explanatory variable itself is in a certain interval, resulting in inaccurate estimation. Additionally, it can estimate the impact of unobserved variables on efficiency and conduct in-depth analysis of the efficiency. Coelli (1998) subsequently proposed the DEA Tobit two-stage analysis method based on DEA model and Tobit model to analyse the influencing factors of innovation efficiency.

Based on this, the study selected the Tobit model to analyse the determinants of efficiency of China brand automobile industry innovation system. The basic form of Tobit

model is as follows:

$$Y_i^* = \beta X_i + \mu_i, \mu_i \sim N(0, \delta^2)$$

$$\begin{cases} Y_i^* = Y_i, & \text{if } Y_i^* > 0 \\ Y_i^* = 0, & \text{if } Y_i^* \leq 0 \end{cases}$$
Equation 3.14

where, Y_i^* is restricted observation value, the explained variable Y_i is observed in a restricted way, X_i is independent variable, μ_i is random interference term, and β is parameter vector.

Firstly, it constructs the basic model of the determinants of the efficiency of China brand automobile industry innovation system for empirical analysis. Based on previous studies (Li & Zhong, 2021; Yang, et al., 2022), determinants of efficiency of China brand automobile industry innovation system mainly included two aspects: macro external factors and enterprise internal operation factors. The macro external factors include market level and government level and the market macro level includes economic development level, degree of openness, foreign direct investment, degree of marketisation, etc. The government level includes financial support for science and technology, while the enterprise level includes enterprise scale (Hu & Liang, 2021). Based on this, the basic measurement model of the determinants of efficiency of China brand automobile industry innovation system is as follows:

$$ine_{i,t} = \alpha_0 + \alpha_1 gdp_{i,t} + \alpha_2 do_{i,t} + \alpha_3 fdi_{i,t} + \alpha_4 mal_{i,t} + \alpha_5 tf_{i,t} + \alpha_6 sca_{i,t} + \varepsilon_i + \mu_{i,t}$$
Equation 3.15

where, $ine_{i,t}$ is innovation efficiency of own brand automobile industry innovation system of province I during the period T, $gdp_{i,t}$ is economic development level of province I during the period T, $do_{i,t}$ is degree of internationalisation of province I during the period T, $fdi_{i,t}$ refers to foreign direct investment of province I in the period T, $mal_{i,t}$ is degree of marketisation of province I during the period T, $tf_{i,t}$ is scientific and technological financial

support of province I during the period T, sca_{it} is enterprise scale of China brand automobile industry of province I during the period T, and ε_i represents unobservable individual fixed effect of province I, μ_{it} represents random interference term, α_0 represents intercept term of the model, and α represents regression coefficient of each variable.

The variance inflation factor (VIF) test was utilised before conducting the regression analysis. VIF) is a measure of the severity of multicollinearity in multiple linear regression models. It represents the ratio of variance of the regression coefficient estimator to the variance when the independent variables are assumed to be non-linearly correlated.

In multiple regression, whether the regression model has serious multicollinearity problems, it can be tested by calculating the variance expansion coefficient VIF. The equation of VIF is as follows:

$$VIF = \frac{1}{1 - Ri^2} \quad \text{Equation 3.16}$$

where, R_i is the negative correlation coefficient between the independent variable and the other independent variables for regression analysis. The larger the coefficient of variance expansion (VIF), the greater the likelihood of collinearity between independent variables. Generally speaking, if the variance inflation factor exceeds 10, the regression model exhibited severe multicollinearity. According to Hair's (1995) collinearity diagnostic criteria, when the tolerance of the independent variable is greater than 0.1 and the variance expansion coefficient is less than 10, it is acceptable, indicating that there is no collinearity problem between the independent variables (Li, 2010).

After performing the likelihood ratio test, Hausman test, and VIF test on the relevant data, the panel Tobit regression analysis was performed, and the steps are shown

in Figure 3.2.

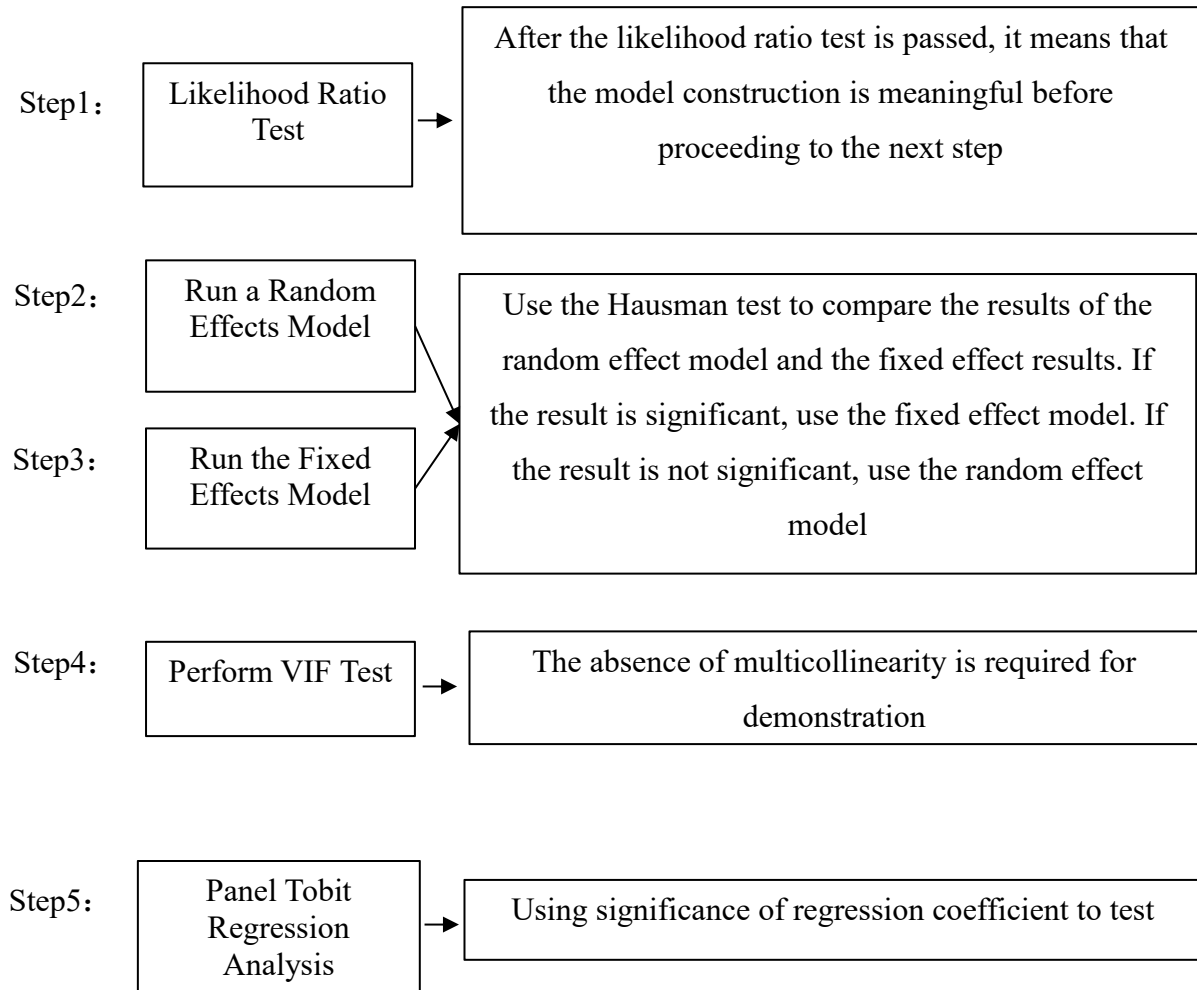


Figure 3.2: Empirical Steps of Tobit Model

3.3 Conceptual Framework

This study focused on evaluating the efficiency performance of China brand automobile industry innovation system. It utilised DEA model (Charnes et al., 1978), which is a linear programming to construct a nonparametric production boundary envelop, and subsequently evaluated the efficiency of DMUs. The DEA model treated the weights of input and output indicators of each DMU as variables. This study adopted the total number of technical employees in enterprises and total R&D investment of the enterprise as the input index and total number of patent applications by enterprises, sales revenue of

the enterprise were considered as the output index. Based on those inputs and outputs, the efficiency performance and productivity of innovation system of China brand automobile could be evaluated. Efficiency performance was measured from the perspective of TE, PTE and SE. Productivity was measured from perspective of Malmquist efficiency value (Malmquist, 1953), comprehensive technical efficiency and technical progress index. (Dong, 2014; Hu & Liang, 2021; Lu & Meng, 2022).

According to the literature review, the determinants of efficiency included: economic development level, degree of openness, foreign direct investment, degree of marketisation, financial support for science and technology, and enterprise scale (Gui, 2014; Yang et al., 2022; Hu & Liang, 2021).

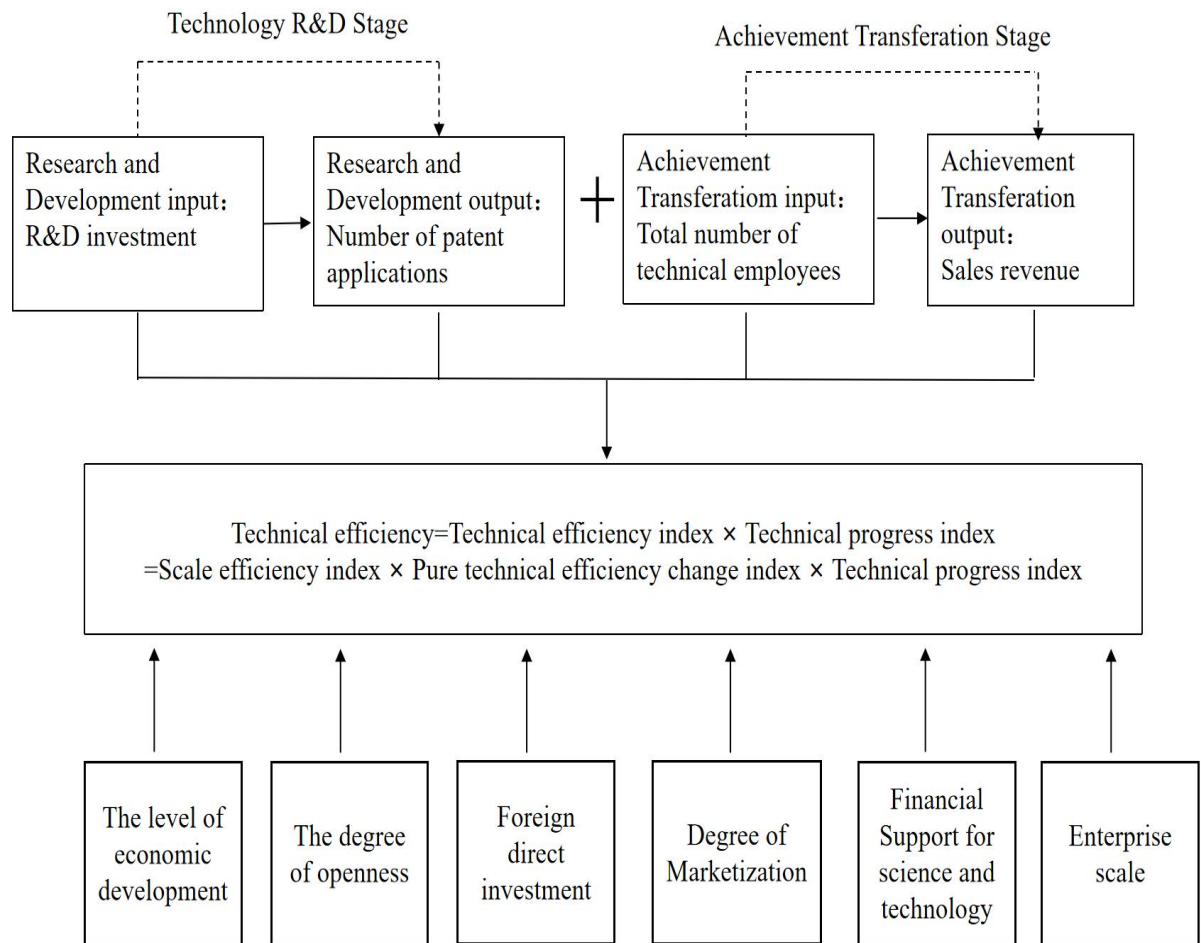


Figure 3.3: Conceptual Framework

Source: Dong et al. (2014); Hu and Liang (2021); Lu and Meng (2022)

3.4 Description of Variables

3.4.1 Input-output Variables of Innovation System Efficiency

In this study, the input-output variables of innovation system efficiency were selected from the perspective of industrial value chain. The industrial innovation process could be divided into the scientific and technological R&D stage and achievement transformation stage (Hu & Liang, 2021).

(1) Innovation system efficiency input variables

In terms of efficiency investment in innovation systems, it is divided into capital investment and personnel investment. The R&D investment in the technology research and development stage is measured by the amount of R&D investment. The investment of R&D personnel in the achievement transformation stage is measured by the intensity of R&D personnel investment, represented by the number of technical employees (Dong et al., 2014; Zhao et al., 2019).

(2) Innovation system efficiency output variables

The output of the innovation system in the technology research and development stage is mainly reflected in the intermediate output in the industrial research and development innovation process. The number of patent applications in this study is usually used as an important indicator to evaluate the amount of innovation output. Therefore, the study utilised the number of patent applications in the own brand automobile industry to represent it. The output of innovation system during the achievement transformation stage was measured by the sales revenue of the own brand automobile industry (Dong et al., 2014; Zhao et al., 2019).

3.4.2 Determinant Variables of Innovation System Efficiency

Based on the influencing factors of innovation system efficiency in the literature review and referring to a study by Yin (2016), the enterprise technological behaviour, enterprise characteristics and external environment were considered for this study. The specific variables are as follows:

(1) Economic development level (GDP)

Gross Domestic Product (GDP) is the total value of all final products produced in a country or region's economy during a certain period of time (quarterly or yearly) and is the most important indicator reflecting the overall economic situation. GDP can reflect the scale of economic development of a country or region, judge its overall economic strength and the speed of economic development and can also be used for economic structure analysis. It is an important basis for macroeconomic decision-making (Yan et al., 2023). This research selected the regional per capita GDP (nominal) to measure the level of economic development.

(2) Degree of openness (DO)

Market openness refers to the degree of openness (DO) of a country or region to foreign trade and international investment. The degree of market openness reflects the degree in which foreign means of production, such as labour, capital, land and entrepreneurial talent are allowed to exchange within the country. Market openness is inversely proportional to trade costs, with higher trade costs indicating lower market openness. The high level of market openness directly affects the economic vitality and competitiveness of a region. Open markets can provide enterprises with greater business opportunities and customer base and provide a broader stage for innovation. Meanwhile, the increase in market openness also means more intense competition, requiring enterprises to continuously enhance their innovation capabilities to maintain a competitive advantage (Feng et al., 2011). There is a close interrelationship between innovation capability and market openness. This study used the ratio of regional total import and export to GDP to express the degree of trade openness.

(3) Foreign direct investment (FDI)

Foreign direct investment (FDI) reflects the ability of a region to attract foreign capital. Dunning (2008) proposed that the motivations for multinational corporations to make outward FDI included expanding international markets, improving production efficiency (for example, by introducing new technologies) and acquiring resources (including strategic assets). Scholars have also conducted relevant research on the technology reverse spillover effects of FDI in other countries, such as Lee (2010) pointed out that Korean companies have completed technological innovation in the process of outward FDI and some companies have even achieved technological breakthroughs, and thus enhancing their business capabilities. According to a study by Hkatsuka (2018), Japanese companies have absorbed foreign technology and innovation capabilities in high-end manufacturing, electronic information and semiconductors through outward direct investment in developed countries, enhancing the competitiveness of products in these fields internationally. This study selected the proportion of FDI in GDP to express the level of regional FDI.

(4) Degree of marketisation (MAL)

The degree of marketisation (MAL) reflects the level of resource allocation regulated by a regional market. It reflects the market liberalisation. The standard market economy theory holds the idea that the role of market mechanisms can achieve effective allocation of resources for existing (established) production factors (Hong, 2010). The market mechanism determines the allocation and efficiency of independent innovation resources. For enterprises, innovation is both good and costly. The direct motivation for micro subject innovation stems from the scarcity of resources, hoping to replace more scarce resources with general resources to obtain excess profits. In this sense, the

efficiency of independent innovation has always faced two dimensions: “optimal technology” and “minimum cost”. For the micro entities of technological innovation in high-tech industries, the adoption of technology and the way it is adopted depends entirely on the entrepreneur’s judgment of the market and the balance of production factor prices (Dai & Liu, 2013). This research utilised the proportion of employees in non-state-owned enterprises to measure the degree of marketisation in different regions.

(5) Financial support for science and technology (TF)

Government support is an important influencing factor for technological innovation. Innovation led by market entities can easily lead to market failure, requiring government financial support for innovation activities to compensate for externalities and avoid market failures. The most direct way for government finance to support innovation activities is through direct funding allocation, which is reflected in local government’s science and technology expenditures. Local fiscal technology expenditures have an impact on innovation efficiency through two aspects: innovation costs and innovation risks(Fang, 2022). This study selected the proportion of regional government science and technology financial expenditure in GDP to represent TF.

(6) Enterprise scale (SCA)

Schumpeter (1942) was the first to propose the relationship between enterprise size and technological innovation in his book “Capitalism, Socialism and Democracy”. Schumpeter (1942) believed that large-scale enterprises played a crucial role in promoting technological innovation. He pointed out that large-scale enterprises were powerful machines for technological progress and enterprise research and development require strong funding and technological accumulation. Therefore, small and medium-sized

enterprises usually shy away, but large-scale enterprises have obvious advantages. Large scale enterprises can effectively mitigate innovation risks and reduce losses caused by research and development failures through diversification and large-scale R&D innovation. Furthermore, Schumpeter (1942) posited that monopoly was one of the prerequisites for achieving technological innovation. Due to the existence of high monopoly profits, entrepreneurs will continuously increase their research and development innovation. Subsequently, scholars summarised the above viewpoint as the Schumpeter hypothesis, represented as there is a positive correlation between firm size and technological innovation. This research used the ratio of the total industrial output value of regional own brand enterprises to the number of enterprises to measure the scale of enterprises.

To sum up, the input-output variables and determinant variables of innovation system efficiency in this study are shown in Table 3.1.

Table 3.1: Description of Variables

Item	Variable	Measurement Indicators	Citation
Input variables of innovation system's efficiency	Investment in scientific and technological research and development stage	R&D investment	Jin et al. (2023); Dong et al. (2014)
	Input in achievement transformation stage	Total number of technical employees	Jin et al. (2023); Hu & Liang (2021)

Table 3.1 continued

Output Variables of Innovation system's efficiency	Output of scientific and technological research and development stage	Number of patent applications	Dong et al. (2014); Lu & Meng (2022)
	Output of achievement transformation stage	Sales revenue	Li & Zhong (2021); Lu & Meng (2022)
Variables of determinants of innovation system's efficiency	The level of economic development	Regional per capita GDP	Gui (2014); Yan, Mou & Wang (2023)
	The degree of openness	Ratio of total import and export to GDP	Fan et al. (2011); Baumol (2002)
	Foreign direct investment	Proportion of foreign direct investment in GDP	Dunning (2008); Xu & Song (2011)
	Degree of Marketization	Proportion of employees in non- state-owned enterprises	Dai & Liu (2013); Yang et al. (2022)

Table 3.1 continued

	Financial support for science and technology	Proportion of government expenditure on science and technology in GDP	Fang (2022); Jin et al. (2023)
	Enterprise scale	Ratio of total industrial output value to the number of enterprises	Gayle (2001); Rogers (2004); Hu & Liang (2021)

3.5 Development of Hypothesis

The factors that affected the efficiency of innovation efficiency could be divided into external factors and internal factors. Internal factors can be influenced and changed to some extent by various management measures and strategies of the enterprise itself, such as scale of enterprise, R&D input. Social or market factors constitute external factors, which are generally uncontrollable by the enterprise itself, such as market, international, social and other environment. Based on the previous research results and some characteristics of the automotive industry itself, the study proposes the following hypotheses.

H1: GDP positively influences the innovation efficiency performance

Any industrial innovation system takes the region as the carrier and is affected by the level of local economic development. Generally, if the economic development level of a region is higher, on the one hand, it can attract more highly skilled talents and a large amount of funds to invest in industrial scientific and technological innovation. On the other hand, the regions with higher economic development level usually have more own funds to

invest in the development of corresponding industries, which will positively affect the efficiency of industrial innovation system (Yan et al., 2023).

H2: Degree of openness positively influences the innovation efficiency performance

Generally, with the development and improvement of the market, a region with a higher degree of opening to the international market can not only carry out independent R&D and innovation activities through the innovation subjects with certain capital and profit accumulation. However, it also has more exchanges with other international regions, and thus access more foreign high-end knowledge and technology, finally improving the innovation efficiency of local industrial system (Baumol, 2002).

H3: Foreign direct investment positively influences the innovation efficiency performance

On the one hand, the more FDI in a region, the greater the development potential of the region and the higher the level of innovation. On the other hand, FDI can also increase the local capital stock in order for more funds to be invested in the industrial system innovation. At the same time, the more foreign direct investment can also realise local technology spillover, and thus affecting the innovation efficiency of industrial system (Xu & Song, 2011).

H4: Degree of marketisation positively influences the innovation efficiency performance

The degree of marketisation reflects market liberalisation (Cheng & Sun, 2012). The higher the degree of marketisation of a region, whereby it can reduce the distortion of resource allocation, will enable all kinds of innovation elements to be more fully and reasonably allocated according to the relevant information of the market in order to have

an impact on the efficiency of the regional automobile industry innovation system (Dai & Liu, 2013).

H5: Financial support for science and technology positively influences the innovation efficiency performance

The operation of any industrial innovation system is inseparable from the government's support. Financial expenditure on science and technology can reflect the policy tendency of a regional government on industrial development. The government supports the development of industrial innovation system by using funds, and subsequently guides, coordinates and optimises innovation activities through resource allocation to affect the innovation efficiency of the industrial system (Jin et al., 2023).

H6: There is a significant impact between enterprise scale and innovation efficiency performance

The impact of enterprise scale on the innovation efficiency of the industrial system is mainly reflected in two aspects. On the one hand, larger enterprises have stronger available funds and can improve the innovation efficiency by purchasing advanced machinery and equipment and employing more advanced technical talents. When there are more large-scale enterprises in an industrial system, they can affect the innovation efficiency of the whole industrial system through this mechanism (Wakasagi & Koyata, 1997 ; Gayle, 2001). On the other hand, the management of large-scale enterprises is also more difficult. There may be many loopholes in the corresponding innovation management, which may hinder the improvement of innovation efficiency, and thus inhibiting the efficiency of industrial innovation system (Rogers, 2004; Wu, 2006).

3.6 Data Source and Data Processing

3.6.1 Data Source

(1) Data source of input-output data of innovation system efficiency

The data of 24 provinces from 2011 to 2021 in China were selected for analysis. Due to the obvious lack of data in Hong Kong, Macao, Taiwan and Tibet Autonomous Region and some provinces, the data of these regions was eliminated. The data of R&D investment, number of technical employees, patent applications and sales revenue were mainly from the China's automobile industry yearbook, science and technology statistical yearbook, automobile industry database of EPS DATA, industrial industry database and industrial economy database, and statistical yearbook of provinces in China.

(2) Data source of determinants variables of innovation system efficiency

Data on the level of economic development, degree of internationalisation, foreign direct investment, degree of marketisation, financial support for science and technology, enterprise scale was mainly from the yearbook of China's automobile industry, statistical yearbook, statistical yearbook of population and employment and statistical yearbook of provinces and cities in China.

3.6.2 Data Processing

(1) Data processing of innovation system efficiency on input-output

On the one hand, R&D capital investment in the scientific and technological R&D stage was measured by the R&D capital stock in this study. According to previous studies, the perpetual inventory method was used for estimation, which is specifically expressed as: $RD_{i,t} = (1 - d)RD_{i,t-1} + I_{i,t}$. Where, d is depreciation rate, $RD_{i,t}$ and $RD_{i,t-1}$ are capital stock

in year t and year $T-1$, and $I_{i,t}$ is actual R&D expenditure, which is calculated by the nominal R&D expenditure according to 45% fixed asset price index and 55% consumer price index (Zhu & Xu, 2003). The nominal R&D expenditure was measured by the internal expenditure of R&D expenditure in this study. For the estimation of capital stock in the base period, the specific calculation formula is $RD_{i,t} = I_{i,t} / (d + g_i)$, $RD_{i,t}$ is actual R&D expenditure of the province i in year t , and g_i is average growth rate of the actual R&D expenditure from year t to t_1 . On the other hand, appropriate units should be selected for the R&D investment, number of technical employees, number of patent applications and sales revenue.

(2) Data processing of determinants of innovation system efficiency

Some data on the degree of internationalisation and foreign direct investment were converted, mainly the total import and export volume and the US dollar of foreign direct investment were converted according to the central parity of RMB exchange rate every year.

3.6.3 Analysis Tools

In this study, DEAP 2.5 was utilised to measure the efficiency of China brand automobile industry innovation system, including static and dynamic innovation efficiency. Subsequently, Excel was used to show the decomposition results of static and dynamic innovation efficiency in tabular and discounted forms. Furthermore, Stata 15 was utilised to produce a quantitative empirical analysis on the determinants of efficiency of China brand automobile industry's innovation system.

3.7 Chapter Summary

This chapter studies and designs the efficiency, determinants of China brand automobile industry innovation system. Firstly, the study presents the research philosophy, introduces the evaluation method and efficiency of China brand automobile industry's innovation system. Additionally, the study calculates the static and dynamic efficiency using CRS, VRS and Malmquist index, respectively, and subsequently selects and constructs the quantitative empirical model of the determinants of efficiency of China brand automobile industry's innovation system. The Tobit model is selected for quantitative analysis. Secondly, it selects and measures the indicators of input-output measurement of the efficiency of the industrial innovation system, and selects and measures other variables of the empirical model. Other variables include the level of economic development, degree of openness, foreign direct investment, degree of marketisation, scientific and technological financial support and enterprise scale. The research hypothesis is developed accordingly. Then, it presents the data sources used in the empirical process of efficiency measurement and determinants of China brand automobile industry's innovation system. Furthermore, it analyses the intermediate data processing and finally presents the analysis tools used in the quantitative analysis of efficiency measurement and determinants of efficiency performance of China brand automobile industry's innovation system. The efficiency measurement is mainly analysed using DEAP 2.5, whereby the efficiency is presented by Excel. The empirical econometric analysis is mainly analysed by Stata.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Introduction

This chapter presents the descriptive statistics of the variables used in this study, including the input-output variables required to measure efficiency and various influencing factor variables. Based on the measurement results of decomposition terms, this study also shows the results of technical efficiency (TE), pure technical efficiency (PTE) and scale efficiency (SE) of China brand automobile industry innovation system from a static perspective. On this note, this chapter clarifies the changes and rankings of total factor productivity, comprehensive technical efficiency and technical progress index of China brand automobile industry innovation system from a dynamic perspective. This study selects the regional per capita GDP, total import and export, FDI, proportion of non-state-owned enterprise employees, proportion of government scientific and technological fiscal expenditure, ratio of total industrial output value to the number of enterprises and other variables to accurately explore the influencing factors of TE, PTE, SE, total factor productivity, comprehensive technical efficiency and technical progress index. Based on the abovementioned empirical research results, a corresponding summary is made and the underlying policy implications are briefly proposed.

4.2 Descriptive Statistics

Table 4.1 reports the descriptive statistical results of the required variables in terms of mean, standard deviation, minimum, median and maximum values.

Table 4.1: Descriptive Statistics

Variables	Obs.	Mean	S.D	Min	Median	Max
T-EMP	264	33461.152	64757.600	813.000	12077.000	397701.000
R&D	264	26056.084	41845.977	334.890	10302.715	340330.620
PATENT	264	2029.367	1488.293	276.000	1658.000	7724.000
S-REV	264	74569.420	146236.392	1375.090	25271.225	887626.210
PTE	264	0.403	0.201	0.064	0.355	1.000
TE	264	0.339	0.166	0.062	0.303	0.980
SE	264	0.857	0.058	0.732	0.861	0.986
MALM	240	0.801	0.221	0.463	0.758	1.878
EFFCH	240	0.678	0.334	0.087	0.630	1.806
TECH	240	1.410	0.716	0.866	1.202	5.422
GDP	264	10.891	0.455	9.997	10.851	12.339
DO	264	0.255	0.204	0.012	0.169	0.917
FDI	264	0.041	0.023	0.012	0.038	0.158
MAL	264	0.478	0.084	0.256	0.476	0.721
TF	264	0.005	0.003	0.001	0.004	0.020

Table 4.1 continued

SCA	264	2.766	0.072	2.598	2.758	2.950
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Note: TEMP - Total number of technical employees in the enterprise; R&D - Total R&D investment of the enterprise; PATENT - Total number of patent applications by enterprises; S-REV - The sales revenue of the enterprise; PTE - Pure Technical Efficiency; TE - Technical Efficiency; SE - Scale Efficiency; MALM - Malmquist Index; EFFCH - Comprehensive technical efficiency change index; TECH - Technical progress index; GDP - Economic development level; DO - Degree of openness; FDI - Foreign direct investment; MAL - Degree of marketization; TF - Financial support for science and Technology; SCA - Enterprise scale

Focusing on TE, PTE and SE analysis, in terms of mean, the mean of SE was the highest at 0.857. The figure of PTE ranked second at 0.403, while TE was the lowest. In terms of standard deviation, PTE had the highest standard deviation at 0.201, followed by TE at 0.166 and SE was the lowest at 0.058. The results of standard deviation indicated that in PTE, there was the greatest difference between the values of each province and its overall average. In terms of median, the numbers were sorted in descending order, namely SE (0.861), PTE (0.355) and TE (0.303).

From the perspective of input-output indicators of enterprises, there were significant differences in technical employees' absorption and R&D capital investment as well as significant differences in the scale of business revenue. However, the differences in the number of patent applications of enterprises were relatively small. From the changes in efficiency indicators, it could be seen that the deviation of SE and Score-MA from the average level was relatively small, indicating that indicators, such as SE had relatively small changes in each province and year.

Table 4.2 shows the mean and standard deviation of input-output indicators for each province or municipality directly under the central government. Firstly, from the perspective of investment indicators, Guangdong and Shanghai showed that the total number of technical employees exceeded 100,000, Hebei exceeded 50,000 and Anhui,

Hunan, Zhejiang and other provinces showed that the total number exceeded 20,000. In terms of technical employee investment, there were significant differences amongst provinces. Secondly, from the perspective of total R&D investment of enterprises, Shanghai, Chongqing, and Jiangxi had R&D investment exceeding 50 billion yuan, while Guangdong, Guizhou, Hebei and Hubei had R&D investment exceeding 30 billion yuan. From the perspective of total R&D investment of enterprises, there were significant differences in R&D investment amongst provinces, but there was a certain correlation with the investment of technical staff. Looking at the output indicators again, Anhui and Chongqing had a total number of patent applications exceeding 5,000, while Shandong, Hebei, Henan, Hubei, Jiangxi, Liaoning, Tianjin, Zhejiang and other provinces have more than 2,000 applications. From the perspective of corporate revenue, there were four regions with over 100 billion yuan, including Guangdong, Shandong, Shanghai, and Chongqing, and Anhui, Hebei, Henan, Hubei and other regions with over 50 billion yuan. Overall, from the distribution of input-output indicators amongst provinces, there were certain differences, but the input-output indicators had a certain degree of correlation overall.

Table 4.2: Input and Output Variables by Province

Province	Total number of technical employees in the enterprise		Total investment in enterprise research and development funds (Unit: Million yuan)		Total number of enterprise patent applications (Unit: piece)		Enterprise operating income (Unit: Million yuan)	
	Mean	S.D	Mean	S.D	Mean	S.D	Mean	S.D

Table 4.2 continued

Anhui	41991. 091	5149.9 62	24503.8 59	16125.9 26	5114.5 45	487.8 02	68408.6 15	9383. 470
Beijing	11974. 182	2339.4 49	25721.0 42	23598.4 00	1445.1 82	258.1 03	21511.1 75	3959. 357
Fujian	8881.3 64	1275.9 62	4032.48 5	1222.54 9	1664.5 45	310.6 47	29041.7 42	4090. 569
Guangdong	283630 .909	61769. 881	31461.6 15	17440.8 60	1926.3 64	165.6 47	265000. 035	1245 39.28 1
Guangxi	13109. 273	1806.3 51	3300.70 7	742.270	1121.6 36	116.5 10	13849.2 45	1912. 856
Guizhou	7423.4 55	1030.4 12	33081.3 82	43627.2 17	1000.2 73	284.1 24	7168.12 5	1854. 176
Hainan	7357.9 09	2921.2 55	1983.61 9	1098.70 6	945.45 5	230.2 85	8262.98 3	4372. 530
Hebei	74212. 000	10534. 101	43297.0 60	39107.4 92	2122.8 18	143.6 74	90232.7 06	3084 5.116
Henan	16013. 000	4332.3 00	9510.80 9	1521.75 7	2530.3 64	210.8 39	64783.4 94	2017 0.333

Table 4.2 continued

Heilongji ang	10882. 818	3549.6 17	2965.42 3	1758.94 8	1121.7 27	353.5 96	19343.4 42	6946 .965
Hubei	3268.8 18	789.37 4	30310.5 96	25828.1 48	2327.1 82	228.5 97	54951.2 08	8149 .357
Hunan	2136.0 91	1093.8 89	3724.56 2	1238.48 2	739.54 5	209.8 12	8091.06 9	1351 .390
Jilin	10121. 636	5644.7 04	10031.2 76	9035.28 6	826.18 2	89.99 6	47189.6 82	3591 0.61 5
Jiangsu	8190.3 64	1150.9 43	28080.9 42	32259.6 58	838.72 7	92.65 2	6765.05 7	1628 .623
Jiangxi	17193. 182	1676.8 11	50047.3 26	53447.0 86	2161.1 82	444.0 43	32771.6 19	6522 .528
Liaoning	10402. 909	2295.8 73	3660.15 4	1126.37 8	2870.9 09	150.1 92	22240.5 48	5351 .318
Shandong	11373. 818	1840.4 24	23519.3 15	5268.70 6	4279.7 27	441.3 60	107328. 999	3435 1.01 6
Shanxi	5652.6 36	2767.8 87	4405.44 6	1440.94 4	537.18 2	117.8 19	9518.54 5	1902 .635

Table 4.2 continued

Shaanxi	12403. 273	1456.7 46	28560.1 81	32119.0 79	357.36 4	101.1 33	6768.83 3	2067. 063
Shanghai	15880 7.727	80045. 143	100447. 220	79859.9 40	1192.2 73	281.2 92	687662. 541	15053 9.766
Sichuan	9309.5 45	4824.7 96	11484.6 20	1429.43 5	1819.0 00	454.2 43	31594.0 82	3424. 490
Tianjin	14750. 455	2043.7 05	29201.8 90	36612.6 95	2533.5 45	241.0 78	17840.9 88	4146. 761
Zhejiang	44474. 000	15165. 320	24735.4 63	17798.0 09	2762.0 91	297.8 62	16124.1 29	3169. 376
Chongqing	19507. 182	1955.4 27	97279.0 31	101073. 102	6467.0 00	788.6 08	153217. 208	22784 .762

4.3 Efficiency Performance of China Brand Automobile Industry

Based on the measurement results of various decomposition items for the efficiency of China brand automobile industry's innovation system, this section explores the changes and rankings of TE, PTE and SE of China brand automobile industry's innovation system. Furthermore, it clarifies the shortcomings and potential for improvement in the efficiency of the own brand automobile industry innovation system.

4.3.1 Technical Efficiency

Figure 4.1 shows the evolution trend of technical efficiency (TE) at the national level. It could be seen that TE at the national level showed no significant upward or downward trend throughout the entire sample inspection period, rising from 0.3129 in 2011 to 0.3738 in 2014, reaching the highest value during the sample period (Figure 4.1). The development of China's automotive market was crucial in 2014, whereby it was a qualitative leap in the development of new energy vehicles in China, with the annual production and sales of new energy vehicles exceeding 300,000 units. The introduction of a series of policies, such as the fuel consumption limits, automobile brand sales management measures and exemption from purchase tax for new energy vehicles are closely related to automotive companies. These policies have to some extent affected the direction of the development of China's automotive industry and may lead the industry into a new stage. A series of policies promoted and applied new energy vehicles in government agencies and public institutions at all levels in accordance with the principles of unified deployment, tailored measures, classified promotion and gradual promotion. These gradually improve the relevant policies and supporting facilities, continuously expand the scale of application, promote technological progress and optimisation upgrading of the new energy vehicle industry. Furthermore, promoting the development of energy conservation and environmental protection industries, and preventing and controlling air pollution, strengthening the construction of ecological civilisation. After 2014, the fluctuation decreased to 0.3811 in 2021, with an average annual growth rate of about 0.003058.

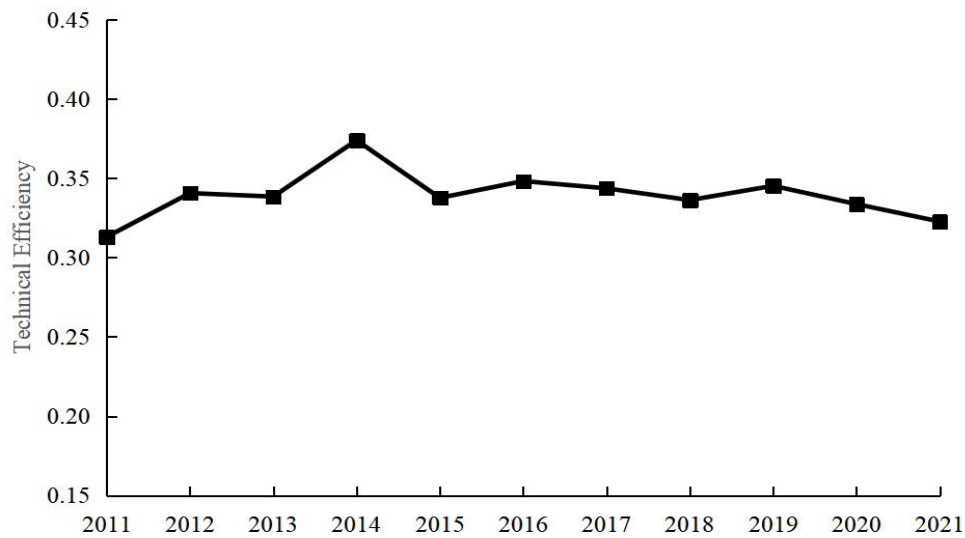


Figure 4.1: The Evolution Trend of Technical Efficiency of China Brand Automobile Industry's Innovation System

In summary, it was noted that during the sample review period, TE of the innovation system of China brand automobile industry did not show a significant sustained growth trend throughout the entire sample period. However, it showed an upward and downward trend in fluctuations. After reaching its peak of 0.3738 in 2014, it dropped to 0.3375 in 2015, and the fluctuations had relatively stable thereafter. This may be due to various factors, such as fluctuations in technology investment, changes in market competition and adjustments in policy environment affecting China. Generally, although some progress has been made by China brand automobile enterprises, TE of the innovation system of the national own brand automobile industry has not yet stabilised.

Appendix A presents the measurement results of TE of the own brand automobile industry innovation system in different provinces of China. It could be seen that TE of provinces, such as Shanghai, Liaoning, Shandong, Fujian, Henan, Hainan, etc., showed a significant upward trend, while TE of other provinces has decreased.

Specifically, during the entire sample inspection period, TE of Shanghai's own brand automobile industry innovation system reached 0.8837, ranking first. The TE of Hubei (0.5503), Liaoning (0.4862), Shandong (0.4406), Fujian (0.4121) ranged from 0.4 to 0.6, ranking from 2nd to 5th, respectively. The TE of Hunan (0.3891), Henan (0.3861), Heilongjiang (0.3839), Chongqing (0.3720), Hainan (0.3674), Jilin (0.3500), Guangdong (0.3323) and Sichuan (0.3040) ranged from 0.3 to 0.4, ranking from 6th to 13rd, respectively. The TE of other provinces was lower than 0.3, especially Zhejiang (0.1681) and Shaanxi (0.1031), which were both lower than 0.2, ranking from 23rd and 24th, respectively. Therefore, the most efficient China brand automobile was in Shanghai. Guangdong and Sichuan were in the middle position, while the TE of Shaanxi's own brand automobile was the lowest. In the top ten rankings, there were a relatively small difference in the average TE amongst Hunan, Henan and Heilongjiang. Heilongjiang has a trend of catching up with Henan, while Henan has a trend of catching up with Hunan.

This reflects the diversity and dynamism of the Chinese automotive market. This diversity may be influenced by various factors, such as local policies, economic conditions, market demand, technological progress, etc. This situation could be analysed from three aspects. Firstly, the diversity of this trend indicated that different provinces might face different opportunities and challenges in the development of independent brand automotive industry innovation systems. Therefore, each province needs to formulate suitable development strategies based on its own situation. For example, some provinces may be more suitable to focus on technological research and innovation to enhance the technological content and competitiveness of their products. Other provinces may need to pay more attention to market development and brand building to enhance their product awareness and market share. Secondly, the dynamism of this trend requires provinces to

have a certain degree of flexibility and foresight in formulating and implementing development strategies. With changes in the market and development of technology, the competitive advantages and disadvantages of each province may change. Therefore, each province needs to continuously conduct self-assessment and adjustment to adapt to market changes and seize development opportunities. Finally, at the national level, the government can take a series of measures to promote coordinated development between different provinces. For example, by formulating unified industrial policies and standards, promoting the rational allocation of resources and technological exchange. Furthermore, by strengthening cross-provincial cooperation and communication, sharing resources and experiences as well as by providing financial support and tax incentives and other policy measures, encouraging enterprises to increase their investment in the innovation system of the independent brand automobile industry.

Based on this, provinces with low TE in the innovation system of the main own brand automotive industry in Zhejiang and Shaanxi should focus on strengthening relevant technological support and training to promote the improvement of innovation capacity and competitiveness of the own brand automobile industry.

The average of TE of each province from 2011 to 2013, 2014 to 2016, 2017 to 2019, and 2020 to 2021 is presented in Figure 4.2. It could be seen that the overall trend of each province was basically consistent with Appendix A, but there were some different trends in each province. Shanghai, Shandong, Henan, Hainan, etc., amongst which, had a clear upward trend in TE in these years, while the index of Hubei, Heilongjiang, Beijing, Hebei, Jiangxi, Jiangsu, Zhejiang and Shaanxi had a clear downward trend. The upward and downward trends of the other provinces were not obvious.

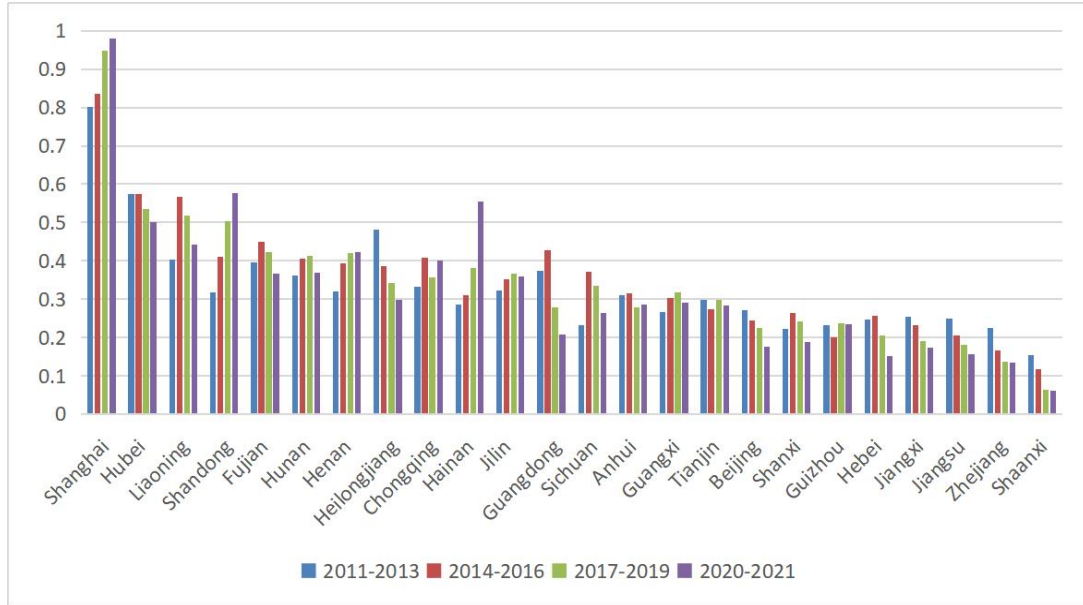


Figure 4.2: Technical Efficiency of China Brand Automobile Industry's Innovation System

4.3.2 Pure Technical Efficiency

Figure 4.3 shows the evolution trend of pure technical efficiency (PTE). It could be viewed that the evolution trend of PTE of China brand automobile industry's innovation system during the entire sample review period was similar to that of TE (Figure 4.3). It showed no significant upward or downward trend, rising from 0.3662 in 2011 to 0.4508 in 2014, reaching the highest value throughout the entire sample period, and subsequently fell back to 0.3811 with an average annual growth rate of about 0.3996%.

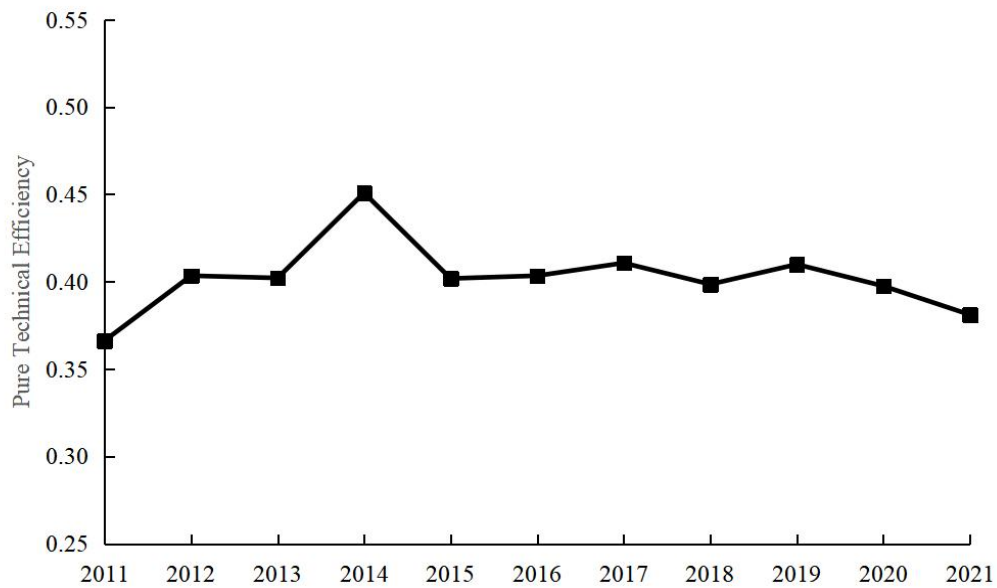


Figure 4.3: The Evolution Trend of Pure Technical Efficiency of China Brand Automobile Industry's Innovation System

In summary, it could be seen that PTE of the innovation system of China brand automobile industry has not shown a significant sustained growth trend. The reason may be that although relevant government departments are gradually paying attention to innovation in the own brand automobile industry, foreign investment has formed a technological monopoly to a high extent in technology introduction, transfer, research and development, including technology transfer restrictions, parts procurement restrictions, research and development cooperation restrictions, talent flow restrictions, etc. This has constrained China's ability to improve core technology research and innovation in the independent brand automobile industry, resulting in slow progress in the research and development of core technologies and improvement of innovation capabilities in China brand automobile industry. Therefore, China has made relatively slow progress in

improving the core technology research and innovation capabilities of the own brand automobile industry.

Appendix B presents the PTE measurement results of the innovation system of China brand automobile industry. As seen from Appendix B, PTE of Shanghai's own brand automobile industry innovation system remained the highest, reaching 0.9073. However, Hubei (0.7348) and Liaoning (0.6335), ranked 2nd and 3rd and had a significant difference in PTE compared to Shanghai. The PTE of Shandong (0.5608), Fujian (0.5128), Hunan (0.4777), Heilongjiang (0.4752), Henan (0.4735), Chongqing (0.4530), Hainan (0.4527), Jilin (0.4226) and Guangdong (0.4021) ranged from 0.4 to 0.6, ranking from 4th to 12th, respectively. The PTE of Sichuan (0.3579), Anhui (0.3481), Guangxi (0.3433), Tianjin (0.3357), Shanxi (0.2684), Beijing (0.2645), Guizhou (0.2527), Hebei (0.2486), Jiangxi (0.2425) and Jiangsu (0.2245) ranged from 0.2 to 0.4, ranking from 13th to 22nd, respectively. The PTE of Zhejiang (0.1841) and Shaanxi (0.1100) was lower than 0.2. In the top ten rankings, the average difference in PTE between Heilongjiang and Henan as well as Chongqing and Hainan was relatively small. Hainan had a trend of catching up with Chongqing.

From the perspective of the evolution trend of PTE by province, during the sample review period, except for regions, such as Shanghai, Fujian, Henan, Chongqing, Hainan, Jilin, Anhui, Tianjin and Shanxi, showed a stable or upward trend in PTE. The other provinces showed a downward trend.

This phenomenon may be influenced by various factors. Firstly, technological innovation and R&D investment. For provinces with no obvious trend or an upward trend, it is mainly due to their increased efforts in technological innovation and R&D investment, which promotes the improvement of PTE. These provinces focus on introducing and

absorbing advanced technologies, strengthening industry university research cooperation and promoting the transformation and application of scientific and technological achievements. Secondly, is the adjustment of industrial structure. With the development of the economy and the adjustment of industrial structure, some provinces may have undergone transformation and upgrading in the automotive industry, optimising resource allocation and technological level, thereby improving PTE. Thirdly, is the policy and institutional environment, whereby government policies and institutions have a significant impact on the development of the automotive industry. Some provinces may have introduced policies that are conducive to innovation and development in the automotive industry, providing a favourable institutional environment and promoting the improvement of PTE. Fourthly, is market competition and openness, which are also important factors affecting PTE. Some provinces have strengthened market competition, attracted more resources and factors to flow in and improved the vitality and competitiveness of industries.

Based on this, high-tech efficient regions, such as Shanghai should continue to support and encourage innovation activities for own brand cars to maintain a leading position. Provinces with a moderate level of efficiency, such as Guangdong and Sichuan should strengthen their investment in technology research and innovation in own brand cars, encourage industrial upgrading and transformation to improve PTE. Low efficiency provinces, such as Zhejiang and Shaanxi should focus on strengthening cooperation with high efficiency province and guide enterprises to strengthen technology introduction and transformation, improve management, thereby effectively improving their research and development capabilities and innovation levels.

The average of PTE of each province from 2011 to 2013, 2014 to 2016, 2017 to 2019, and 2020 to 2021 are shown in Figure 4.4. It showed that the overall trend of each

province was basically consistent with Appendix B, but there were some different trends in each province. Shanghai, Shandong, Hainan, etc., amongst which, had a significant upward trend in PTE in these years, while Hubei, Henan, Shanxi, Guangdong, Anhui, Hebei, Jiangxi, Jiangsu, Zhejiang and Shaanxi had a significant downward trend in PTE. The upward and downward trends of the other provinces were not obvious.

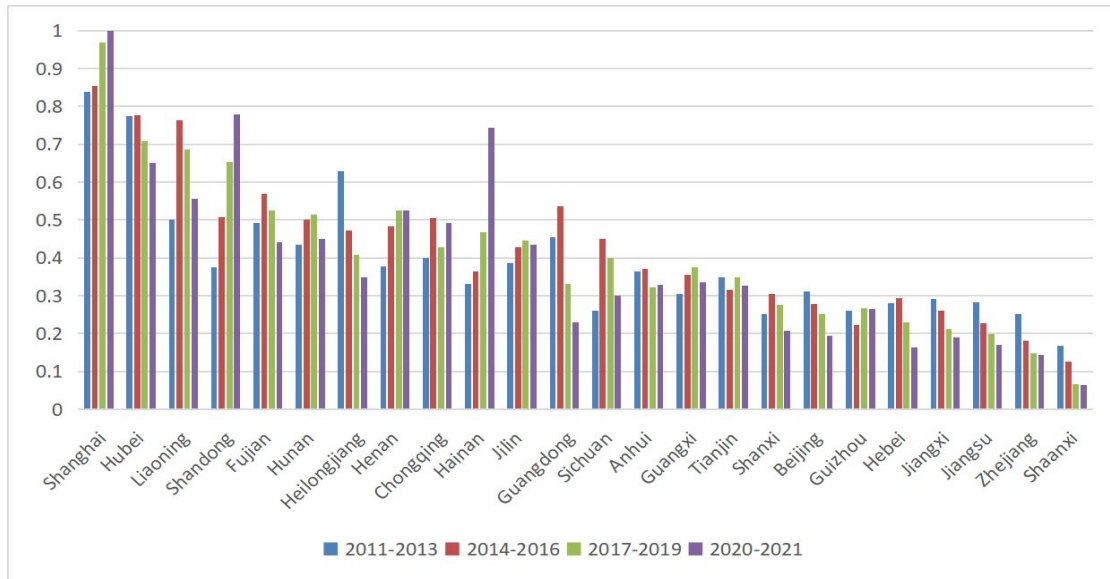


Figure 4.4: Pure Technical Efficiency of China Brand Automobile Industry's Innovation System

4.3.3 Scale Efficiency

Figure 4.5 shows the evolution trend of scale efficiency (SE) of the own brand automobile industry innovation system. It could be seen that compared to TE and PTE, the dynamic trend of SE at the national level was relatively stable throughout the entire sample inspection period, from 0.8665 in 2011 to 0.8668 in 2021 (Figure 4.5). The values of SE during the inspection period were all higher than 0.8, indicating that overall, China's input production factor allocation in the innovation of its own brand automobile industry was close to the optimal combination state.

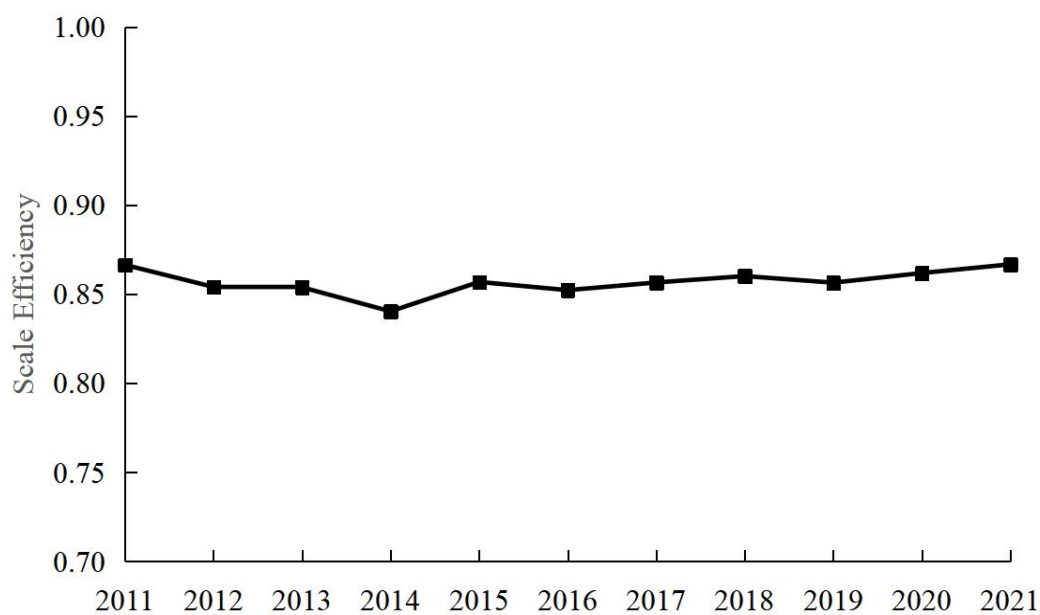


Figure 4.5: The Evolution Trend of Scale Efficiency of China Brand Automobile Industry's Innovation System

The average annual growth rate of SE of the national own brand automobile industry innovation system was about 0.0035%, indicating that SE change of the innovation system was relatively small and basically maintains a relatively stable state.

Appendix C presents the measurement results of SE by province in China. According to Appendix C, overall, there was a small gap in SE of the own brand automobile industry innovation system amongst various provinces in China, with most provinces having SE exceeding 0.8. Shanghai ranked first with the highest SE. The SE of the majority of provinces ranged from 0.8 to 0.9. The efficiency of Guangdong and Sichuan was at an intermediate level, while the efficiency of Shaanxi was low.

Specifically, throughout the entire sample investigation period, except for Jiangsu, Zhejiang and Shaanxi, where SE was 0.7966, 0.7795 and 0.7500, respectively, all other provinces exceeded 0.8. The SE of Shanghai's own brand automobile industry innovation

system reached 0.9734, ranking first, while Hubei (0.9495), Liaoning (0.9184) and Shandong (0.9027) also exceeded 0.9, ranking from 2nd to 4th, respectively. The SE of Fujian (0.8958), Hunan (0.8939), Heilongjiang (0.8917), Henan (0.8880), Chongqing (0.8878), Hainan (0.8624), Jilin (0.8601), Guangdong (0.8583), Sichuan (0.8560), Anhui (0.8440), Guangxi (0.8356), Tianjin (0.8286), Shanxi (0.8258), Beijing (0.8211), Guizhou (0.8196), Hebei (0.8182) and Jiangxi (0.8084) ranged from 0.8 to 0.9, ranking from 5th to 21st. In the top ten rankings, the average difference in scale and technological efficiency between Henan and Chongqing was relatively small and Chongqing tends to catch up with Henan. From the evolution trend of SE by province, it could be seen that during the sample inspection period, the SE of most provinces showed no obvious fluctuation trend.

The SE is an indicator that reflects whether a company has reached the optimal production state at a certain scale and there is no obvious fluctuation trend indicating that the adjustment and optimisation of the company's production scale has not yet reached a stable stage. For provinces with no obvious trend in SE, there are three main reasons. Firstly, industrial scale adjustment. With changes in market demand and competitive landscape, enterprises need to continuously adjust their production scale to adapt to market changes. During this process, there will be no significant trend in SE. Secondly, is technological progress and innovation capability, which are important factors affecting the SE of enterprises. If a company does not make significant breakthroughs in technological innovation and research and development, it may lead to a lack of clear trends in its SE. Thirdly, is the policy and market environment. The government's industrial policies and market environment have a significant impact on the adjustment of enterprise production scale. If there are changes in policy orientation and market environment, enterprises need

to adjust their production scale to adapt to these changes, resulting in a lack of clear trends in SE.

On this basis, the average of SE of each province from 2011 to 2013, 2014 to 2016, 2017 to 2019 and 2020 to 2021 were calculated. As shown in Figure 4.6, the changes in SE of each province were not significant at the average level in different years.

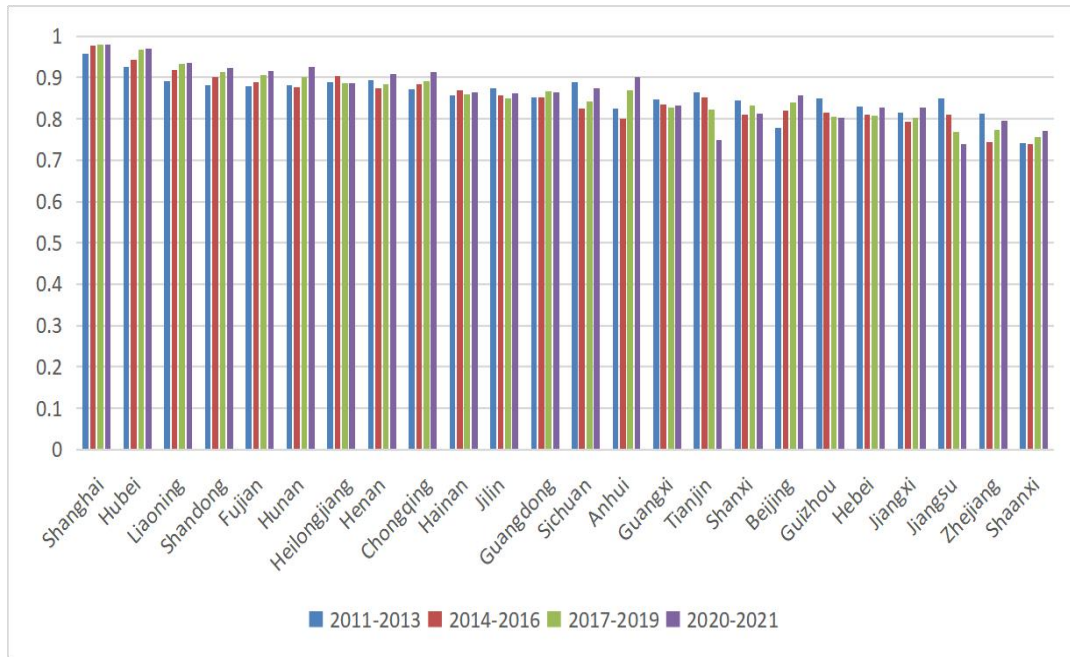


Figure 4.6: Scale Efficiency of China Brand Automobile Industry's Innovation System

4.4 The Productivity of China Brand Automobile Industry

4.4.1 Total Factor Productivity

Figure 4.7 shows the evolution trend of Malmquist total factor productivity (TFP) of the own brand automobile industry. It could be seen from Figure 4.7 that generally from 2012 to 2021, the Malmquist index of total factor productivity of the own brand automobile industry innovation system did not exceed 1.0.

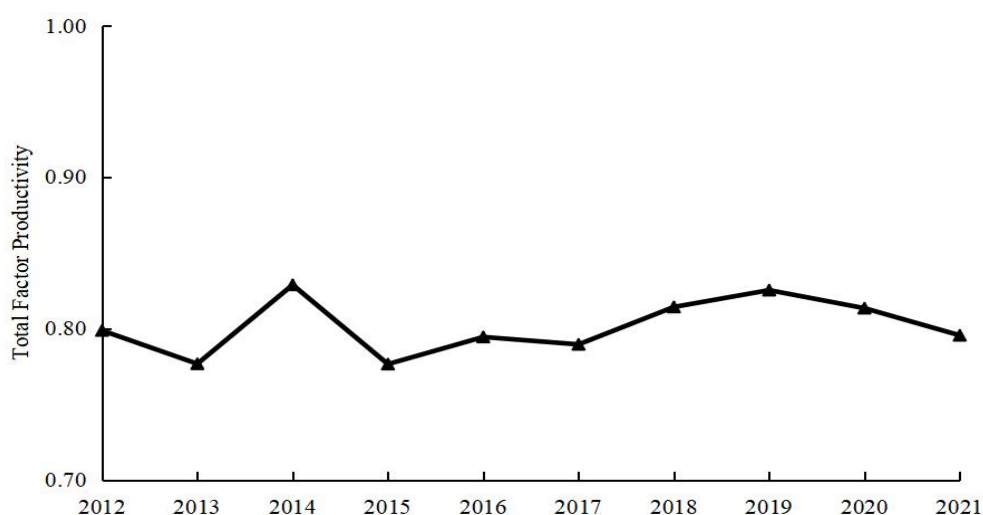


Figure 4.7: Evolution Trend of Total Factor Productivity of China Brand Automobile Industry's Innovation System

Specifically, the total factor productivity of the innovation system fluctuated from 0.7987 in 2012 to 0.7955 in 2021, with an average annual growth rate of about -0.0004%. This showed that the overall productivity growth of the country is relatively slow and the TFP of the innovation system still has a large room for improvement.

Appendix D shows the measurement results of Malmquist total factor productivity of China brand automobile industry's innovation system from 2012 to 2021. Generally, the Malmquist total factor productivity of the innovation system in Hubei, Fujian, Heilongjiang, Guangdong, Anhui, Shanxi, Beijing, Guizhou, Hebei, Jiangxi, Jiangsu, Zhejiang and Shaanxi had declined in the sample period, while the productivity of Shanghai, Shandong, Henan, Chongqing, Hainan, Jilin, Sichuan, Guangxi and Tianjin showed an upward trend. Focusing on the analysis of the mean value in the sample period, it was noted that the Malmquist total factor productivity of Shanghai, Hubei and Liaoning was more than 1.0, and the productivity of other provinces were significantly less than 1.0. This indicated that throughout the entire sample period, productivity of the related own brand automobile industries in Shanghai and Hubei increased rapidly, while the

productivity of related industries in other provinces decreased during that period.

Furthermore, this result is mainly attributed to three reasons. Firstly, is technological innovation and R&D investment. Shanghai and Hubei may have increased their investment in technology research and innovation in the own brand automotive industry, promoting the improvement of productivity. These two provinces placed greater emphasis on introducing and absorbing advanced technologies, strengthening industry university research cooperation, promoting the transformation and application of scientific and technological achievements, and thus improving their technological level and innovation capabilities. Secondly, is the policy and institutional environment. Shanghai and Hubei have introduced policies that are conducive to the innovation and development of the own brand automobile industry, providing a good institutional environment and promoting the development of productivity. For example, the government provides tax incentives, financial support and other policy measures to encourage enterprises to increase investment in technology research and production. Thirdly, is market demand and consumption upgrading. With the development of the economy and increasing demand for automotive quality and performance from consumers, the own brand automotive industry in Shanghai and Hubei has keenly captured market changes, timely adjusted product structure and improved quality, met consumer needs, and thus achieved rapid productivity improvement.

Specifically, TFP of Shanghai's own brand automobile industry innovation system reached 1.2775, ranking first. The TFP of Hubei (1.1232) and Liaoning (1.0491) also exceeded 1.0, ranking 2nd and 3rd, respectively. The TFP of Shandong (0.9727), Fujian (0.9258), Henan (0.8861), Hunan (0.8764), Chongqing (0.8689), Hainan (0.8656), Jilin (0.8361) and Heilongjiang (0.8360) was between 0.8 to 1.0, ranking from 4th to 11th,

respectively. The TFP of Guangdong (0.7912), Sichuan (0.7672), Anhui (0.7465), Guangxi (0.7401), Tianjin (0.7339), Shanxi (0.6714), Beijing (0.6539), Guizhou (0.6480), Hebei (0.6397), Jiangxi (0.6357) and Jiangsu (0.6146) was between 0.6 to 0.8, ranking from 12th to 22nd, respectively. The TFP of the own brand automobile industry innovation system in Zhejiang (0.5744) and Shaanxi (0.4968) was lower than 0.6.

Therefore, Shanghai and Hubei have shown a high Malmquist total factor productivity in terms of the own brand automobile industry, while other provinces, especially Shaanxi, should still optimise the innovative development of the own brand automobile industry by increasing investment, strengthening cooperation and exchange.

Figure 4.8 shows that TFP of Shanghai, Shandong and Hainan increased rapidly in 2017-2019 and 2020-2021, while TFP of Hubei, Fujian, Heilongjiang, Guangdong and Jiangxi declined significantly during the same period.

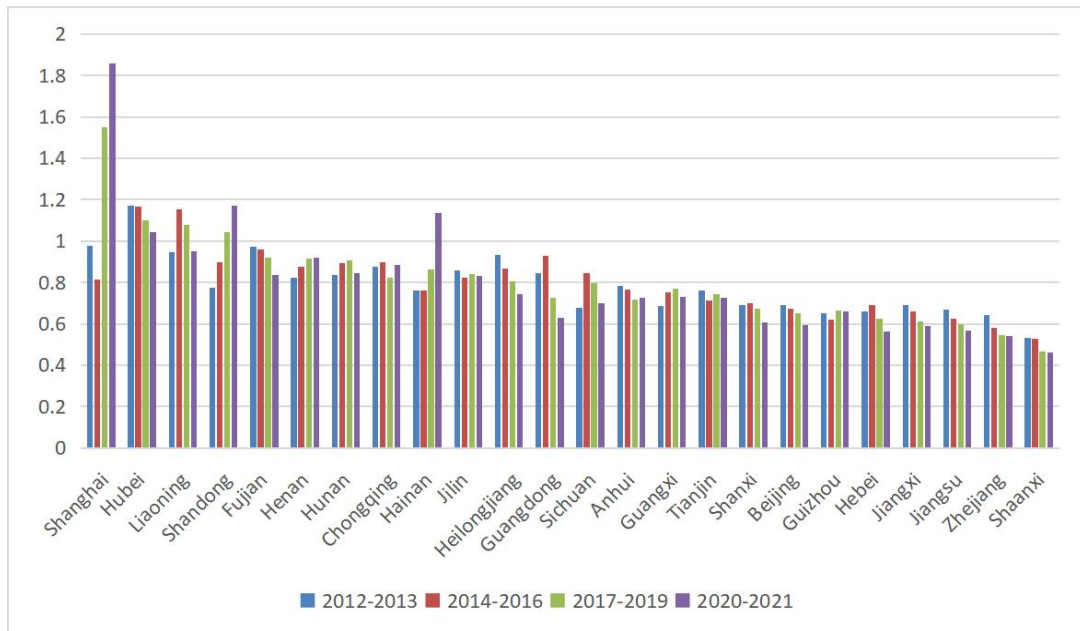


Figure 4.8: Total Factor Productivity of China Brand Automobile Industry's Innovation System

4.4.2 Comprehensive Technical Efficiency

Figure 4.9 shows the evolution trend of comprehensive technical efficiency (TE) in the own brand automobile industry innovation system. It could be seen that the comprehensive TE showed no obvious fluctuation trend throughout the entire sample period, fluctuating from 0.6890 in 2012 to 0.6624 in 2021, with an average annual growth rate of -0.0039% (Figure 4.9). This fluctuation trend indicated that the comprehensive TE has not steadily improved over time. This may be due to factors, such as innovation bottlenecks and insufficient resource utilisation, which affect the improvement of comprehensive TE.

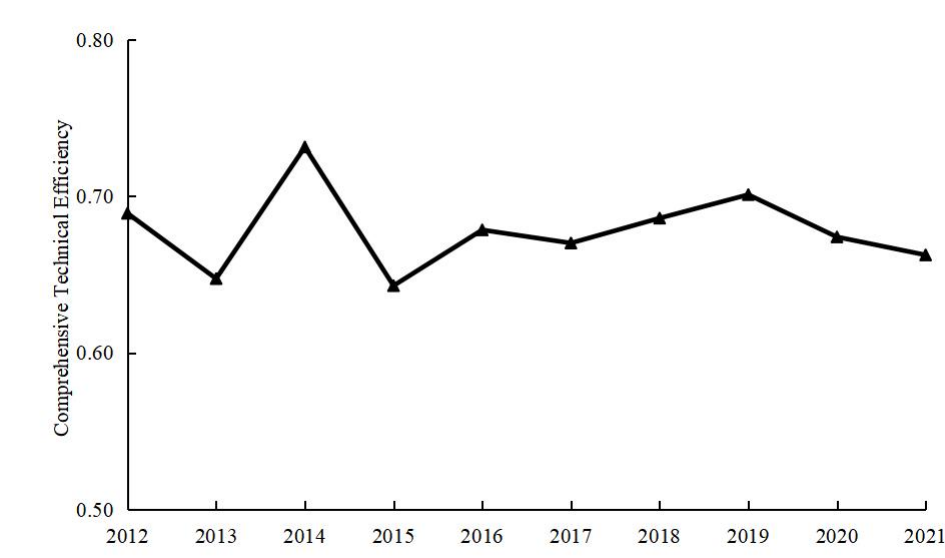


Figure 4.9: Evolution Trend of Comprehensive Technical Efficiency of China Brand Automobile Industry's Innovation System

Based on this, it is necessary to strengthen technical innovation support for the own brand automobile industry, encourage enterprises to strengthen research and development investment, and also strengthen cooperation and exchange with advanced technologies at

home and abroad to promote technology introduction and absorption. This will help improve the comprehensive TE of the own brand automobile industry innovation system.

From a dynamic perspective, Appendix E presents the comprehensive TE measurement results of the provinces own brand automobile industry from 2012 to 2021. On the whole, the changes of comprehensive TE and Malmquist total factor productivity were relatively similar. The comprehensive TE of Hubei, Fujian, Hunan, Heilongjiang, Guangdong, Tianjin, Anhui, Shanxi, Beijing, Hebei, Jiangxi, Jiangsu, Zhejiang and Shaanxi declined during the sample period. However, the comprehensive TE of Shanghai, Shandong, Henan, Chongqing, Hainan, Jilin and Guangxi showed varying degrees of fluctuation and upward trend. Analysing the mean over the sample period, it was noted that only Hubei, Shanghai and Liaoning had a comprehensive TE exceeding 1.0. This indicated that throughout the entire sample period, independent automobile brands in Hubei, Shanghai and Liaoning had significant advantages in technology and resource utilisation compared to other provinces.

This result is mainly attributed to five reasons. Firstly, is being technological innovation and research and development. Hubei, Shanghai and Liaoning invested a large amount of resources in the automotive technology research and development, promoting technological innovation in the own brand cars. These provinces have advanced research and development facilities and excellent technical teams, committed to the research and application of cutting-edge technologies. Secondly, is policy support. The government may provide more support to Hubei, Shanghai and Liaoning in terms of automobile industry policies, encouraging the research and innovation of independent brands. For example, these provinces have enjoyed policy dividends, such as tax incentives and R&D subsidies, allowing more resources to be used for technological upgrades and product development.

Thirdly, is the improvement of the industrial chain. Hubei, Shanghai and Liaoning have a relatively complete automotive industry chain with high efficiency and quality from component manufacturing to vehicle assembly. The integrity of this industrial chain helps to improve resource utilisation efficiency, reduce production costs and enhance the level of technological application. Fourthly, is market orientation. Autonomous car brands in these provinces may pay more attention to market demand, making technological improvements and product upgrades based on consumers' demands. The application of market-oriented technology helps to improve resource utilisation efficiency and makes technology more closely aligned with market demand. The final reason is enterprise cooperation and communication. Automobile companies in Hubei, Shanghai and Liaoning place greater emphasis on cooperation and exchange, promoting technology diffusion and resource sharing through technology sharing, joint research and development, and other means. This cooperation model helps to improve the technological level of the entire industry.

Specifically, the comprehensive TE of Hubei, Shanghai and Liaoning reached 1.2335, 1.2171 and 1.1077, ranking from 1st to 3rd, respectively. The comprehensive TE of Shandong (0.9924), Fujian (0.9045), Henan (0.8541), Hunan (0.8279) and Chongqing (0.8146) ranged from 0.8 to 1.0, ranking from 4th to 8th, respectively. The comprehensive TE of Hainan (0.7979), Jilin (0.7774), Heilongjiang (0.7542), Guangdong (0.6698), Sichuan (0.644) and Guangxi (0.6011) ranged from 0.6 to 0.8, ranking from 9th to 14th, respectively. The comprehensive PTE of Jiangxi, Jiangsu, Zhejiang and Shaanxi was lower than 0.4, especially Shaanxi, which had a comprehensive PTE of only 0.1492.

Based on this, Hubei, Shanghai and Liaoning ranked in the top three in terms of comprehensive TE of the own brand automobile innovation systems. Guangdong and Sichuan were in the middle of the ranking, while Shaanxi had the lowest comprehensive

TE. Therefore, provinces with low efficiency should comprehensively consider support from policies, industrial collaboration, talent cultivation, market promotion, etc., to improve their comprehensive TE and promote innovation and development of the entire industry.

As presented in Figure 4.10, comprehensive TE of regions, such as Shanghai, Shandong and Hainan from 2017 to 2019 and 2020 to 2021 had significantly improved. Whereas the comprehensive TE of provinces, such as Hubei, Fujian, Heilongjiang, Guangdong, Shanxi, Hebei, Jiangxi, Jiangsu and Shaanxi had significantly decreased from 2017 to 2019 and 2020 to 2021.

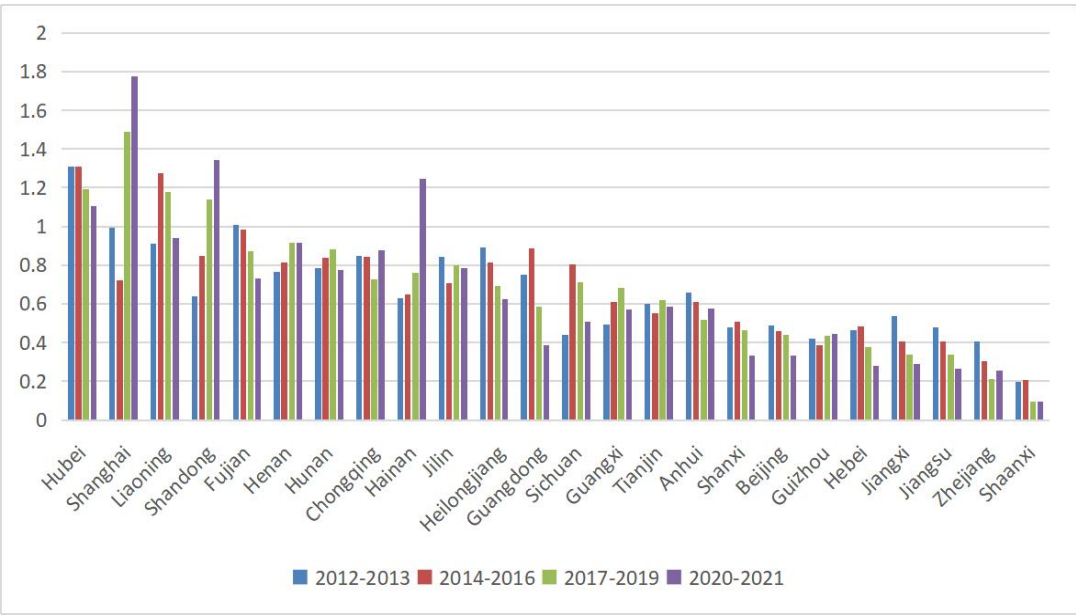


Figure 4.10: Comprehensive Technical Efficiency of China Brand Automobile Industry's Innovation System

4.4.3 Technical Progress Index

Figure 4.11 shows the evolution trend of technical progress index (TECH) of the own brand automotive industry innovation system. It could be seen from Figure 4.11 that

compared with TFP and comprehensive TE of Malmquist, TECH showed an obvious upward trend in the entire sample review period, rising from 1.2584 in 2011 to 1.5274 in 2021.

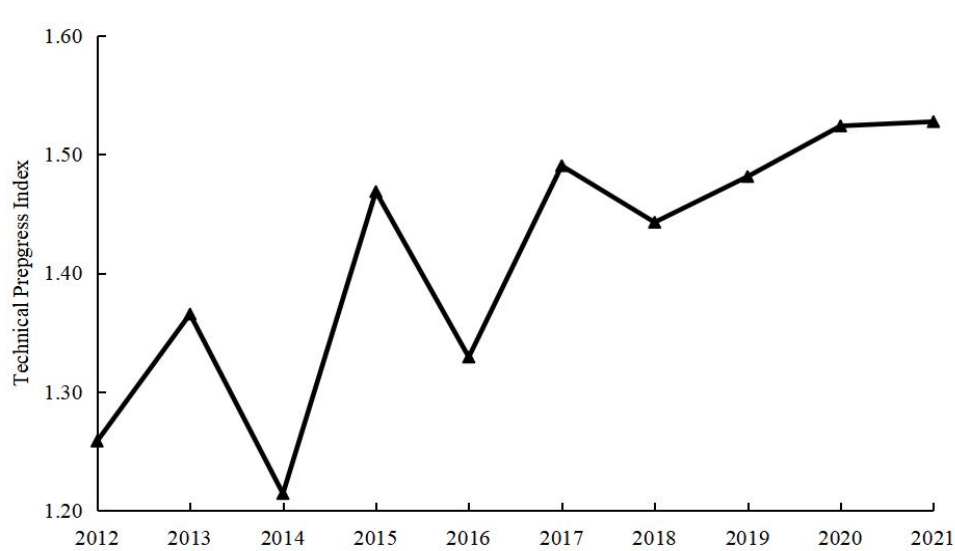


Figure 4.11: Evolution Trend of Technical Progress Index of China Brand Automobile Industry's Innovation System

The TECH during the review period was higher than 1.0, indicating that on the whole, technical progress was the main source of Malmquist total factor productivity of the innovation system. At the same time, the average annual growth rate of TECH of the domestic brand automobile industry innovation system at the national level was about 1.9561%. This indicated that although the technical progress showed a relatively stable growth trend, in the rapidly developing automobile industry today, a slower pace of improvement may also lead to a widening technological gap between the own brand automobile industry and domestic and foreign competitors.

From a dynamic perspective, Appendix F presents the measurement results of TECH of China brand automobile industry innovation system from 2012 to 2021.

Generally, the change of TECH was quite different from that of comprehensive TE and Malmquist total factor productivity. The TECH of Shaanxi, Zhejiang, Jiangsu, Jiangxi, Hebei, Shanxi, Beijing, Guangdong, Sichuan, Heilongjiang, Shanghai, Hunan, Fujian and Hubei showed a significant upward trend of fluctuations, while TECH of other provinces decreased.

Furthermore, by analysing the mean over the sample period, it was noted that throughout the entire sample period, 22 provinces, such as Shaanxi, Zhejiang, Jiangsu, etc., had technology progress indices exceeding 1.0, in terms of the own brand automobile innovation system. This indicated that compared to comprehensive PTE, TECH was the main source of improvement in the Malmquist total factor productivity in most provinces. Additionally, provinces should continue to increase innovation investment, scientific and technological talent cultivation and industry university research cooperation. This is to further promote TECH of the own brand automobile innovation systems in various provinces, and thus improving the Malmquist total factor productivity and accelerating a healthy development of the own brand automobile industry.

Specifically, Shaanxi's TECH was high at 4.0269, ranking first. The TECH of provinces, such as Zhejiang (2.1635), Jiangsu (1.7499), Jiangxi (1.7118), Hebei (1.6504), Shanxi (1.5603), Guizhou (1.5567), Beijing (1.5536), Anhui (1.2852), Guangdong (1.2840), Guangxi (1.2577), Tianjin (1.2523), Sichuan (1.2351), Hainan (1.1337), Heilongjiang (1.1312), Jilin (1.1058), Chongqing (1.0744), Shanghai (1.0720), Hunan (1.0673), Henan (1.0451), Fujian (1.0347) and Shandong (1.0125) also exceeded 1.0. While TECH of Hubei and Liaoning was below 1.0.

Based on this, provinces, such as Shaanxi, Zhejiang and Jiangsu performed

outstandingly in the technical progress of the own brand automobile innovation systems, while the technical progress of Hubei and Liaoning was relatively slow. In response to these provinces with insufficient technical progress, the government departments should learn from provinces with outstanding technical progress for their degree of new technologies or production methods. Meanwhile, they should promote their own technological progress by strengthening scientific research investment and innovation support, encourage enterprises to increase R&D investment and technological upgrading, establish industry university research cooperation platforms and strengthen intellectual property protection.

The average TECH of each province from 2012 to 2013, 2014 to 2016, 2017 to 2019 and 2020 to 2021 was calculated, as shown in Figure 4.12. It could be seen that TECH of Shaanxi was significantly higher than other provinces and TECH of Zhejiang, Jiangsu, Jiangxi, Hebei, Shaanxi and Beijing showed a clear upward trend (Figure 4.12).

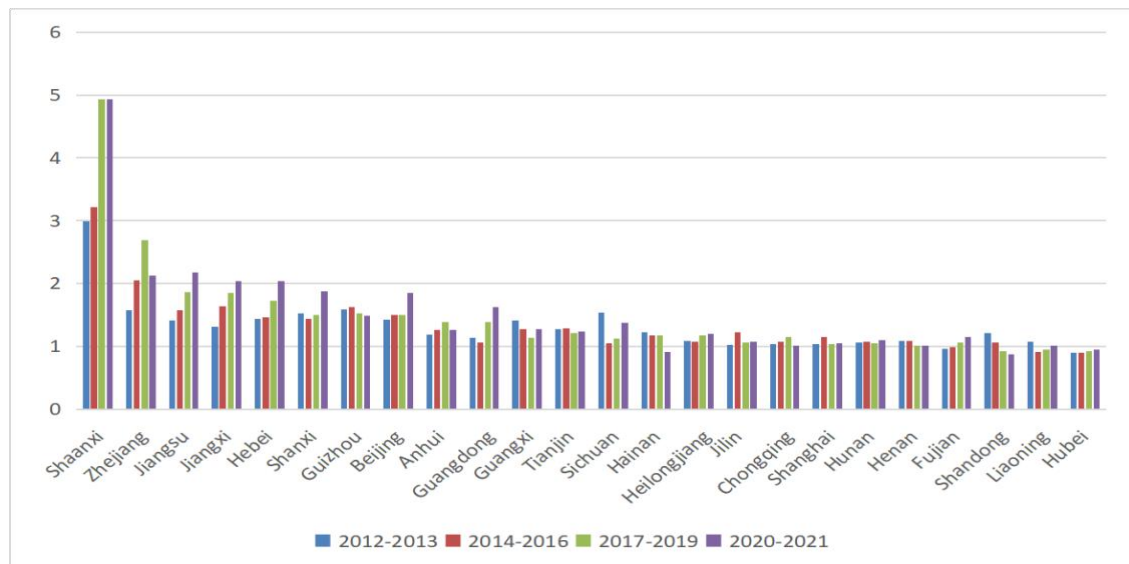


Figure 4.12: Technical Progress Index of China Brand Automobile Industry's Innovation System

4.5 Determinants of Efficiency

This section mainly takes TE, PTE and SE as the dependent variables to explore the impact of factors, such as economic development level (GDP), degree of openness (DO), foreign direct investment (FDI), degree of marketisation (MAL), financial support for science and technology (TF) and enterprise scale (SCA).

Before the regression analysis, the study conducted a likelihood ratio test to demonstrate whether the model construction is significant, and subsequently the Hausman test was performed to compare the results of the random effect model and fixed effect model to identify which one was more effective. Furthermore, a VIF test was performed to test whether the model has multicollinearity problems. The relevant results are shown in Table 4.3 and Table 4.4.

Table 4.3: Diagnostic Results 1

Dependent Variables	Model Test	Statistics	P- Value	Result
Technical Efficiency	Likelihood ratio test	140.62	0.0000	Model is valid
	Hausman test	27.77	0.0001	Fixed-effects models are better than random-effects models

Table 4.3 continued

Pure Technical Efficiency	Likelihood ratio test	109.98	0.0047	Model is valid
	Hausman test	18.71	0.0047	Fixed-effects models are better than random-effects models
Scale Efficiency	Likelihood ratio test	54.35	0.0000	Model is valid
	Hausman test	20.18	0.0173	Fixed-effects models are better than random-effects models

From Table 4.3, it could be seen that the P-values corresponding to the likelihood ratio test in each model were less than 0.01, indicating that each model was reasonable. From the Hausman test, it was noted that the P-values corresponding to the Hausman test were less than 0.05, and the fixed effects model estimation method was superior to the random effects model in each model. The VIF values of each model variable were less than 10, indicating that the model was effective (Table 4.4).

Table 4.4: Diagnostic Results 2

Variable	VIF	1/VIF
gdp	5.57	0.1794
ln_mal	4.23	0.2362
ln_tf	3.39	0.2947
ln_do	2.80	0.3577
ln_fdi	2.00	0.4989
ln_sca	1.35	0.7420
Mean VIF	3.22	

(1) Factors affecting technical efficiency

Table 4.5 presents the regression results of the influencing factors of TE, with columns (1) - (6) showing the regression results of increasing the influencing factor variables in sequence. It could be seen from column (6), the regression coefficients for GDP, Do to the outside world and MAL were significantly positive, while the regression coefficients for enterprise size were significantly negative. This indicated that with the continuous improvement of economic development, opening up to the outside world and marketisation level, it could promote the improvement of TE in the innovation system of the own brand automobile industry and the expansion of SCA will have a negative impact on TE. Specifically, with the development of the economy, opening up to the outside world and increasing level of marketisation, the own brand automobile industry is more likely to obtain more high-quality resources and market opportunities, thereby improving its PTE.

However, as SCA expands, it may lead to increased management complexity, dispersed innovation resources and flattened decision-making levels. Therefore, while expanding the SCA, it is necessary to effectively address these issues to overcome negative impacts and achieve the improvement of their own TE.

Table 4.5: Regression Results of Factors Influencing Technical Efficiency

	(1)	(2)	(3)	(4)	(5)	(6)
Score_CR	Score_CR	Score_CR	Score_CR	Score_CR	Score_CR	Score_CR
S	S	S	S	S	S	S
Score_CR						
S						
gdp	0.038** (2.341)	0.063*** (4.360)	0.062*** (4.383)	0.035* (1.733)	0.011 (0.437)	0.060** (2.343)
ln_do		0.833*** (8.843)	0.626*** (5.933)	0.614*** (5.802)	0.600*** (5.671)	0.600*** (5.898)
ln_fdi			1.077*** (3.742)	1.034*** (3.609)	0.663* (1.882)	0.233 (0.670)
ln_mal				0.349* (1.851)	0.350* (1.868)	0.357** (1.988)
ln_tf					7.387* (1.790)	5.155 (1.292)
ln_sca						-1.660***

Table 4.5 continued

						(-4.523)
_cons	-0.076	-0.527***	-0.510***	-0.350*	-0.104	1.585***
	(-0.420)	(-3.158)	(-3.163)	(-1.918)	(-0.457)	(3.651)
/						
sigma_u	0.147***	0.157***	0.140***	0.142***	0.141***	0.150***
	(6.775)	(6.495)	(6.406)	(6.385)	(6.364)	(6.447)
sigma_e	0.066***	0.056***	0.055***	0.055***	0.055***	0.052***
	(21.900)	(21.788)	(21.761)	(21.751)	(21.743)	(21.768)
N	264	264	264	264	264	264

t statistics in parentheses

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

(2) Factors affecting pure technical efficiency

Table 4.6 presents the regression results of the influencing factors on PTE, with columns (1) - (6) showing the regression results of increasing the influencing factor variables in sequence. As shown in column (6), the regression coefficients of GDP, DO to the outside world and MAL were positive and passed the significance level test to varying degrees. This indicated that with the continuous improvement of economic development, opening up to the outside world and marketisation level, it can promote the improvement of PTE in the innovation system of the own brand automobile industry. Firstly, with the growth of the economy, purchasing power will correspondingly increase and the demand

for automobiles will increase. This provides more sales opportunities and returns for enterprises, and thus promoting them to increase technological investment and strengthen innovation, research and development. Secondly, the continuous improvement of openness to the outside world has enabled relevant own brand automobile enterprises to obtain more international technological resources and cooperation opportunities. At the same time, it has also brought about more intense market competition, and thus promoting relevant enterprises to strengthen their innovation capabilities and achieve PTE improvement. Finally, the improvement of marketisation level provides a relatively fair market environment for the independent brand automotive industry. Through a certain degree of market-oriented mechanism guidance and incentives, enterprises will pay more attention to improving PTE to gain market share and competitive advantage.

Table 4.6: Regression Results of Factors Influencing Pure Technical Efficiency

	(1)	(2)	(3)	(4)	(5)	(6)
Score_VR	Score_VR	Score_VR	Score_VR	Score_VR	Score_VR	Score_VR
S	S	S	S	S	S	S
Score_VR						
S						
gdp	0.052** (2.262)	0.082*** (3.905)	0.079*** (3.846)	0.045 (1.536)	0.008 (0.236)	0.069* (1.823)
ln_do		1.099*** (7.892)	0.824*** (5.198)	0.810*** (5.088)	0.793*** (4.984)	0.795*** (5.163)
ln_fdi			1.374***	1.316***	0.744	0.214

Table 4.6 continued

			(3.259)	(3.131)	(1.442)	(0.414)
ln_mal				0.447	0.450*	0.456*
				(1.631)	(1.656)	(1.731)
ln_tf					11.227*	8.679
					(1.880)	(1.486)
ln_sca						-2.033***
						(-3.785)
_cons	-0.162	-0.727***	-0.692***	-0.489*	-0.118	1.952***
	(-0.641)	(-3.001)	(-2.930)	(-1.830)	(-0.356)	(3.069)
/						
sigma_u	0.171***	0.208***	0.182***	0.185***	0.186***	0.193***
	(6.721)	(6.200)	(6.013)	(5.987)	(5.973)	(6.083)
sigma_e	0.094***	0.081***	0.081***	0.080***	0.079***	0.077***
	(21.902)	(21.678)	(21.608)	(21.594)	(21.586)	(21.629)
N	264	264	264	264	264	264

t statistics in parentheses

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

The regression coefficient of the enterprise size was -2.033 and passed the significance level test of 1%, indicating that the expansion of enterprise size will have a

certain negative impact on TE. This may be due to two reasons, on the one hand, the expansion of SCA may lead to difficulties in communication, decision-making and execution, and thereby affecting the efficient operation of the innovation system. On the other hand, after the expansion of SCA, it is necessary to allocate and optimise technology research and development, human resources and investment funds in a reasonable manner. However, in large-scale enterprises, there may be phenomena, such as resource dispersion and complex processes, leading to resource waste related to the innovation system of the own brand automobile industry, leading to a decrease in TE.

In summary, it could be viewed that economic development, opening up to the outside world, and marketisation have a positive impact on TE of the innovation system in the own brand automobile industry, while the expansion of SCA will have a certain negative impact.

(3) Factors affecting scale efficiency

Table 4.7 presents the regression results of the influencing factors of SCA, with columns (1) - (6) showing the regression results of increasing the influencing factor variables in sequence. Focusing on column (6), the regression coefficients for DO and MAL were -0.244 and -0.148, respectively, and both passed the significance level test. This indicated that the continuous improvement of openness and marketisation will have a certain negative impact on the efficiency of the innovation system of the own brand automobile industry. This is because with the opening up of the international market and improvement of marketisation, more competitors will emerge in the regional markets, causing the own brand automobile industry to face more competitive pressure in the market. This can lead to the own brand automobile industry paying more attention to short-

term profit and market share competition. At the same time, when facing more competitors, it may also lead to the dispersion of related resources and the complexity of management, resulting in a decrease in the investment ability of the own brand cars for long-term innovation and technological improvement. Therefore, although the increase in openness and marketisation may have a positive impact on other aspects of the own brand automobile industry innovation system, it may have a negative effect on SE.

Table 4.7: Regression Results of Factors Influencing Scale Efficiency

	(1)	(2)	(3)	(4)	(5)	(6)
	SE	SE	SE	SE	SE	SE
SE						
gdp	-0.000	-0.011*	-0.011	0.000	0.009	-0.009
	(-0.063)	(-1.687)	(-1.635)	(0.028)	(0.773)	(-0.738)
ln_do		-0.284***	-0.259***	-	-	-
				0.255***	0.254***	0.244***
		(-6.226)	(-4.861)	(-4.793)	(-4.808)	(-4.686)
ln_fdi			-0.118	-0.100	0.034	0.175
			(-0.901)	(-0.765)	(0.210)	(1.064)
ln_mal				-0.147*	-0.148*	-0.148*
				(-1.706)	(-1.722)	(-1.765)
ln_tf					-2.604	-1.789
					(-1.367)	(-0.954)

Table 4.7 continued

ln_sca						0.601***
						(3.506)
_cons	0.862***	1.041***	1.036***	0.970***	0.887***	0.268
	(11.358)	(13.397)	(13.334)	(11.191)	(8.385)	(1.305)
/						
sigma_u	0.051***	0.075***	0.073***	0.074***	0.076***	0.073***
	(6.716)	(6.075)	(5.948)	(5.941)	(5.962)	(5.915)
sigma_e	0.028***	0.025***	0.025***	0.025***	0.025***	0.024***
	(21.901)	(21.615)	(21.559)	(21.554)	(21.563)	(21.542)
N	264	264	264	264	264	264

t statistics in parentheses

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

The regression coefficient of the enterprise size was 0.601 and passed the significance level test of 1%, indicating that the expansion of enterprise size can promote the improvement of SE. This is mainly due to the fact that when a company expands in size, it has more resources, including funds, manpower and technology, which can achieve greater economies of scale in R&D, production and sales. Additionally, large-scale enterprises usually have larger R&D teams and experimental facilities, which can carry out more own brand car research and innovation projects, ultimately promoting the improvement of SE.

In summary, it could be seen that the expansion of SCA has a positive impact on the scale of the innovation system of the own brand automobile industry, while the improvement of openness and marketisation will have a certain negative impact.

4.6 Determinants of Productivity

This section mainly utilises the Malmquist total factor productivity and its decomposition items (comprehensive TE and TECH) as the explanatory variables to explore the extent in which factors, such as economic development level, openness, foreign direct investment, marketisation, scientific and technological financial support and enterprise size affect it.

Before the regression analysis, the study conducted a likelihood ratio test to demonstrate whether the model construction is significant, and subsequently the Hausman test was performed to compare the results of the random effect model and fixed effect model to identify which one was more effective. Additionally, a VIF test was performed to test whether the model has multicollinearity problems. The relevant results are shown in Table 4.8 and Table 4.9.

Table 4.8: Diagnostic Results 1

Dependent Variables	Test	Statistics	P- Value	Result
Total Factor Productivity	Likelihood ratio test	335.73	0.0000	Model is valid
	Hausman test	47.96	0.0000	Fixed-effects models are better than random-effects models
Comprehensive Technical Efficiency	Likelihood ratio test	194.25	0.0000	Model is valid
	Hausman test	36.55	0.0000	Fixed-effects models are better than random-effects models
Technical Progress Index	Likelihood ratio test	31.4	0.0000	Model is valid
	Hausman test	14.91	0.0209	Fixed-effects models are better than random-effects models

Table 4.9: Diagnostic Results 2

Variable	VIF	1/VIF
gdp	5.20	0.1925
ln_mal	4.22	0.2368
ln_tf	3.39	0.2947
ln_do	3.10	0.3228
ln_fdi	2.05	0.4868
ln_sca	1.31	0.7626
Mean VIF	3.21	

From Table 4.8, it could be seen that the P-values corresponding to the likelihood ratio test in each model were less than 0.01, indicating that each model was reasonable. From the Hausman test, it could be reviewed that the P-values corresponding to the Hausman test were less than 0.05, and the fixed effects model estimation method was superior in each of the random effects model. The VIF values of each model variable were less than 10, indicating that the model was effective (Table 4.9).

(1) Factors affecting the total factor productivity

Table 4.10 shows the regression results of influencing factors of Malmquist total factor productivity, whereby columns (1) - (6) are the regression results of increasing influencing factor variables in turn. It could be seen from column (6) that the regression coefficients of GDP, DO, FDI and TF were all positive and passed the significance level

test to varying degrees. This indicated that the improvement of GDP, strengthening of opening-up, rise of FDI and strengthening of TF could provide more market opportunities, technical resources and financial support to comprehensively improve the Malmquist total factor productivity of the own brand automobile industry innovation system. The regression coefficient of SCA was -3.030 and it passed the significance level test of 1%, which indicated that the expansion of SCA will not directly promote productivity growth and may inhibit growth of the Malmquist total factor productivity in the own brand automobile industry innovation system.

Table 4.10: Regression Results of Total Factor Productivity

	(1)	(2)	(3)	(4)	(5)	(6)
Score_M	Score_M	Score_M	Score_M	Score_M	Score_M	Score_M
A	A	A	A	A	A	A
Score_M						
A						
gdp	0.142*** (3.989)	0.195*** (5.959)	0.172*** (6.316)	0.141*** (4.111)	0.093** (2.322)	0.186*** (4.381)
ln_do		1.971*** (8.565)	0.670*** (2.905)	0.665*** (2.880)	0.671*** (2.950)	0.684*** (3.216)
ln_fdi			5.478*** (11.003)	5.380*** (10.818)	4.546*** (7.339)	3.802*** (6.339)

Table 4.10 continued

ln_mal				0.548	0.569	0.543
				(1.545)	(1.627)	(1.638)
ln_tf					15.125**	11.279*
					(2.172)	(1.697)
ln_sca						-3.030***
						(-4.887)
_cons	-0.746*	-1.746***	-1.439***	-1.302***	-0.839**	2.224***
	(-1.915)	(-4.572)	(-4.541)	(-3.960)	(-2.155)	(3.036)
/						
sigma_u	0.165***	0.332***	0.197***	0.205***	0.213***	0.219***
	(6.506)	(5.667)	(4.968)	(4.969)	(5.048)	(5.275)
sigma_e	0.133***	0.106***	0.088***	0.087***	0.085***	0.081***
	(20.785)	(20.269)	(19.851)	(19.844)	(19.896)	(20.044)
N	240	240	240	240	240	240

t statistics in parentheses

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

To sum up, although economic development, opening up, foreign direct investment, scientific and technological financial support and other factors will have a positive impact

on TFP of own brand automobile industry innovation system, the expansion of enterprise size may have a negative impact on productivity growth. In practice, it is necessary to comprehensively consider various factors and reasonably plan and manage the scale of enterprises to achieve the growth of TFP.

(2) Factors Affecting Comprehensive Technical Efficiency

Table 4.11 presents the regression results of the influencing factors of comprehensive TE, with columns (1) - (6) showing the regression results of sequentially increasing the influencing factor variables. It could be analysed from column (6) that the regression coefficients for GDP, DO to the outside world and FDI ranged from 0.1 to 3.7 and passed the significance level test to varying degrees. This indicated that the above factors could have a positive driving effect on comprehensive TE. The regression coefficient of enterprise size was still significantly negative, indicating that the expansion of enterprise size may inhibit the overall TE improvement of the innovation system. Therefore, in response to the regression results of the comprehensive TE, relevant government departments should, on the one hand, vigorously develop the economy. Additionally, at the same time, introduce foreign investment and advance technology, management experience, etc., by reducing market access barriers to promote improvement of comprehensive TE of the innovation system. On the other hand, to effectively avoid the inhibitory effect of SCA expansion on comprehensive TE, the government encourages enterprises to optimise and innovate their internal management mechanisms by formulating relevant policies, helping them optimise their organisational structure, strengthen internal communication and collaboration, and thus achieve the improvement of comprehensive TE.

Table 4.11: Regression Results of Comprehensive Technical Efficiency

	(1)	(2)	(3)	(4)	(5)	(6)
	EFFCH	EFFCH	EFFCH	EFFCH	EFFCH	EFFCH
EFFCH						
gdp	0.138*** (2.756)	0.211*** (4.718)	0.186*** (4.530)	0.148*** (2.829)	0.081 (1.313)	0.183*** (2.736)
ln_do		2.732*** (8.836)	1.356*** (3.989)	1.336*** (3.918)	1.340*** (3.972)	1.313*** (3.994)
ln_fdi			5.694*** (7.510)	5.594*** (7.366)	4.423*** (4.655)	3.643*** (3.840)
ln_mal				0.632 (1.163)	0.657 (1.222)	0.615 (1.174)
ln_tf					21.312** (1.982)	16.831 (1.596)
ln_sca						-3.397*** (-3.460)
_cons	-0.826 (-1.505)	- (-4.235)	- (-3.924)	- (-3.401)	-1.032* (-1.734)	2.434** (2.094)

/

Table 4.11	continued					
sigma_u	0.270***	0.474***	0.333***	0.340***	0.351***	0.350***
	(6.623)	(5.866)	(5.371)	(5.350)	(5.404)	(5.452)
sigma_e	0.182***	0.146***	0.134***	0.133***	0.132***	0.128***
	(20.784)	(20.372)	(20.115)	(20.099)	(20.128)	(20.155)
<i>N</i>	240	240	240	240	240	240

t statistics in parentheses

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

(3) Factors affecting the index of technical progress

Table 4.12 presents the regression results of influencing factors of TECH, with columns (1) - (6) showing the regression results of sequentially increasing the influencing factor variables. The regression results of column (6) were mostly the same as those of Malmquist total factor productivity and comprehensive TE. Only the regression coefficients of openness to the outside world and enterprise size passed the significance level test, with values of -1.118 and 9.488, respectively. This indicated that with the increase of openness to the outside world, it will hinder the improvement of TECH of the own brand automobile industry's innovation system. The expansion of SCA will have a significant driving effect on technical progress. The reason for this phenomenon may be, on the one hand, although the increase in openness to the outside world may lead to the inflow of relevant advanced technology and knowledge, which may make it easier for the own brand automobile enterprises to achieve technical progress. However, excessive reliance on technology introduction can also weaken the motivation for independent innovation in the own brand automobile industry, and thereby inhibiting the improvement

of TECH. On the other hand, with the expansion of SCA, it may bring certain management challenges. However, the expansion of SCA will also be accompanied by higher R&D investment and resource allocation capabilities, which can form a larger innovation team and a more complete R&D system. It will significantly enhance the innovation ability and efficiency of the own brand cars, and thus promote the improvement of TECH.

Table 4.12: Regression Results of Technical Progress Index

	(1)	(2)	(3)	(4)	(5)	(6)
	TECH	TECH	TECH	TECH	TECH	TECH
TECH						
gdp	0.262*** (2.594)	0.255** (2.573)	0.252** (2.548)	0.170 (1.264)	0.280* (1.719)	-0.001 (-0.007)
ln_do		-1.484*** (-2.742)	-1.199* (-1.929)	-1.315** (-2.068)	-1.235* (-1.939)	-1.118* (-1.791)
ln_fdi			-1.714 (-0.914)	-1.820 (-0.970)	-0.082 (-0.035)	2.099 (0.883)
ln_mal				1.277 (0.898)	1.236 (0.870)	1.422 (1.031)
ln_tf					-33.293 (-1.193)	-22.901 (-0.837)
ln_sca						9.488***

Table 4.12 continued

						(3.705)
_cons	-1.451	-1.063	-1.025	-0.602	-1.703	-11.456***
	(-1.306)	(-0.967)	(-0.935)	(-0.505)	(-1.132)	(-3.804)
/						
sigma_u	0.625***	0.592***	0.583***	0.589***	0.584***	0.581***
	(6.679)	(6.675)	(6.642)	(6.633)	(6.625)	(6.612)
sigma_e	0.362***	0.358***	0.358***	0.357***	0.356***	0.345***
	(20.776)	(20.782)	(20.773)	(20.767)	(20.766)	(20.757)
N	240	240	240	240	240	240

t statistics in parentheses

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

In summary, it could be seen that the opening up to the outside world has a negative impact on TECH, while the expansion of SCA will have a significant driving effect.

4.7 Robustness Analysis

In order to further enhance reliability of the conclusions for this study, considering that the outbreak of the COVID-19 pandemic from 2020 to 2021 will have an impact on the production and operation of China's automobile industry, this section carries out the corresponding robustness test by removing the samples from 2020 to 2021. Table 4.13

shows the robustness test results excluding the impact of the COVID-19 pandemic, in which columns (1) - (6) shows the robustness test results with TE, PTE, SE, Malmquist total factor productivity, comprehensive TE and TECH, as the explanatory variables.

Table 4.13: Robustness Analysis

	(1)	(2)	(3)	(4)	(5)	(6)
	Score_VRS	Score_CRS	SE	Score_MA	EFFCH	TECH
main						
gdp	0.160*** (3.488)	0.127*** (4.038)	-0.034 (-1.321)	0.275*** (5.055)	0.310*** (3.504)	-0.051 (-0.213)
ln_do	0.921*** (5.503)	0.683*** (6.155)	- (-4.546)	0.999*** (4.025)	1.567*** (3.906)	-0.988* (-1.795)
			0.264***			
ln_fdi	-0.142 (-0.257)	0.010 (0.026)	0.194 (1.093)	2.925*** (4.443)	2.892*** (2.677)	0.364 (0.129)
ln_mal	0.350** (2.220)	0.264* (1.711)	-0.132* (-1.701)	0.271 (0.737)	0.264 (0.441)	1.079 (0.640)
ln_tf	0.276 (0.044)	-0.475 (-0.109)	0.881 (0.433)	9.060** (2.218)	8.163 (0.675)	-10.142 (-0.309)
ln_sca	-2.623*** (-3.905)	-2.071*** (-4.465)	0.732*** (3.392)	-3.917*** (-4.891)	-4.222*** (-3.243)	9.809*** (2.760)

Table 4.13 continued

<u>_cons</u>	1.810**	1.457**	0.354	2.515**	2.310	-11.233***
	(2.196)	(2.563)	(1.306)	(2.529)	(1.427)	(-2.595)
sigma_u	0.218***	0.166***	0.076***	0.273***	0.391***	0.540***
	(5.949)	(6.308)	(5.648)	(5.114)	(4.995)	(6.382)
sigma_e	0.071***	0.049***	0.023***	0.076***	0.124***	0.365***
	(19.211)	(19.376)	(19.040)	(17.367)	(17.284)	(18.261)
<i>N</i>	216	216	216	192	192	192

t statistics in parentheses

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

U exclude 2020 & 2021

According to Table 4.13, from the perspective of PTE, the regression coefficients for GDP, DO and MAL were still positive and passed the significance level test to varying degrees. The regression coefficient for SCA was -2.623 and passed the 1% significance level test.

From the perspective of TE, the regression coefficients of variables, such as GDP, DO, MAL and enterprise size passed the significance level test, with values of 0.127, 0.683, 0.264 and -2.071, respectively.

From the perspective of SE, the regression coefficients for the DO and MAL were -0.264 and -0.132, respectively and passed the significance level test. However, the

regression coefficient for the size of enterprises was 0.732, which also passed the significance level test.

From the perspective of Malmquist total factor productivity, the regression coefficients of GDP, DO, FDI and TF were positive and passed the significance level test to varying degrees. However, the regression coefficient of enterprise size was significantly negative.

From the perspective of comprehensive TE, the regression coefficients of GDP, Degree of openness and FDI were significantly positive, while the regression coefficient of enterprise size was significantly negative. From the perspective of TECH, the regression coefficients between opening up to the outside world and SCA were -0.988 and 9.809, respectively, and passed the significance level test. The empirical results were basically the same as the previous text, indicating that the empirical results in this section have a certain degree of robustness.

4.8 Discussion on the Results

Research Objective 1: To estimate the efficiency performance of industrial innovation system of China brand automobile.

The empirical results showed that in terms of measurement results, from the provincial level, there were obvious spatial imbalances in the efficiency development of China brand automobile industry's innovation system. The efficiency of the automobile industry innovation system in provinces, such as Shanghai and Hubei was relatively high, while the efficiency in provinces, such as Zhejiang and Shaanxi was relatively low.

Generally, there was no significant upward or downward trend in the overall efficiency, TE and SE of the own brand automobile industry's innovation system. This means that during the inspection period, TE, PTE and SE were relatively stable and did not show significant improvement or deterioration. Therefore, it is still necessary to continue to pay attention to the improvement of technological innovation, R&D investment and production efficiency. By improving the technical level, optimising the production process and improving resource utilisation efficiency, the TE, PTE and SE of the own brand automobile industry's innovation system can be further improved.

The reason for this difference is that there are differences in the economic level, technical strength, policy environment and resource allocation of various regions. In regions with relatively developed economies, the innovation efficiency of the automobile industry is relatively high, while in regions with relatively backward economies, the innovation efficiency of the automobile industry is relatively low.

The imbalance of efficiency in the industrial innovation system of China brand automobiles is supported by previous studies. For example, Lei et al. (2016) proposed a data envelopment analysis evaluation method based on weighted constraints to evaluate the efficiency of China's automotive industry innovation system. They pointed out that there was a significant imbalance in the efficiency of China brand automobile industry's innovation system, mainly due to differences in economic level, technological strength, policy environment, resource allocation and other factors amongst different regions. Li (2020) concluded through empirical analysis that TE and PTE of China brand automobile industry innovation system had significantly improved, but the SE still needs to be improved.

Therefore, different provinces can draw on and learn from each other, strengthen cooperation and exchange and form good experiences and models in technology research and development, innovation management and resource allocation. This includes other aspects that are conducive to the development of the independent brand automotive industry, and thus achieving comprehensive development of the independent brand automotive industry innovation system.

Research Objective 2: To assess the productivity of industrial innovation system of China brand automobile.

From a dynamic perspective, TFP and comprehensive TE were high in Shanghai and Hubei, while provinces, such as Shaanxi and Zhejiang had a high index of technical progress, which indicated that the development of different provinces in the own brand automobile industry's innovation system was quite different. This may be related to their advantages in technology research and development, innovation investment and talent training.

From the overall trend perspective, TFP and comprehensive TE of the own brand automobile industry's innovation system showed no obvious fluctuation trend and did not exceed 1.0, while TECH showed an upward trend and the values were higher than 1.0 throughout the sample period. From the research results, there was no obvious change in TFP and comprehensive TE in the innovation system of China brand automobile industry, which means that the industry has insufficient resources for technological innovation.

The own brand automobile industry needs to invest considerably on human, material and financial resources in technological innovation. If these resources are insufficient, the process of technological innovation will be limited, resulting in an insignificant upward or downward trend of TFP and comprehensive TE. Additionally,

because the traditional fuel vehicles have entered the mature stage, the technical level, management process, resource allocation and other aspects have been relatively stable. Furthermore, the innovation activities have tended to gradual innovation and improvement, and thus TFP and comprehensive TE have no obvious upward or downward trend, while the technical innovation of new energy vehicles mainly occurs in a few regions and manufacturers, and the driving role of the industry is slightly insufficient.

The growth of TFP, comprehensive TE and technical progress in China brand automobile industry is supported by previous studies. Several studies evaluated TFP of China brand automobile industry, indicating that the TFP growth mainly comes from technical progress, while the improvement of TE has a relatively small contribution to TFP growth (Ye et al., 2014). Furthermore, the imbalance in productivity across regions has also been confirmed by an empirical analysis, which shows the significant differences amongst regions in China's automobile industry (Wu, 2011).

This study adopted the Malmquist index method, integrated the micro level data, verified the growth of TFP, comprehensive TE and technical progress of China brand automobile industry, and thus obtained some new research results. Government departments should focus on optimising the comprehensive TE of the innovation system, by improving enterprise management and operational efficiency, strengthening industry collaboration and cooperation, and ultimately promoting the sustainable development of the own brand automobile industry.

Research Objective 3: To investigate the determinants of efficiency performance of China brand automobile industry innovation system.

In terms of influencing factors, from a static perspective, which included GDP, DO to the outside world and MAL could significantly promote the improvement of TE and PTE in the innovation system of the own brand automobile industry. This is because these factors can provide a better economic environment and policy support, promote technological innovation and production technology improvement, and thus improving TE and PTE.

The expansion of SCA had a significant inhibitory effect on the improvement of TE and PTE. This was due to the increase in management costs and complexity of organisational structure caused by the expansion of SCA, which affected the innovation and production efficiency of enterprises.

From the perspective of SE of the innovation system in the own brand automobile industry, DO to the outside world and MAL had a significant negative impact on SE. This was due to the intensification of competition caused by openness and marketisation. To survive and develop in the competition, enterprises will pursue economies of scale, leading to a decrease in SE. Furthermore, the expansion of SCA could play a positive driving role to a certain extent, since the expansion of SCA can improve production efficiency and reduce costs, and thereby improving the SE.

From a dynamic perspective, GDP, DO and FDI could positively promote TFP and comprehensive TE of the innovation system, which indicated that over time, the continuous strengthening and optimisation of these factors could promote the innovation and development of the own brand automobile industry. At the same time, TF could also promote the growth of TFP, indicating that the government support for science and technology can provide a strong guarantee for the innovation and development of the own brand automobile industry. The SCA had a significant negative impact on both, similar to

the reasons from a static perspective. The increase in management costs and complexity of organisational structure caused by the expansion of SCA affected the innovation and production efficiency of the enterprise.

From the perspective of TECH, opening up to the outside world had a significant negative impact on it, which might be due to the greater competition and challenges faced by the domestic market due to opening up, which promoted enterprises to pursue technical progress and more innovation, and thus promoting the improvement of TECH. The expansion of SCA had a significant positive impact on TECH. This may be due to the expansion of SCA that can improve research and development capabilities and technological levels, and thus promoting technical progress. Given the complexity of the regression results, relevant government departments should regularly evaluate the development of the own brand automobile industry innovation system from both static and dynamic perspectives, adjust relevant policies in a timely manner to achieve continuous improvement and enhance the overall competitiveness of the industry.

In previous studies, scholars have used different methods to study the factors that affect efficiency. Wu and Chen (2011) found the production scale had a significant promoting effect on technical progress. As the production scale continues to expand, it tends to form a scale economy, mainly promoting the improvement of production efficiency. Chen (2010) proposed that FDI and R&D mainly promoted the improvement of TFP by acting on TE and also had a promoting effect on technical progress, but the effect was not as significant as that on TE. Fang et al. (2016) used the SFA model to measure and analyse the innovation efficiency of high-tech industries and found that market structure factors had a significant impact on innovation efficiency.

This study considered both internal and external factors in the industry and explored the influencing factors from aspects, such as GDP, DO to the outside world, MAL and SCA. From the static and dynamic perspectives, factors, such as GDP, DO, MAL and the size of enterprises had different degrees of influence on TE, PTE, SE, TFP, comprehensive TE and TECH of the own brand automobile industry's innovation system. The interaction and influence between these factors is a complex process that requires comprehensive consideration and balance to achieve the comprehensive development of the own brand automobile industry's innovation system.

4.9 Chapter Summary

This chapter mainly utilises the DEA-VRS, DEA-CRS method and DEA Malmquist index model to study the innovation efficiency of China brand automobile industry. It calculates TE, PTE, SE, comprehensive TE and TECH. Furthermore, based on various TE indicators, a panel regression model is used to study the innovation efficiency of China brand automobile industry from the perspectives of GDP, DO, FDI, MAL, TF and SCA. The research results mainly support the following conclusions:

In terms of measurement results, at the provincial level, there are obvious spatial imbalances in the efficiency development of China brand automobile industry innovation system.

From a national perspective, there is no significant upward or downward trend in TE, PTE and SE of the own brand automobile industry's innovation system from a static perspective. From a dynamic perspective, TFP and comprehensive TE show no obvious fluctuation trend and did not exceed 1.0, while TECH shows an upward trend and the values are higher than 1.0 throughout the sample period.

In terms of influencing factors, from a static perspective, GDP, DO to the outside world and MAL can significantly promote the improvement of TE and PTE of the innovation system, while the expansion of SCA has a significant inhibitory effect on it. From the perspective of SE of the innovation system, there is a significant negative impact on DO and MAL, while SCA plays a promoting role. From a dynamic perspective, GDP, DO and FDI could positively promote TFP and comprehensive TE. Additionally, TF could promote the growth of TFP. From the perspective of TECH, opening up to the outside world has a significant negative impact on it and SCA plays a positive impact.

CHAPTER 5

CONCLUSION

5.1 Introduction

This chapter mainly summarises and organises the study results, and extracts the main research conclusion. On this basis, this section starts from the perspective of innovation in China brand automobile industry and combines the research conclusion to propose policy implications and recommendations to provide beneficial suggestions for the long-term sustainable development of China brand automobiles. Furthermore, this chapter provides a preliminary exploration of the research limitations and future research directions.

5.2 Summary of the Results

Based on the relevant panel data of 24 provinces or municipalities in Chinese mainland from 2011 to 2021, this study constructs the DEA-VRS, DEA-CRS model and DEA Malmquist model to measure the efficiency change of the own brand automobile industry's innovation system. On this basis, by using a series of measurement models, the study deeply explores the factors that affect the efficiency change of the innovation system. Based on the empirical research, conclusions of the study are as follows:

Firstly, based on relevant measurement results, at the provincial level, the efficiency development of China brand automobile industry innovation system exhibits spatial imbalance characteristics. From a static perspective, regions, such as Shanghai and Hubei have higher levels of efficiency, while provinces, such as Zhejiang and Shaanxi have lower levels of efficiency. From a dynamic perspective, the Malmquist total factor

productivity (TFP) and comprehensive technical efficiency (TE) are still high in regions, such as Shanghai, Hubei and Liaoning, while provinces, such as Shaanxi, Zhejiang and Jiangsu have high technical progress indexes (TECHs). From a static perspective, the technical efficiency (TE), pure technical efficiency (PTE) and scale efficiency (SE) of the innovation system basically shows a relatively stable trend, without any significant improvement or deterioration. From a dynamic perspective, the Malmquist total factor productivity and comprehensive TE of the innovation system also show no obvious fluctuation trend and did not exceed 1.0, while the technical progress index (TECH) shows an upward trend and the values are higher than 1.0 throughout the sample period.

These results can be explained by relevant theories. As to the perspective of spatial imbalance in the efficiency of China brand automotive industry innovation system, the theory of industrial innovation holds that innovation is a systematic process that involves multiple elements and links (Malerba & Breschi, 1997). In the automotive industry, innovation not only includes technological innovation, but also organisational innovation, market innovation and management innovation (Freeman, 1974). These innovative activities require corresponding resource investment and institutional support and there are differences in the conditions and support levels amongst different regions, leading to spatial imbalances in innovation efficiency. The performance evaluation theory emphasises the comprehensive evaluation of the efficiency and effectiveness of an organisation or system (Li, 2008). In the automotive industry, performance evaluation not only focuses on production efficiency, but also on indicators, such as technological progress, product quality and market share. There may be differences in these aspects amongst the automotive companies in different regions, leading to differences in performance evaluation results and spatial imbalance (Lei et al., 2016). Specifically, the spatial

imbalance of China brand automotive industry innovation system is influenced by four factors. The first being the uneven level of economic development between regions, which may result in significant differences in innovation investment, talent reserves and market demand, and thus affecting innovation efficiency. Another factor is the difference in policy support, as different regions have different industrial policies and support levels, which have a positive or negative impact on the innovation activities of automotive enterprises. Additionally, there are differences in the industrial structure and development stages, which leads to different efficiency and effects in technological innovation, market development and industrial chain synergy. The final factor is the difference in resources and environmental conditions, which have an impact on the production, operation and innovation activities of automotive enterprises. For example, factors, such as raw material and component supply, energy and transportation conditions affect a company's production efficiency and innovation capability.

Furthermore, based on the correlation regression results, from a static perspective, the level of economic development (GDP), degree of openness (DO) to the outside world and degree of marketization (MAL) can significantly promote the improvement of TE and PTE of the own brand automobile industry's innovation system, while the expansion of enterprise scale (SCA) has a negative effect on it. The DO and MAL have a significant negative impact on SE, while the expansion of enterprise scale (SCA) can play a positive role to a certain extent. From a dynamic perspective, GDP, DO and FDI can positively promote TFP and comprehensive TE of the own brand automobile industry's innovation system. At the same time, scientific and technological financial support (TF) can also promote the growth of TFP, while SCA has a significant negative impact on both. The

opening up to the outside world and the scale of enterprises have a negative and positive impact on TECH, respectively.

From a static perspective, the level of economic development is usually closely related to technological innovation and resource investment capacity (Lopes, 2021). In an economically developed region, enterprises often have more opportunities to obtain high-quality talent, funding and technical support, which helps to promote TE and PTE improvement of the own brand automobile industry. Therefore, GDP plays a positive role in promoting the development of innovation systems in the own brand automotive industry. The DO to the outside world usually means that enterprises can have access to more external resources and market information, which helps them understand international advanced technologies and development trends, and thereby promoting technological innovation. In regions with a higher DO to the outside world, enterprises are more likely to cooperate and exchange with internationally renowned automotive companies and improve their technological level and innovation capabilities through cooperative research and development, technology introduction and other means (Sun, 2015). Therefore, the DO to the outside world has a positive impact on TE and PTE improvement of the innovation system in the own brand automotive industry. The MAL usually reflects the level of competition environment and market mechanism improvement in a region. In regions with a high MAL, enterprises need to face more intense market competition and diversified market demand, which prompts them to increase investment in technological innovation, improve their own technological level and product competitiveness. Therefore, MAL also has a positive promoting effect on TE and PTE improvement of the innovation system in the independent brand automotive industry (Yang, 2020).

However, the factors affecting SE are more complex. The expansion of SCA may have a negative impact on SE, as large-scale enterprises often face more management and coordination difficulties, which may lead to economies of scale. Therefore, the expansion of SCA has a negative impact on SE of the innovation system in the own brand automotive industry (Xiao, 2014). The DO and MAL have a significant negative impact on SE. This may be due to the intensification of market competition caused by the increase in openness and marketisation to the outside world. Enterprises need to continuously expand their scale to cope with market competition, but at the same time, they also face challenges in management and coordination, leading to a decrease in SE. However, the expansion of SCA can play a positive driving role to a certain extent. Large scale enterprises usually have strong economic strength and resource integration ability, which can better cope with market competition and technological innovation risks and is conducive to improving SE.

From a dynamic perspective, GDP still has a positive impact on the Malmquist TFP and comprehensive TE of the innovation system in the own brand automotive industry. This is because with the continuous development of the economy, enterprises have more resources and capabilities to carry out technological innovation and improve production efficiency, and thus promoting the efficiency and effectiveness of the industrial innovation system. The DO to the outside world and FDI have a positive impact on the Malmquist TFP and comprehensive TE of the innovation system. The improvement of openness to the outside world means that enterprises can better utilise international resources, technology and market information to enhance their innovation capabilities. The FDI provides opportunities for domestic enterprises to learn and catch up through capital and technology transfer. Through cooperation and technological exchange with foreign-funded enterprises, the own brand automobile enterprises can improve their technological level and production

efficiency. The TF has a driving effect on the Malmquist TFP growth of the innovation system. This indicates that the government can provide necessary funding and policy support for enterprises through technological and financial support, incentivizing them to engage in technological innovation and improve production efficiency. The government can support the technological innovation activities of enterprises by establishing special funds for science and technology, providing tax incentives and other measures, and thus promoting the efficiency and effectiveness of the industrial innovation system.

However, from a dynamic perspective, the size of the enterprise has a significant negative impact on the Malmquist TFP and comprehensive TE of the own brand automobile industry's innovation system. This may be because as the scale of the enterprise expands, the difficulty of management and coordination increases, leading to a decrease in production efficiency and innovation capability. Large-scale enterprises need to face more organisational and management challenges, such as resource allocation, internal communication, technological innovation, etc. These problems will constrain the innovation ability and production efficiency improvement of the enterprise. Additionally, DO to the outside world has a negative impact on TECH, while the size of enterprises has a positive impact on it. This may be because the increase in openness to the outside world has led to more intense market competition and technological innovation pressure for enterprises, requiring continuous technological updates and upgrades to maintain a competitive advantage. However, this also leads to fluctuations and uncertainties in the process of technological innovation for enterprises, and thus have a negative impact on TECH. The expansion of SCA provides more resources and capability support for enterprises, which is conducive to sustain technological innovation and improvement of TECH.

Based on the research results, from the perspective of sustainable development of China brand automobile industry, analysis can be presented on three aspects: the development direction of China's automobile industry, orientation of automobile manufacturers and current level of competitiveness.

(1) Development direction of the automotive industry in China

Firstly, is to strengthen the construction of independent brands. Self-owned brands are key in enhancing competitiveness of the automotive industry. China should increase the cultivation and support of self-owned brands, enhance their visibility and reputation and enhance consumer's trust and loyalty to self-owned brands. Secondly, is to promote the development of new energy vehicles. New energy vehicles are the development direction of the future automotive industry. Although the Chinese government has established subsidies for promoting new energy vehicles and providing support for technological innovation, it is still necessary to increase the research and promotion efforts in new energy vehicles, improve their technological level and market share and promote the rapid development of the new energy vehicle industry. Thirdly, is to strengthen international cooperation and exchanges. The Chinese automotive industry should actively engage in international cooperation and exchange, introduce advanced international technology and management experience, and improve its innovation ability and competitiveness.

(2) Automobile manufacturers' orientation

The Chinese automobile manufacturers should focus on three aspects: Firstly, is to strengthen technological innovation and R&D. Automobile manufacturers should increase investment in technology research and innovation, improve their technological level and

innovation capabilities, and continuously launch new products with market competitiveness. Secondly, is to strengthen brand marketing and promotion. Automobile manufacturers should focus on brand marketing and promotion, improve brand awareness and reputation, and enhance consumers' trust and loyalty to the brand. Thirdly, is to strengthen quality management. Automobile manufacturers should focus on quality management, establish a sound quality management system, improve product quality and reliability, and enhance consumers' trust and satisfaction with their products. From the current situation, the technological innovation and R&D of manufacturers, such as BYD and Chery amongst the own brand cars are at a relatively advanced level, with strong development potential.

(3) Competitiveness level

From the current level of competitiveness, the competitiveness of China brand automotive industry is constantly improving, but there are still some challenges and problems. Specifically, this is reflected in two aspects. Firstly, the technical level is relatively low. Compared with internationally renowned automobile brands, there is still a certain gap in the technological level of China brand automobile industry, especially in the field of new energy vehicles. Secondly, the brand awareness and reputation need to be improved. Although the number and variety of China brand cars are constantly increasing, their popularity and reputation in the minds of consumers are relatively low, and it is necessary to strengthen brand marketing and promotion. In the own brand automotive industry, multiple manufacturers are developing towards improving their core technology research and innovation capabilities, with notable examples being BYD, Geely, Great Wall and others. These enterprises have made significant progress in technology research and development, product innovation and market expansion. Taking BYD as an example, the

company has made significant breakthroughs in the field of new energy vehicles in recent years, with core technologies, such as batteries, motors and electronic controls reaching international advanced levels. Geely and Great Wall have also made significant investments in intelligence, networking and electrification, launching multiple new products with market competitiveness.

Additionally, it is worth noting that from both static and dynamic perspectives, most innovation efficiency indicators in China have significantly improved since 2014. This is mainly due to the intensive introduction of multiple policies and standards in the automotive industry in 2014, including policies and standards, such as used car evaluation, used car scrapping standards, new car inspection exemption, new energy vehicle purchase tax exemption and public transportation reform. These policies and standards have been introduced, it has played a good role in promoting the development of China's automobile industry, especially the introduction of policies related to new energy vehicles, which has a significant promoting effect on the development of China brand automobile industry.

5.3 Limitations and Future Research

Based on a review of relevant literature and theories, this study takes China brand automobile industry as the research object and conducts corresponding research on the efficiency of its innovation system. Specifically, on the basis of organising and summarising relevant literature and the development process of China brand automobile industry, this study summarises the current development status of the own brand automobile industry. Based on the constructed input-output indicator system, the DEA-CRS model, DEA-VRS model and DEA-Malmquist index model were constructed to measure the efficiency of the innovation system in different provinces, quantifying the

level of innovation system efficiency in China brand automobile industry and the differences amongst provinces. Furthermore, based on theoretical analysis of the factors that affect the efficiency of the innovation system, this study explores the factors that affect the efficiency of the innovation system of China brand automobile industry by constructing a panel data model. Moreover, based on the research findings of the study, a policy mechanism was constructed to enhance the efficiency of China brand automobile industry innovation system. However, due to the limitations of research level and data integrity, the study still has some shortcomings as follows.

Firstly, in terms of variable selection for the efficiency of the innovation system, due to limitations in data availability, this study uses variables, such as R&D investment and number of technical employees in the enterprise to characterise the input variable selection of the innovation system efficiency. This could lead to the possibility of not accurately focusing on the corporations of China's own brand series. To some extent, it may exaggerate the level of investment, resulting in a lower efficiency value of the measurement. Secondly, in terms of research on influencing factors, due to data acquisition reasons, such as the degree of importance attached by enterprises to technological innovation, etc., some influencing factors have not been studied and the design of alternative variables for some influencing factors needs further improvement. Thirdly, in terms of research nature, this study mainly focuses on macro research, not fully considering the relationship amongst different own brand automobile innovation entities, such as research institutions, teaching institutions, companies and individuals, and the government.

Based on the abovementioned limitations, relevant research should mainly focus on the following aspects in the future.

Firstly, in terms of data acquisition, it is possible to clarify the proportion of the own brand automobile industry in terms of overall R&D capital stock, per capita R&D personnel full-time equivalent, technical transformation expenditure and number of employees based on on-site research and expert interviews to obtain investment data for the own brand automobile industry and improve the accuracy of measurement results. Secondly, to deepen research in the micro field and increase research on the innovation of own brand cars by different innovation entities, such as teaching institutions, research institutions, companies and individuals. This is to adhere to the principle that each innovation entity plays its own role and position in the entire innovation of own brand automobiles, but is interconnected and collaborative with each other. In future research, researchers should design relevant survey questionnaires based on the enterprise's characteristics and conduct first-hand data investigation and collection work within the enterprise, laying the foundation for studying issues related to the innovation of the own brand cars in the enterprise.

5.4 Policy Implication

Research conducted for this study on the efficiency of the innovation system in the own brand automobile industry has practical and theoretical significance, as follows:

5.4.1 Empirical Studies Significance

The contribution of this study towards enriching the empirical studies is twofold: firstly, it enriches the evaluation study on the efficiency of the innovation system in the own brand automobile industry. From existing literature, it could be seen that most of the current literature mainly focuses on exploring the efficiency of innovation systems in new

energy vehicles and there is no literature specifically examining the efficiency level of innovation systems in the own brand automobile industry. On the one hand, from the perspective of the industrial value chain, this study constructs a multiple input and output indicators for the evaluation of efficiency of the own brand automobile innovation system, making the measurement results more accurate, compared to traditional measurement method. As the basic principle of the DEA method is to treat the weights of the input and output indicators of each decision-making unit (DMU) as variables, rather than subjectively determining the index weights, this reduces the risk caused by subjective judgment and makes the evaluation conclusions more scientific and reasonable (Fan, 2023). Considering that DEA is an effective method for measuring the relative efficiency of several systems or departments with the same type of input and output (Fan, 2023), the study measures it under the DEA framework. Additionally, under the DEA framework, this study constructs the DEA-CRS model, DEA-VRS model and DEA Malmquist model for measurement and comparison, respectively. By constructing diversified measurement models, it expands and enriches the evaluation research on the efficiency of innovation systems in the own brand automobile industry.

Secondly, this study enriches theoretical research on the efficiency of innovation systems in the own brand automobile industry. Based on the conceptual model of determining factors, the study starts from the perspectives of external government factors, external market factors and internal enterprise factors, and selects GDP, DO to the outside world, FDI, MAL, TF and SCA as factors that affect the efficiency of the innovation system. Based on the existing research, the study discusses on the potential impact of various factors on the efficiency of the innovation system in the own brand automobile industry. This study not only clarifies the basic logic of various factors affecting the

efficiency of the innovation system, but also lays a solid theoretical foundation for improving the efficiency of the innovation system. It can also theoretically clarify the impact paths of external government factors, external market factors and internal enterprise factors on the efficiency of the innovation system, helping to fill the existing research gaps and providing certain theoretical reference value for other scholars to conduct in-depth research on this topic in the future.

Thirdly, this study enriches empirical research on the factors affecting the efficiency of the innovation system in the own brand automobile industry. The study measures the innovation efficiency of China brand automobile industry from both static and dynamic perspectives. Based on this, a panel regression model is used to comprehensively examine the factors that affect the efficiency of the innovation system. The research process for this study constructs a logical mainline of “efficiency measurement - identification of influencing factors”, constructs a scientific and unified analysis framework and provides rich theoretical support for future related research. This provides a reference framework for future related research and solidifies the theoretical foundation for research on related topics.

5.4.2 Practical Significance

The practical significance of the study is twofold. Firstly, by scientifically measuring the efficiency of the innovation system in the own brand automobile industry, it reveals the current production status and potential for improvement in innovation of China brand automobile industry on the path of high-quality development led by technological innovation. In terms of quantitative evaluation, scientific measurement of the efficiency of the innovation system is conducted to provide a certain scientific basis for grasping the

development status, existing shortcomings and potential improvement of China brand automobile industry. In terms of feature analysis, based on the exploration of efficiency of the innovation system in different provinces, the spatio-temporal characteristics of the innovation system efficiency in different provinces are comprehensively revealed. This provides a fundamental basis for optimising the spatial layout of China brand automobile industry, providing reference for formulating regional differentiation policies to improve the efficiency of the innovation system in the context of high-quality development.

Secondly, benchmarking China's policies and measures to promote brand building and deeply explore various factors that affect the efficiency of the innovation system in the own brand automobile industry. This is done by systematically studying the theoretical mechanisms of various factors that affect the efficiency of the innovation system, aiming to clarify the impact of external government factors, external market factors and internal enterprise factors on the efficiency of the innovation system. Studying various influencing factors, both internally and externally, within an enterprise is both logical and in line with the current reality and trends of economic and policy development. Following the logical mainline of "efficiency measurement - identification of influencing factors", it provides a certain basis for promoting the formulation of policy measures related to the efficiency optimisation of the innovation system of the own brand automobile industry.

5.5 Policy Recommendation

Only by having the own brands can China's automobile industry have sufficient initiative and will no longer be restricted by foreign investment. Based on the above research conclusions, this study mainly proposes relevant policy recommendations from

the aspects of internal improvement and external environment optimisation of the own brand automobile industry, as follows.

5.5.1 Recommendation for Improving Internal Innovation of Enterprises

Firstly, to strengthen technological research and development. Although China brand cars are currently developing rapidly, most of them have achieved market share through lower prices and the majority of them are low-end cars. In the long run, it will become a bottleneck problem that restricts the development of China's automobile industry. Therefore, it is necessary to improve technological research and development.

The 20th National Congress of China's Communist Party Report emphasised the need to gather strength, carry out innovative and leading scientific and technological research, especially the research on key core technologies, which pointed out the direction of China's automobile industry for high-quality development (Xing et al., 2023). Specifically, from the perspective of technology research and development, the enterprise needs to first adhere to the concept of keeping pace with the time, strengthen the leading role of the enterprise leadership and establish a good atmosphere of self-progress required by the enterprise. At the same time, the enterprise should learn from the advanced technology experience, management experience, marketing experience and brand management methods of foreign developed countries' automobile enterprises. Additionally, market segmentation should be done to understand market demand. While clarifying the market positioning of the enterprise, the brand value positioning of the enterprise should be accurately determined. Then, different brand value models should be used to explore different segmented markets to accurately meet the needs of consumers' own value system.

Secondly, to choose the optimal development model and adhere to the path of intensive development. Currently, there are various development models for the construction of own brands, including independent research and development, joint development and design outsourcing. In terms of the development model of independent research and development, it is a difficult and lengthy process that requires a large amount of investment in human, material and financial resources. Considering that independent research and development cannot bring benefits in a short period of time, most local enterprises rarely rely solely on independent research and development for innovation. However, this is something that the country should cross in the development process of the automobile industry. Therefore, large enterprises with strong strength should take the responsibility of independent research and development actively. In terms of the model of joint development, the model refers to the implementation of independent brand building plans in joint ventures, which is most convenient for absorbing advanced automotive technology. However, from the current reality of joint ventures, core technologies are easily controlled by foreign parties. When referring to the development model of design outsourcing, it is a feasible approach for domestic automobile companies that are just in the initial stage, which meets the requirements of international division of labour. Nevertheless, in the long run, it is necessary to master key automotive technologies. In summary, while choosing joint development and design outsourcing, the own brand automobile companies should also focus on increasing the research and development efforts of key technologies. At the same time, own brand enterprises should firmly follow the path of specialisation and division of labour. On the one hand, they should focus on breaking regional blockades and constructing the industrial chain in accordance with the

principle of optimal procurement. On the other hand, to set up parts production group to improve professional benefits.

5.5.2 Recommendations for Optimising External Innovation of Enterprises

Firstly, collaborate to optimise the efficiency of China brand automobile industry's innovation system. Integrate technological innovation into China's regional coordinated development strategy and achieve comprehensive coordination of the efficiency of China brand automobile industry innovation system. China has a vast territory and the resource endowment and development situation vary greatly amongst different regions. The innovation environment of China brand automobile industry under different geographical unit division standards shows significant heterogeneity characteristics. To promote the comprehensive coordination and optimisation of the innovation environment for China's automobile industry, firstly, it is necessary to adapt to local conditions and fully leverage on the regional comparative advantages in market, technology, resources and other aspects when optimising the overall innovation environment in various regions. From a national perspective, improving the level of economic development is the main driving mechanism for effectively improving the efficiency of the innovation system of the own brand automobile industry in various regions. However, China's innovation environment presents significant regional differences. On the basis of clarifying the innovation orientation of the own brand cars, the government at all levels cannot generalise and blindly imitate specific plans. For example, under the division of the three major regions, the eastern and western regions should invest highly skilled talents and a large amount of funds in industrial technological innovation to promote the improvement of the efficiency of the innovation system. When using funds in the central region, attention should be paid to the rationality

of fund allocation, and the transformation and upgrading of industries should be strengthened first to find dynamic economic growth points.

Secondly, optimising and improving the opening up and FDI are the main factors to improve the efficiency of the innovation system of the own brand automobile industry. Therefore, on the one hand, the “introduction” of foreign capital should be supported. The government should serve to build a new system of a higher level of open economy, further improve the laws, regulations and service system of foreign investment, and give enterprises greater autonomy in overseas operation and management, by promoting the formation of a two-way opening-up pattern that organically combines “bringing in” and “going out”. On the other hand, optimising the business environment, regional and main structure of funding sources, reducing the volatility of FDI, and at the same time, establishing a convenient foreign exchange management model for FDI that is suitable for expanding high-level openness.

Thirdly, the advantages of regions with rapidly developing innovation systems in the own brand automobile industry should be considered as great importance and their driving role should be leveraged. According to the calculation results of the study, regions such as Shanghai, Hubei, Liaoning and Shandong have high efficiency and growth in the innovation system of their own brand automobile industry and the development process of their own brand automobile innovation is fast. It is necessary to attach great importance to the regional advantages of these regions, so that they can actively play the role of “leaders” and play an important demonstration and driving role, while maintaining development. Other provinces, especially those with low growth rates, such as Shaanxi should learn and draw on the innovation experience of relevant own brand cars, combine their own actual

situation and carry out targeted innovation and improvement. Attention should be paid to seeking progress, while maintaining stability and not acting too hastily.

5.5.3 Recommendations for the Government to Promote Innovation Efficiency

Firstly, to increase government investment in research and development of the own brand automobile enterprises. The independent innovation of the own brand automobile industry requires a large amount of government investment, especially in areas, such as basic research and theoretical research, which requires government investment to encourage enterprises to innovate independently. From an international perspective, the automobile industry is an important pillar industry and export industry in countries, such as Germany, Japan, the United States and France. The government attaches great importance to the automobile industry, especially since the financial crisis, revitalising the automobile industry has become an important choice for the government of developed country to push their economies out of the crisis. Government investment can help companies diversify innovation costs and reduce innovation risks. Currently, the scale of China brand automobile enterprises is still relatively small and innovation investment is relatively limited. It is even more necessary for the government to provide more support in the field of technological innovation.

In fact, to promote innovation and development in the automobile industry, China has introduced a series of policies from the early launch of the “Ten Cities and Thousand Vehicles” project by the Ministry of Science and Technology to the issuance of the “Double Points” policy by the Ministry of Industry and Information Technology in 2018, and subsequently to the issuance of the “Notice on Issuing the Development Plan for the New Energy Vehicle Industry (2021-2035)” by the State Council. All of these policies

reflect the country's support for innovation and high-quality development of the new energy vehicle industry, mainly through fiscal and technological policies. Fiscal policies can support and guide enterprises in technological updates and expand R&D investment through two main policy tools: fiscal subsidies and tax incentives (Liu, et al., 2023).

Therefore, the government can increase financial investment in taxation, subsidies, innovation incentives and the integration of industry, academia and research. These support the enterprises' independent innovation and research activities through income tax reduction, establishing independent innovation incentive funds and technical personnel incentives to create a favourable policy environment for enterprises to carry out the own brand automobile innovation. At the same time, the government can also provide support for innovative products of enterprises in the market sales, encouraging consumers to purchase innovative products of their own brands through tax incentives, direct subsidies, and others. Additionally, the government procurement can support innovative products and help the own brand automobile enterprises expand the market.

Secondly, to promote the effective integration of industry, academia and research, creating a sound independent innovation system. Strengthening the integration of industry, academia and research is key to promoting independent innovation in enterprises. Currently, the automobile industry has become an important integrated field of modern technological innovation. However, there is still a significant gap between China and the international community in basic research fields, such as new materials and electronic technology. Innovation breakthroughs in these fields require active government's guidance, creating effective cooperation platforms between the industry, academia and research, collaborative innovation and the promotion of the development of related technologies.

It is necessary for the government to coordinate and assist the automotive industry in establishing a joint research and development platform between the industry, academia and research through subsidies, funding support and other means to improve the independent innovation system of the automotive industry. On the one hand, relevant government departments need to attach great importance to the cultivation of innovative talents. To achieve effective cultivation of innovative talents, it is necessary to integrate education, technology and economy into the overall cycle. In this regard, the “National Medium- and Long-Term Science and Technology Development Plan Outline” has clearly stated that it is necessary to fully play the important role of education in the cultivation of innovative talents and organically integrate scientific and technological innovation with talent cultivation. This will encourage research institutes to collaborate with higher education institutions to cultivate research-oriented talents. On the other hand, to further promote cooperation amongst the own brand automobile enterprises, establishing technological innovation alliances, jointly participate in the construction of technological innovation platforms and share innovation achievements. Furthermore, the Chinese government needs to increase support for innovation cooperation platforms, establish special funds, encourage independent innovation of automotive core technology, develop international division of labour cooperation and innovate through independent innovation and introduction, digestion, absorption, and re-innovation, improving the overall technological level of the automotive industry.

Thirdly, to enhance the independent innovation drive of state-owned automobile groups. The improvement of China brand automobile industry independent innovation ability cannot be separated from the efforts of state-owned automobile enterprises. Since the 18th National Congress of China’s Communist Party, the Chinese automobile industry

has stood out in the global automobile industry transformation and repeatedly achieved good results in continuous innovation. In China's automobile industry, state-owned automobile groups occupy a dominant position, receiving a large amount of financial support and policy preferences. However, due to their joint venture route and administrative status, the independent innovation drive of state-owned groups is significantly inferior to that of private automobile enterprises. Leaders of state-owned automobile groups, under greater pressure from quantitative performance evaluations, place greater emphasis on short-term benefits, such as market development and lack of attention to long-term competitiveness enhancement, such as independent innovation. Therefore, it is necessary to improve the incentive mechanism of state-owned automobile enterprises, increase the weight of technological innovation in the performance evaluation of entrepreneurs, protect the technological rights and interests of enterprises and talents, and enhance the independent innovation motivation of state-owned enterprise groups.

5.6 Chapter Summary

This chapter mainly focuses on the conclusion of the study and policy recommendations. Firstly, it summarises the research results, focusing on the accounting and influencing factors of innovation efficiency in China's automobile industry. Based on this, policy recommendations are proposed from both internal and external perspectives and the research implication of the study is proposed from both theoretical and practical perspectives. Additionally, this chapter also analyses the research limitations and future research directions.

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APPENDICES

Appendix A: Technical Efficiency of Performance by Average

Year Province	2011-2013	2014-2016	2017-2019	2020-2021	Mean	Ranking
Shanghai	0.8023	0.8366	0.9481	0.9802	0.8837	1
Hubei	0.5733	0.5750	0.5353	0.5013	0.5503	2
Liaoning	0.4030	0.5674	0.5176	0.4422	0.4862	3
Shandong	0.3188	0.4097	0.5029	0.5762	0.4406	4
Fujian	0.3957	0.4493	0.4221	0.3660	0.4121	5
Hunan	0.3613	0.4065	0.4124	0.3700	0.3891	6
Henan	0.3191	0.3943	0.4210	0.4218	0.3861	7
Heilongjiang	0.4817	0.3858	0.3409	0.2987	0.3839	8
Chongqing	0.3322	0.4085	0.3560	0.4009	0.3720	9
Hainan	0.2857	0.3104	0.3810	0.5551	0.3674	10
Jilin	0.3233	0.3531	0.3670	0.3600	0.3500	11
Guangdong	0.3736	0.4277	0.2793	0.2068	0.3323	12
Sichuan	0.2317	0.3722	0.3356	0.2629	0.3040	13
Anhui	0.3109	0.3146	0.2788	0.2847	0.2984	14
Guangxi	0.2657	0.3025	0.3184	0.2897	0.2945	15

Appendix A continued

Tianjin	0.2987	0.2742	0.2986	0.2833	0.2892	16
Beijing	0.2708	0.2446	0.2242	0.1764	0.2338	17
Shanxi	0.2229	0.2645	0.2430	0.1890	0.2336	18
Guizhou	0.2321	0.2006	0.2364	0.2343	0.2251	19
Hebei	0.2477	0.2565	0.2050	0.1507	0.2208	20
Jiangxi	0.2548	0.2314	0.1918	0.1736	0.2164	21
Jiangsu	0.2491	0.2050	0.1809	0.1567	0.2017	22
Zhejiang	0.2242	0.1662	0.1371	0.1333	0.1681	23
Shaanxi	0.1546	0.1182	0.0641	0.0616	0.1031	24

Appendix B: Pure Technical Efficiency Performance by Average

Year Province	2011-2013	2014-2016	2017-2019	2020-2021	Mean	Ranking
Shanghai	0.8377	0.8546	0.9676	1.0000	0.9073	1
Hubei	0.7742	0.7772	0.7088	0.6509	0.7348	2
Liaoning	0.5016	0.7639	0.6865	0.5562	0.6335	3
Shandong	0.3758	0.5067	0.6539	0.7796	0.5608	4
Fujian	0.4911	0.5685	0.5259	0.4421	0.5128	5
Hunan	0.4355	0.5019	0.5136	0.4509	0.4777	6
Heilongjiang	0.6288	0.4720	0.4093	0.3486	0.4752	7
Henan	0.3783	0.4837	0.5242	0.5248	0.4735	8
Chongqing	0.3995	0.5046	0.4280	0.4932	0.4530	9
Hainan	0.3317	0.3644	0.4679	0.7438	0.4527	10
Jilin	0.3862	0.4277	0.4453	0.4357	0.4226	11
Guangdong	0.4540	0.5357	0.3313	0.2298	0.4021	12
Sichuan	0.2611	0.4513	0.3993	0.3007	0.3579	13
Anhui	0.3651	0.3702	0.3215	0.3294	0.3481	14
Guangxi	0.3045	0.3551	0.3752	0.3361	0.3433	15
Tianjin	0.3484	0.3159	0.3483	0.3275	0.3357	16
Shanxi	0.2524	0.3042	0.2757	0.2082	0.2648	17

Appendix B continued

Beijing	0.3112	0.2778	0.2514	0.1942	0.2645	18
Guizhou	0.2614	0.2222	0.2667	0.2641	0.2527	19
Hebei	0.2813	0.2932	0.2288	0.1627	0.2486	20
Jiangxi	0.2908	0.2605	0.2115	0.1896	0.2425	21
Jiangsu	0.2832	0.2281	0.1986	0.1698	0.2245	22
Zhejiang	0.2515	0.1814	0.1472	0.1426	0.1841	23
Shaanxi	0.1683	0.1264	0.0662	0.0635	0.1100	24

Appendix C: Scale Efficiency of Performance by Average

Year Province	2011-2013	2014-2016	2017-2019	2020-2021	Mean	Ranking
Shanghai	0.9577	0.9783	0.9799	0.9802	0.9734	1
Hubei	0.9248	0.9422	0.9683	0.9695	0.9495	2
Liaoning	0.8921	0.9193	0.9330	0.9349	0.9184	3
Shandong	0.8807	0.9011	0.9123	0.9237	0.9027	4
Fujian	0.8781	0.8888	0.9072	0.9158	0.8958	5
Hunan	0.8813	0.8773	0.9012	0.9266	0.8939	6
Heilongjiang	0.8885	0.9030	0.8865	0.8874	0.8917	7
Henan	0.8930	0.8738	0.8835	0.9085	0.8880	8
Chongqing	0.8707	0.8828	0.8921	0.9146	0.8878	9
Hainan	0.8581	0.8692	0.8582	0.8651	0.8624	10
Jilin	0.8730	0.8566	0.8492	0.8622	0.8601	11
Guangdong	0.8526	0.8510	0.8671	0.8644	0.8583	12
Sichuan	0.8887	0.8254	0.8416	0.8743	0.8560	13
Anhui	0.8249	0.8016	0.8680	0.9002	0.8440	14
Guangxi	0.8476	0.8343	0.8279	0.8311	0.8356	15
Tianjin	0.8641	0.8529	0.8221	0.7490	0.8286	16

Appendix C continued

Shanxi	0.8438	0.8096	0.8326	0.8129	0.8258	17
Beijing	0.7794	0.8196	0.8396	0.8581	0.8211	18
Guizhou	0.8492	0.8158	0.8043	0.8039	0.8196	19
Hebei	0.8303	0.8105	0.8083	0.8268	0.8182	20
Jiangxi	0.8158	0.7922	0.8038	0.8282	0.8084	21
Jiangsu	0.8491	0.8091	0.7696	0.7395	0.7966	22
Zhejiang	0.8126	0.7430	0.7726	0.7951	0.7795	23
Shaanxi	0.7406	0.7399	0.7562	0.7702	0.7500	24

Appendix D: Total Factor Productivity by Average

Year Province	2012-2013	2014-2016	2017-2019	2020-2021	Mean	Ranking
Shanghai	0.9785	0.8159	1.5506	1.8591	1.2775	1
Hubei	1.1718	1.1681	1.0999	1.0423	1.1232	2
Liaoning	0.9463	1.1549	1.0789	0.9486	1.0491	3
Shandong	0.7751	0.8999	1.0453	1.1705	0.9727	4
Fujian	0.9732	0.9609	0.9189	0.8364	0.9258	5
Henan	0.8213	0.8773	0.9172	0.9177	0.8861	6
Hunan	0.8339	0.8952	0.9068	0.8451	0.8764	7
Chongqing	0.8771	0.8979	0.8225	0.8866	0.8689	8
Hainan	0.7602	0.7600	0.8619	1.1350	0.8656	9
Jilin	0.8576	0.8223	0.8396	0.8301	0.8361	10
Heilongjiang	0.9309	0.8658	0.8042	0.7445	0.8360	11
Guangdong	0.8439	0.9286	0.7276	0.6277	0.7912	12
Sichuan	0.6791	0.8454	0.7944	0.6975	0.7672	13

Appendix D continued

Anhui	0.7812	0.7657	0.7179	0.7256	0.7465	14
Guangxi	0.6860	0.7509	0.7707	0.7322	0.7401	15
Tianjin	0.7608	0.7124	0.7442	0.7238	0.7339	16
Shanxi	0.6898	0.7009	0.6729	0.6064	0.6714	17
Beijing	0.6913	0.6749	0.6490	0.5926	0.6539	18
Guizhou	0.6521	0.6203	0.6640	0.6615	0.6480	19
Hebei	0.6618	0.6901	0.6267	0.5615	0.6397	20
Jiangxi	0.6890	0.6580	0.6097	0.5881	0.6357	21
Jiangsu	0.6701	0.6261	0.5970	0.5686	0.6146	22
Zhejiang	0.6408	0.5800	0.5462	0.5417	0.5744	23
Shaanxi	0.5334	0.5256	0.4660	0.4633	0.4968	24

Appendix E: Comprehensive Technical Efficiency by Average

Year Province	2012-2013	2014-2016	2017-2019	2020-2021	Mean	Ranking
Hubei	1.3108	1.3101	1.1906	1.1059	1.2335	1
Shanghai	0.9952	0.7209	1.4883	1.7767	1.2171	2
Liaoning	0.9114	1.2771	1.1795	0.9423	1.1077	3
Shandong	0.6412	0.8475	1.1381	1.3425	0.9924	4
Fujian	1.0094	0.9816	0.8744	0.7294	0.9045	5
Henan	0.7638	0.8124	0.9164	0.9136	0.8541	6
Hunan	0.7868	0.8366	0.8806	0.7768	0.8279	7
Chongqing	0.8476	0.8407	0.7259	0.8757	0.8146	8
Hainan	0.6268	0.6499	0.7620	1.2447	0.7979	9
Jilin	0.8422	0.7076	0.7984	0.7857	0.7774	10
Heilongjiang	0.8894	0.8127	0.6933	0.6224	0.7542	11
Guangdong	0.7514	0.8883	0.5851	0.3875	0.6698	12
Sichuan	0.4421	0.8044	0.7099	0.5063	0.644	13
Guangxi	0.4916	0.6119	0.6819	0.5731	0.6011	14

Appendix E continued

Tianjin	0.5977	0.5537	0.6174	0.5834	0.5875	15
Anhui	0.6603	0.6100	0.5168	0.5734	0.5848	16
Shanxi	0.4805	0.5088	0.4619	0.3311	0.4535	17
Beijing	0.4901	0.4608	0.4397	0.3332	0.4348	18
Guizhou	0.4188	0.3871	0.4371	0.4469	0.4204	19
Hebei	0.4625	0.4826	0.3775	0.2799	0.4065	20
Jiangxi	0.5362	0.4073	0.3368	0.2905	0.3886	21
Jiangsu	0.4776	0.4049	0.3365	0.2648	0.3709	22
Zhejiang	0.4073	0.3038	0.2099	0.2552	0.2866	23
Shaanxi	0.1948	0.2078	0.0969	0.0940	0.1492	24

Appendix F: Technical Progress Index by Average

Year Province	2012-2013	2014-2016	2017-2019	2020-2021	Mean	Ranking
Shaanxi	2.9898	3.2113	4.9320	4.9297	4.0269	1
Zhejiang	1.5761	2.0549	2.6886	2.1263	2.1635	2
Jiangsu	1.4100	1.5755	1.8665	2.1764	1.7499	3
Jiangxi	1.3088	1.6325	1.8434	2.0364	1.7118	4
Hebei	1.4326	1.4595	1.7305	2.0343	1.6504	5
Shanxi	1.5274	1.4300	1.5028	1.8750	1.5603	6
Guizhou	1.5863	1.6232	1.5213	1.4805	1.5567	7
Beijing	1.4248	1.4962	1.4989	1.8507	1.5536	8
Anhui	1.1855	1.2590	1.3904	1.2663	1.2852	9
Guangdong	1.1319	1.0556	1.3897	1.6199	1.2840	10
Guangxi	1.4072	1.2707	1.1320	1.2775	1.2577	11
Tianjin	1.2728	1.2913	1.2073	1.2406	1.2523	12

Appendix F continued

Sichuan	1.5361	1.0522	1.1220	1.3781	1.2351	13
Hainan	1.2274	1.1736	1.1787	0.9127	1.1337	14
Heilongjiang	1.0855	1.0707	1.1758	1.2007	1.1312	15
Jilin	1.0183	1.2268	1.0640	1.0743	1.1058	16
Chongqing	1.0406	1.0681	1.1444	1.0126	1.0744	17
Shanghai	1.0389	1.1474	1.0374	1.0437	1.0720	18
Hunan	1.0614	1.0717	1.0458	1.0990	1.0673	19
Henan	1.0872	1.0837	1.0055	1.0047	1.0451	20
Fujian	0.9642	0.9814	1.0581	1.1502	1.0347	21
Shandong	1.2117	1.0639	0.9192	0.8763	1.0125	22
Liaoning	1.0677	0.9048	0.9425	1.0088	0.9695	23
Hubei	0.8940	0.8918	0.9280	0.9431	0.9134	24

Appendix G: Annual Technological Efficiency of Performance

Province	2011	2012	2013	2014	2015
Shanghai	0.8116	0.8085	0.7867	0.8443	0.8368
Hubei	0.5659	0.5734	0.5807	0.575	0.5676
Liaoning	0.335	0.3543	0.5197	0.588	0.5585
Shandong	0.3134	0.2931	0.3499	0.3977	0.3962
Fujian	0.2709	0.4477	0.4684	0.4082	0.5026
Hunan	0.3559	0.3372	0.3908	0.4374	0.3945
Henan	0.2479	0.3918	0.3177	0.4021	0.3644
Heilongjiang	0.5939	0.5224	0.3288	0.4231	0.4034
Chongqing	0.2083	0.37	0.4182	0.4236	0.4059
Hainan	0.2359	0.2881	0.333	0.3375	0.3123
Jilin	0.2081	0.3802	0.3817	0.3691	0.2507
Guangdong	0.3801	0.415	0.3258	0.4979	0.4073
Sichuan	0.1983	0.2505	0.2463	0.3934	0.3474
Anhui	0.2801	0.34	0.3126	0.3494	0.2978
Guangxi	0.2894	0.2541	0.2537	0.2426	0.2932
Tianjin	0.2738	0.2997	0.3227	0.3055	0.2463
Beijing	0.2963	0.2674	0.2486	0.2891	0.2081

Appendix G continued

Shanxi	0.1582	0.3135	0.197	0.3256	0.2134
Guizhou	0.2431	0.2442	0.209	0.1975	0.2174
Hebei	0.2739	0.2378	0.2313	0.3056	0.235
Jiangxi	0.2532	0.2168	0.2943	0.2483	0.2046
Jiangsu	0.2654	0.2165	0.2654	0.249	0.1838
Zhejiang	0.2377	0.209	0.226	0.1935	0.1833
Shaanxi	0.2123	0.1398	0.1117	0.1673	0.0698

Appendix G continued

Province	2016	2017	2018	2019	2020	2021
Shanghai	0.8286	0.8874	0.9769	0.9799	0.9798	0.9805
Hubei	0.5825	0.5232	0.5771	0.5056	0.5008	0.5017
Liaoning	0.5558	0.6584	0.4549	0.4395	0.4373	0.4471
Shandong	0.4353	0.4743	0.5288	0.5055	0.5957	0.5566
Fujian	0.4371	0.3796	0.4485	0.4382	0.3493	0.3826
Hunan	0.3876	0.3234	0.4374	0.4764	0.4364	0.3036
Henan	0.4163	0.4638	0.4064	0.3928	0.4308	0.4128
Heilongjiang	0.331	0.4142	0.2543	0.3542	0.3264	0.271
Chongqing	0.3959	0.3727	0.3226	0.3727	0.4017	0.4001
Hainan	0.2815	0.2738	0.4246	0.4446	0.5994	0.5108
Jilin	0.4394	0.3208	0.3397	0.4404	0.3033	0.4167
Guangdong	0.3779	0.4433	0.1948	0.1999	0.2034	0.2102
Sichuan	0.3759	0.2981	0.3664	0.3423	0.2627	0.263
Anhui	0.2967	0.2733	0.2765	0.2865	0.2852	0.2841
Guangxi	0.3716	0.3427	0.2919	0.3207	0.2991	0.2802
Tianjin	0.2709	0.2694	0.3	0.3263	0.2721	0.2944
Beijing	0.2365	0.2238	0.2132	0.2355	0.2231	0.1297
Shanxi	0.2545	0.211	0.2851	0.233	0.1793	0.1987

Appendix G continued

Guizhou	0.187	0.2339	0.2298	0.2455	0.2432	0.2254
Hebei	0.2289	0.2682	0.1734	0.1733	0.1619	0.1394
Jiangxi	0.2412	0.2047	0.1942	0.1765	0.1751	0.172
Jiangsu	0.1822	0.2087	0.1531	0.1808	0.1414	0.172
Zhejiang	0.1219	0.1125	0.1546	0.1443	0.1369	0.1297
Shaanxi	0.1175	0.0624	0.0616	0.0684	0.0616	0.0616

Appendix H: Annual Pure Technical Efficiency of Performance

Province	2011	2012	2013	2014	2015
Shanghai	0.8434	0.8376	0.832	0.8688	0.8562
Hubei	0.761	0.7744	0.7873	0.7772	0.7639
Liaoning	0.398	0.4252	0.6815	0.8005	0.748
Shandong	0.368	0.3406	0.4189	0.4884	0.4862
Fujian	0.3111	0.5647	0.5974	0.5042	0.653
Hunan	0.4274	0.401	0.4782	0.5487	0.4836
Heilongjiang	0.8111	0.6861	0.3893	0.5267	0.4969
Henan	0.2813	0.4796	0.3739	0.495	0.4396
Chongqing	0.2316	0.4477	0.5193	0.5275	0.5006
Hainan	0.266	0.3339	0.3952	0.4015	0.3666
Jilin	0.2313	0.4625	0.4648	0.4464	0.285
Guangdong	0.4625	0.5143	0.3851	0.6452	0.5027
Sichuan	0.2193	0.2847	0.2793	0.4821	0.4154
Anhui	0.3233	0.405	0.3669	0.4182	0.347
Guangxi	0.3356	0.2893	0.2887	0.2746	0.3407
Tianjin	0.3149	0.3494	0.3808	0.3573	0.2793
Shanxi	0.1713	0.3682	0.2177	0.3849	0.2379

Appendix H continued

Beijing	0.3449	0.3065	0.2822	0.3352	0.2313
Guizhou	0.2752	0.2766	0.2325	0.2183	0.2428
Hebei	0.3151	0.2684	0.2603	0.3574	0.265
Jiangxi	0.2882	0.2422	0.3421	0.2818	0.227
Jiangsu	0.304	0.2417	0.3039	0.2828	0.2018
Zhejiang	0.2683	0.2325	0.2536	0.2134	0.2012
Shaanxi	0.2365	0.1501	0.1182	0.1821	0.0723

Appendix H continued

Province	2016	2017	2018	2019	2020	2021
Shanghai	0.8389	0.9029	1	1	1	1
Hubei	0.7905	0.6874	0.7809	0.658	0.6501	0.6516
Liaoning	0.7433	0.9317	0.5759	0.552	0.5485	0.5638
Shandong	0.5455	0.6069	0.6969	0.6578	0.8143	0.7448
Fujian	0.5482	0.4617	0.566	0.55	0.4181	0.466
Hunan	0.4734	0.3818	0.5487	0.6102	0.5471	0.3547
Heilongjiang	0.3924	0.5131	0.2896	0.4251	0.386	0.3112
Henan	0.5164	0.5902	0.5014	0.4811	0.5385	0.511
Chongqing	0.4857	0.4516	0.3807	0.4517	0.4944	0.492
Hainan	0.3251	0.3149	0.529	0.5599	0.821	0.6666
Jilin	0.5518	0.3782	0.4045	0.5533	0.3543	0.517
Guangdong	0.4593	0.5578	0.215	0.2212	0.2256	0.2339
Sichuan	0.4564	0.3473	0.4425	0.4082	0.3005	0.3009
Anhui	0.3454	0.3143	0.3185	0.3317	0.3301	0.3286
Guangxi	0.45	0.4087	0.339	0.378	0.3486	0.3235
Tianjin	0.3111	0.3092	0.3498	0.3858	0.3127	0.3423
Shanxi	0.2898	0.2349	0.3299	0.2623	0.1964	0.2199

Appendix H continued

Beijing	0.2668	0.2509	0.2377	0.2656	0.2499	0.1385
Guizhou	0.2056	0.2635	0.2583	0.2783	0.2753	0.2529
Hebei	0.2572	0.3077	0.1894	0.1893	0.1757	0.1496
Jiangxi	0.2728	0.2271	0.2144	0.193	0.1914	0.1877
Jiangsu	0.1998	0.2321	0.1654	0.1982	0.1519	0.1877
Zhejiang	0.1297	0.1191	0.1672	0.1552	0.1467	0.1385
Shaanxi	0.1247	0.0644	0.0635	0.0708	0.0635	0.0635

Appendix I: Annual Scale Efficiency of Performance

Province	2011	2012	2013	2014	2015
Shanghai	0.9623	0.9652	0.9455	0.9718	0.9773
Hubei	0.8976	0.9317	0.9452	0.9187	0.9655
Liaoning	0.8858	0.8991	0.8913	0.9064	0.9112
Shandong	0.8731	0.8957	0.8732	0.8806	0.9109
Fujian	0.8787	0.8955	0.8601	0.881	0.9012
Hunan	0.8693	0.8858	0.8888	0.855	0.8871
Heilongjiang	0.8834	0.8829	0.8991	0.9045	0.8952
Henan	0.923	0.8514	0.9047	0.846	0.8971
Chongqing	0.8591	0.8723	0.8808	0.8624	0.8996
Hainan	0.8694	0.8576	0.8473	0.855	0.8819
Jilin	0.8623	0.8783	0.8785	0.8836	0.8606
Guangdong	0.8665	0.8396	0.8518	0.8354	0.8585
Sichuan	0.9041	0.88	0.8819	0.8161	0.8363
Anhui	0.8219	0.8068	0.846	0.7716	0.8102
Guangxi	0.8996	0.8219	0.8212	0.8268	0.8799
Tianjin	0.8867	0.8628	0.8427	0.8407	0.852
Shanxi	0.8995	0.8264	0.8054	0.8031	0.8107

Appendix I continued

Beijing	0.7323	0.7614	0.8446	0.8033	0.8118
Guizhou	0.8812	0.8169	0.8496	0.8124	0.8289
Hebei	0.8326	0.8409	0.8173	0.7972	0.8157
Jiangxi	0.8707	0.7928	0.784	0.8097	0.7697
Jiangsu	0.8515	0.8606	0.8352	0.8143	0.8149
Zhejiang	0.8418	0.8333	0.7626	0.7346	0.7466
Shaanxi	0.7436	0.7405	0.7376	0.7399	0.7429

Appendix I continued

Province	2016	2017	2018	2019	2020	2021
Shanghai	0.9859	0.9828	0.9769	0.9799	0.9798	0.9805
Hubei	0.9424	0.9691	0.9695	0.9662	0.9695	0.9695
Liaoning	0.9403	0.9448	0.9247	0.9296	0.9331	0.9366
Shandong	0.9117	0.8993	0.9254	0.9123	0.931	0.9164
Fujian	0.8842	0.9012	0.906	0.9143	0.915	0.9165
Hunan	0.8899	0.8719	0.9158	0.9158	0.9212	0.9319
Heilongjiang	0.9094	0.8876	0.8895	0.8823	0.8833	0.8915
Henan	0.8782	0.8982	0.8642	0.888	0.913	0.9039
Chongqing	0.8864	0.8923	0.8972	0.8869	0.8926	0.9366
Hainan	0.8707	0.8713	0.8575	0.8457	0.8701	0.86
Jilin	0.8257	0.8384	0.8611	0.8482	0.8579	0.8664
Guangdong	0.859	0.8696	0.8681	0.8636	0.8641	0.8647
Sichuan	0.8238	0.8583	0.828	0.8386	0.8744	0.8742
Anhui	0.8229	0.7947	0.9058	0.9034	0.9017	0.8986
Guangxi	0.7963	0.8482	0.8397	0.7959	0.856	0.8061
Tianjin	0.8659	0.8694	0.8027	0.7941	0.7316	0.7663
Shanxi	0.8151	0.8252	0.8474	0.8252	0.8125	0.8133

Appendix I continued

Beijing	0.8436	0.8072	0.8782	0.8333	0.8456	0.8706
Guizhou	0.8062	0.7859	0.8105	0.8164	0.8	0.8078
Hebei	0.8187	0.847	0.7972	0.7807	0.7976	0.8559
Jiangxi	0.7973	0.8222	0.7924	0.7968	0.8355	0.8209
Jiangsu	0.7981	0.7815	0.7588	0.7684	0.7316	0.7474
Zhejiang	0.7477	0.7316	0.7898	0.7963	0.7972	0.793
Shaanxi	0.7369	0.7611	0.739	0.7684	0.7704	0.77

Appendix J: Annual Total Factor Productivity

Province	2012	2013	2014	2015	2016
Shanghai	1.2288	0.7283	0.8626	0.7520	0.8332
Hubei	1.1653	1.1783	1.1681	1.1549	1.1814
Liaoning	0.8198	1.0727	1.1914	1.1389	1.1342
Shandong	0.7367	0.8136	0.8819	0.8798	0.9381
Fujian	0.9571	0.9893	0.8974	1.0444	0.9408
Henan	0.8733	0.7694	0.8884	0.8339	0.9094
Hunan	0.7960	0.8718	0.9413	0.8772	0.8672
Chongqing	0.8419	0.9123	0.9204	0.8939	0.8793
Hainan	0.7301	0.7903	0.7964	0.7622	0.7214
Jilin	0.8564	0.8587	0.8406	0.6820	0.9444
Heilongjiang	1.0773	0.7845	0.9196	0.8903	0.7876
Guangdong	0.9074	0.7804	1.0367	0.8960	0.8533
Sichuan	0.6817	0.6765	0.8757	0.8101	0.8504
Anhui	0.7999	0.7626	0.8129	0.7429	0.7414
Guangxi	0.6863	0.6857	0.6718	0.7368	0.8442
Tianjin	0.7454	0.7762	0.7530	0.6765	0.7077
Shanxi	0.7638	0.6158	0.7802	0.6357	0.6867

Appendix J continued

Beijing	0.7032	0.6793	0.7314	0.6292	0.6642
Guizhou	0.6738	0.6304	0.6165	0.6406	0.6039
Hebei	0.6658	0.6578	0.7532	0.6624	0.6547
Jiangxi	0.6399	0.7382	0.6789	0.6250	0.6701
Jiangsu	0.6395	0.7007	0.6799	0.6002	0.5982
Zhejiang	0.6304	0.6511	0.6116	0.5995	0.5290
Shaanxi	0.5491	0.5176	0.5808	0.4721	0.5240

Appendix J continued

Province	2017	2018	2019	2020	2021
Shanghai	0.8961	1.8778	1.8778	1.8778	1.8404
Hubei	1.0785	1.1718	1.0494	1.0415	1.0430
Liaoning	1.3241	0.9682	0.9446	0.9411	0.9562
Shandong	0.9988	1.0880	1.0492	1.2053	1.1357
Fujian	0.8557	0.9584	0.9425	0.8128	0.8599
Henan	0.9822	0.8947	0.8748	0.9313	0.9041
Hunan	0.7772	0.9413	1.0020	0.9397	0.7506
Chongqing	0.8458	0.7760	0.8458	0.8878	0.8854
Hainan	0.7114	0.9219	0.9524	1.2121	1.0579
Jilin	0.7736	0.7995	0.9459	0.7501	0.9100
Heilongjiang	0.9063	0.6865	0.8197	0.7813	0.7078
Guangdong	0.9503	0.6132	0.6193	0.6236	0.6318
Sichuan	0.7433	0.8368	0.8030	0.6973	0.6976
Anhui	0.7109	0.7150	0.7280	0.7264	0.7249
Guangxi	0.8036	0.7351	0.7734	0.7445	0.7198
Tianjin	0.7058	0.7458	0.7811	0.7093	0.7384
Shanxi	0.6328	0.7262	0.6598	0.5948	0.6180

Appendix J continued

Beijing	0.6485	0.6355	0.6630	0.6476	0.5376
Guizhou	0.6609	0.6558	0.6754	0.6725	0.6504
Hebei	0.7043	0.5879	0.5878	0.5744	0.5487
Jiangxi	0.6251	0.6126	0.5915	0.5899	0.5862
Jiangsu	0.6300	0.5642	0.5966	0.5509	0.5863
Zhejiang	0.5185	0.5660	0.5542	0.5458	0.5376
Shaanxi	0.4642	0.4633	0.4705	0.4633	0.4633

Appendix K: Annual Comprehensive Technical Efficiency

Province	2012	2013	2014	2015	2016
Hubei	1.3146	1.3070	1.2931	1.3282	1.3090
Shanghai	1.3758	0.6147	0.8407	0.5847	0.7372
Liaoning	0.6896	1.1333	1.3285	1.2832	1.2195
Shandong	0.5902	0.6922	0.8653	0.7829	0.8944
Fujian	0.9888	1.0301	0.8815	1.1001	0.9630
Henan	0.8709	0.6566	0.8001	0.7394	0.8977
Hunan	0.7340	0.8396	0.9070	0.7888	0.8140
Chongqing	0.7654	0.9298	0.8519	0.8252	0.8449
Hainan	0.5453	0.7082	0.6983	0.6739	0.5776
Jilin	0.8424	0.8419	0.7683	0.4385	0.9159
Heilongjiang	1.1380	0.6407	0.8644	0.8827	0.6910
Guangdong	0.8512	0.6515	1.0770	0.8234	0.7644
Sichuan	0.4433	0.4409	0.8541	0.7474	0.8118
Guangxi	0.4468	0.5363	0.4375	0.6142	0.7841
Tianjin	0.5917	0.6036	0.6020	0.4916	0.5675
Anhui	0.6989	0.6218	0.6741	0.5986	0.5575
Shanxi	0.6249	0.3361	0.6320	0.3582	0.5362

Appendix K continued

Beijing	0.5438	0.4365	0.5612	0.3612	0.4601
Guizhou	0.4827	0.3548	0.3748	0.4529	0.3336
Hebei	0.4475	0.4776	0.5952	0.4641	0.3884
Jiangxi	0.4427	0.6298	0.4464	0.3402	0.4352
Jiangsu	0.4312	0.5240	0.5036	0.3411	0.3700
Zhejiang	0.4216	0.3929	0.3790	0.3440	0.1884
Shaanxi	0.2541	0.1356	0.3156	0.0868	0.2209

Appendix K continued

Province	2017	2018	2019	2020	2021
Hubei	1.1156	1.3527	1.1034	1.0769	1.1348
Shanghai	0.8520	1.8064	1.8064	1.8064	1.7469
Liaoning	1.5874	1.0014	0.9498	0.8951	0.9895
Shandong	1.0797	1.2140	1.1206	1.4034	1.2815
Fujian	0.7437	0.9612	0.9182	0.6774	0.7813
Henan	1.0433	0.8460	0.8598	0.9047	0.9226
Hunan	0.6630	0.9458	1.0332	0.9087	0.6449
Chongqing	0.7597	0.6088	0.8093	0.8859	0.8655
Hainan	0.4920	0.8741	0.9199	1.3434	1.1460
Jilin	0.6843	0.7262	0.9848	0.6404	0.9310
Heilongjiang	0.8469	0.5350	0.6981	0.6789	0.5659
Guangdong	0.9823	0.3605	0.4127	0.3872	0.3877
Sichuan	0.6430	0.7839	0.7029	0.5174	0.4952
Guangxi	0.7322	0.6301	0.6833	0.5735	0.5728
Tianjin	0.5670	0.6198	0.6654	0.5786	0.5881
Anhui	0.5318	0.4973	0.5212	0.5585	0.5883
Shanxi	0.3462	0.5723	0.4673	0.2775	0.3846

Appendix K continued

Beijing	0.4599	0.3630	0.4962	0.4155	0.2509
Guizhou	0.4258	0.4580	0.4276	0.4433	0.4504
Hebei	0.5195	0.3061	0.3070	0.3160	0.2437
Jiangxi	0.3439	0.3906	0.2758	0.3137	0.2674
Jiangsu	0.4186	0.2320	0.3590	0.2297	0.2999
Zhejiang	0.1584	0.2582	0.2131	0.2455	0.2650
Shaanxi	0.0868	0.1172	0.0868	0.0955	0.0925

Appendix L: Annual Technical Progress Index

Province	2012	2013	2014	2015	2016
Shaanxi	2.1611	3.8185	1.8402	5.4219	2.3718
Zhejiang	1.4951	1.6571	1.6136	1.7430	2.8080
Jiangsu	1.4828	1.3372	1.3502	1.7596	1.6167
Jiangxi	1.4456	1.1721	1.5207	1.8373	1.5396
Hebei	1.4879	1.3773	1.2655	1.4271	1.6858
Shanxi	1.2223	1.8324	1.2344	1.7747	1.2808
Guizhou	1.3960	1.7767	1.6446	1.4144	1.8106
Beijing	1.2932	1.5564	1.3032	1.7420	1.4436
Anhui	1.1446	1.2264	1.2059	1.2412	1.3299
Guangdong	1.0661	1.1977	0.9626	1.0881	1.1162
Guangxi	1.5358	1.2785	1.5357	1.1997	1.0766
Tianjin	1.2597	1.2859	1.2508	1.3761	1.2471
Sichuan	1.5380	1.5343	1.0253	1.0839	1.0475
Hainan	1.3390	1.1159	1.1406	1.1311	1.2490
Heilongjiang	0.9467	1.2243	1.0638	1.0086	1.1398
Jilin	1.0166	1.0199	1.0941	1.5552	1.0311
Chongqing	1.1000	0.9812	1.0804	1.0833	1.0407

Appendix L continued

Shanghai	0.8932	1.1847	1.0261	1.2860	1.1302
Hunan	1.0845	1.0383	1.0378	1.1120	1.0653
Henan	1.0027	1.1717	1.1104	1.1278	1.0130
Fujian	0.9679	0.9604	1.0181	0.9493	0.9769
Shandong	1.2482	1.1753	1.0192	1.1237	1.0490
Liaoning	1.1888	0.9466	0.8968	0.8876	0.9301
Hubei	0.8864	0.9016	0.9034	0.8695	0.9025

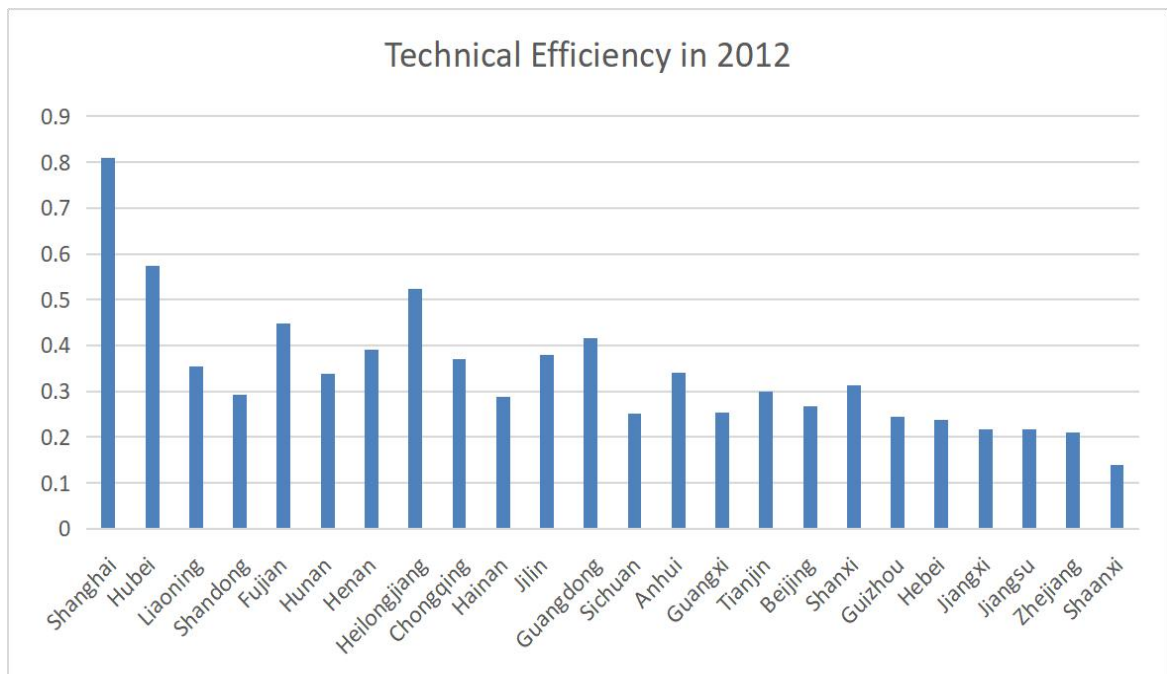
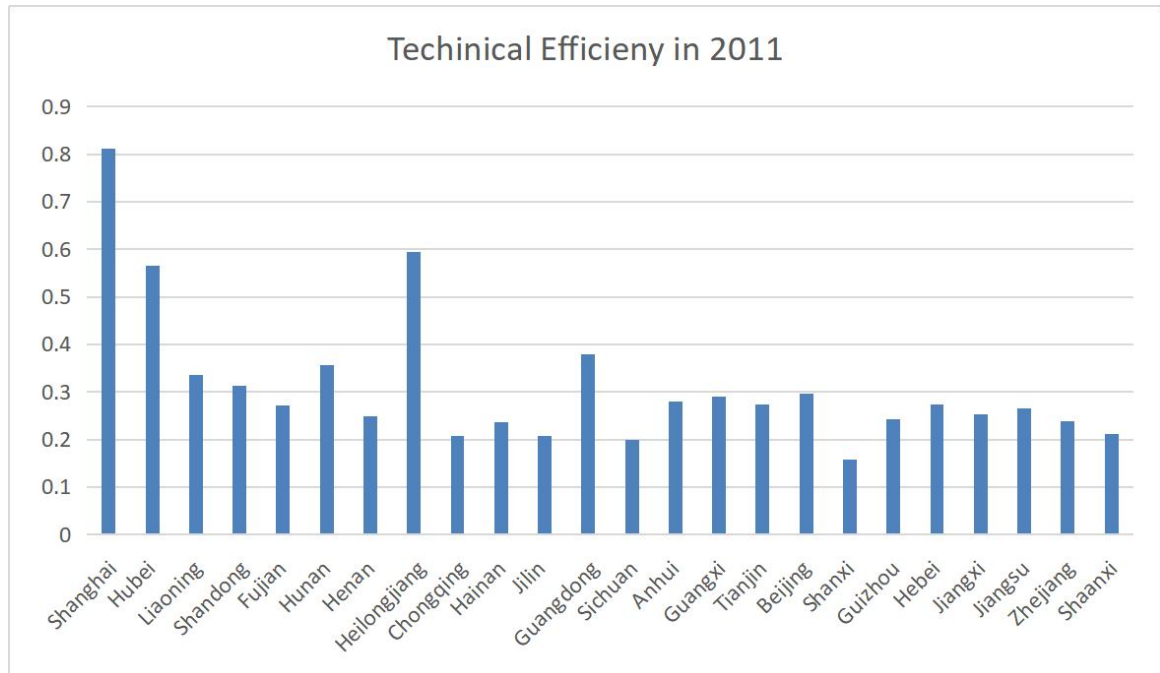
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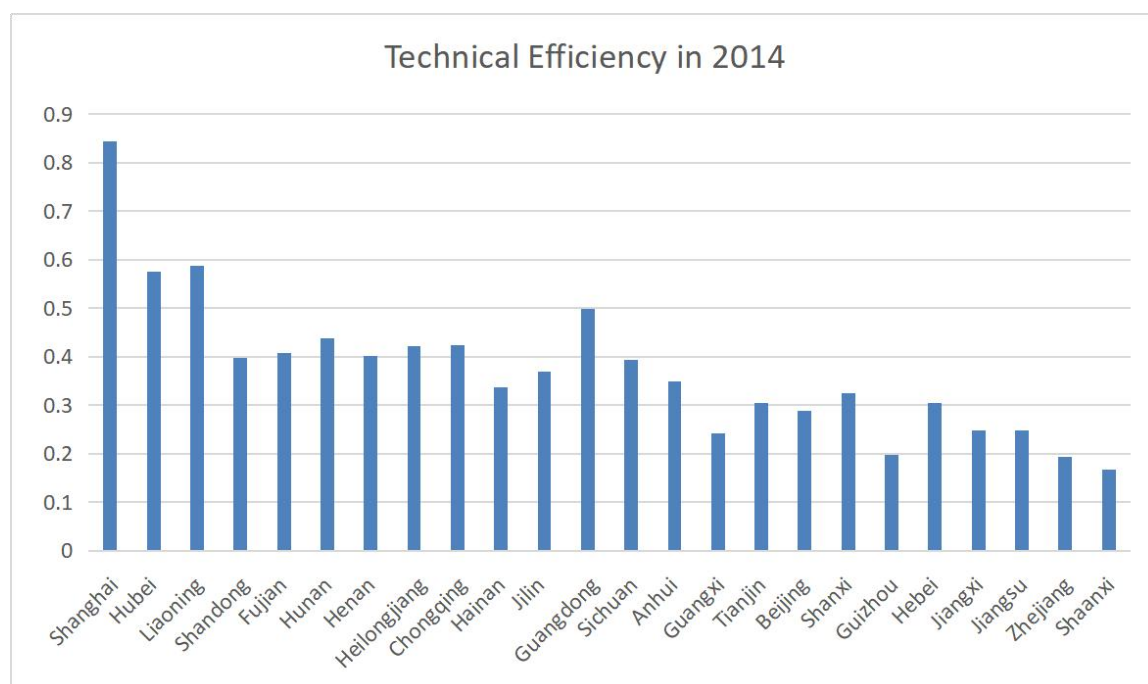
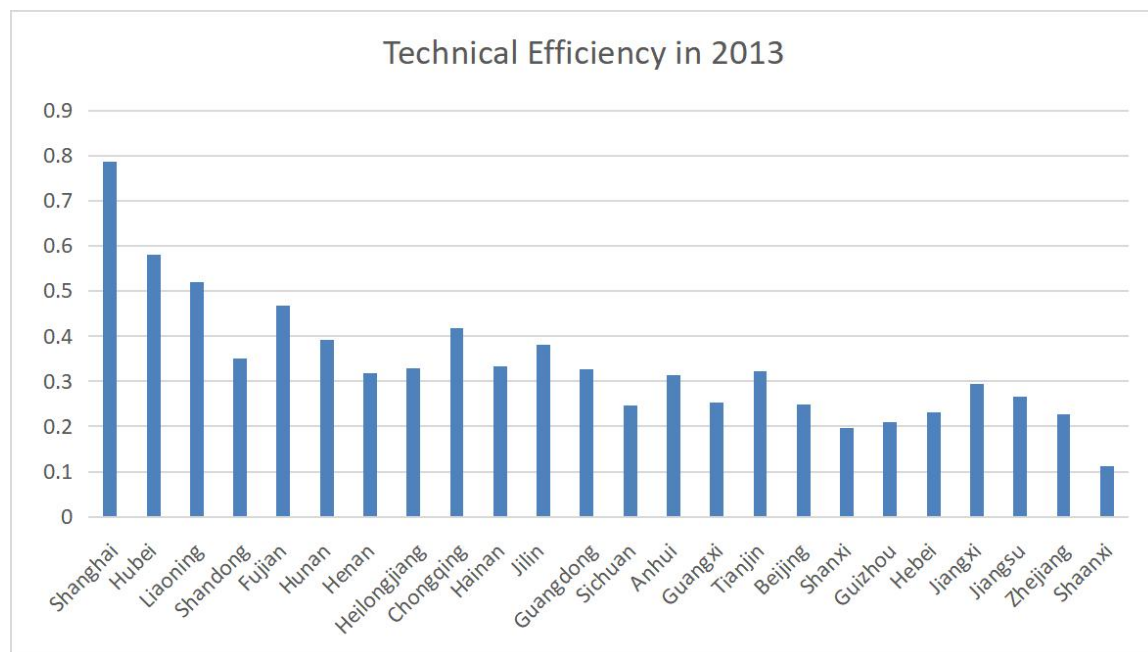
Province	2017	2018	2019	2020	2021
Shaanxi	5.4219	3.9523	5.4219	4.8492	5.0102
Zhejiang	3.2730	2.1918	2.6011	2.2237	2.0289
Jiangsu	1.5051	2.4326	1.6618	2.3980	1.9549
Jiangxi	1.8175	1.5681	2.1445	1.8805	2.1922
Hebei	1.3557	1.9208	1.9150	1.8175	2.2511
Shanxi	1.8277	1.2689	1.4119	2.1433	1.6067
Guizhou	1.5523	1.4318	1.5798	1.5170	1.4441
Beijing	1.4100	1.7507	1.3361	1.5584	2.1431
Anhui	1.3366	1.4376	1.3968	1.3005	1.2321
Guangdong	0.9675	1.7010	1.5008	1.6104	1.6294
Guangxi	1.0974	1.1666	1.1319	1.2982	1.2567
Tianjin	1.2447	1.2033	1.1738	1.2257	1.2555
Sichuan	1.1560	1.0675	1.1425	1.3475	1.4087
Hainan	1.4462	1.0547	1.0353	0.9022	0.9231
Heilongjiang	1.0701	1.2833	1.1741	1.1508	1.2507
Jilin	1.1306	1.1009	0.9605	1.1713	0.9774
Chongqing	1.1134	1.2746	1.0451	1.0022	1.0230

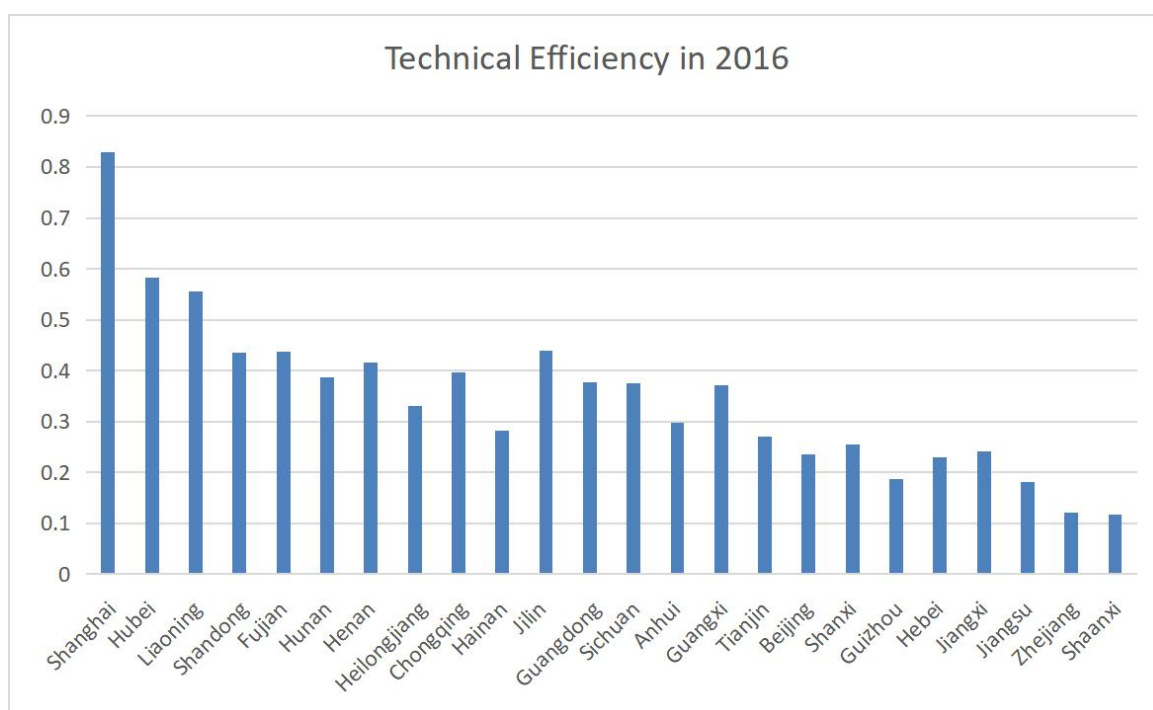
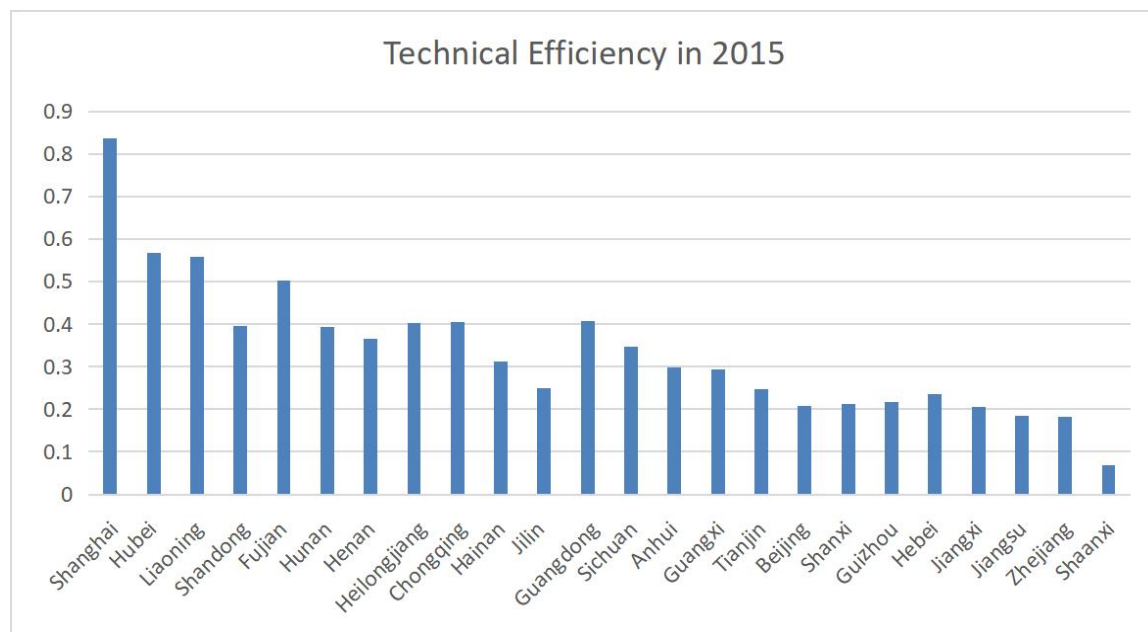
Appendix L continued

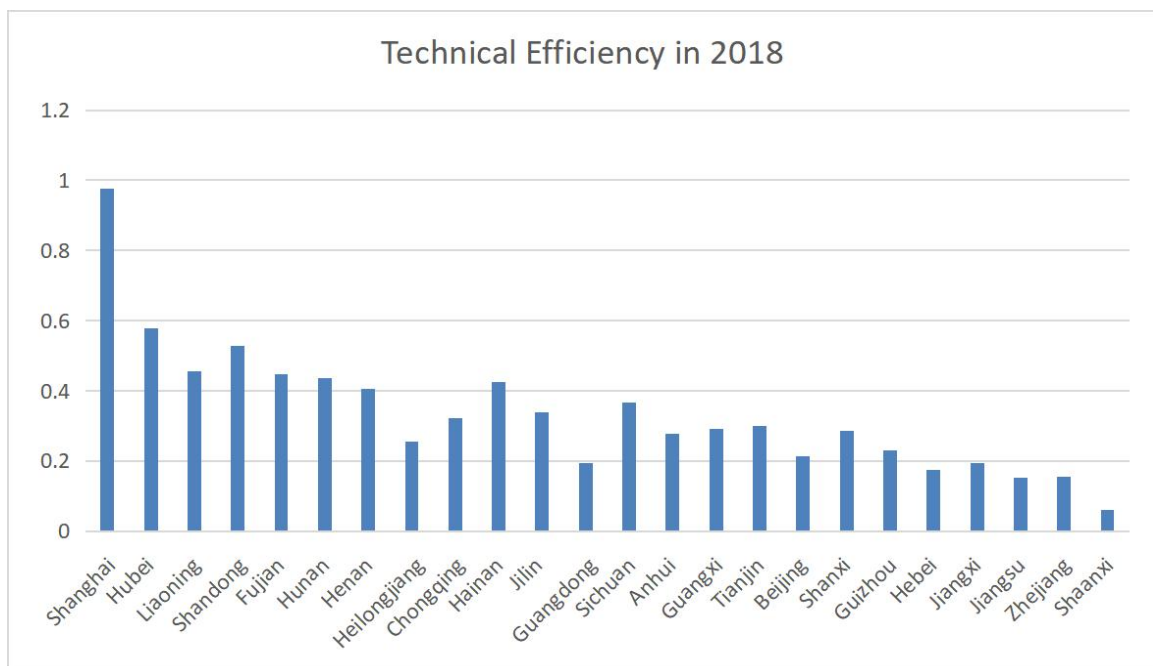
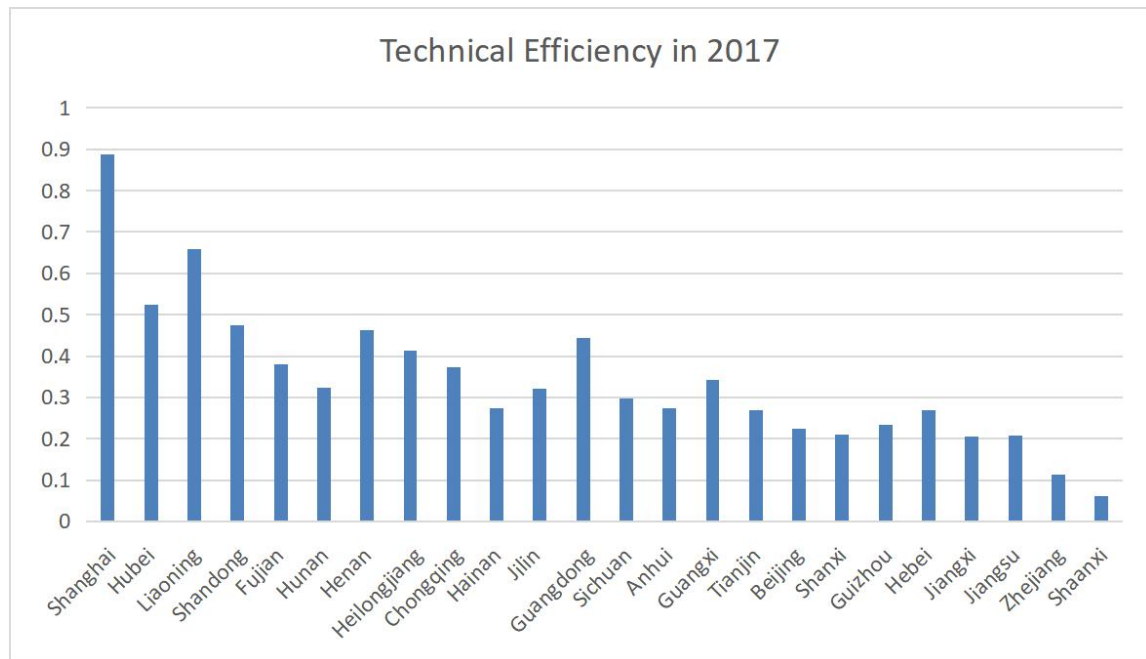
Shanghai	1.0518	1.0395	1.0210	1.0339	1.0535
Hunan	1.1723	0.9952	0.9699	1.0342	1.1638
Henan	0.9414	1.0575	1.0174	1.0294	0.9800
Fujian	1.1506	0.9971	1.0265	1.1998	1.1006
Shandong	0.9251	0.8963	0.9363	0.8663	0.8862
Liaoning	0.8663	0.9668	0.9945	1.0514	0.9663
Hubei	0.9668	0.8663	0.9510	0.9671	0.9191

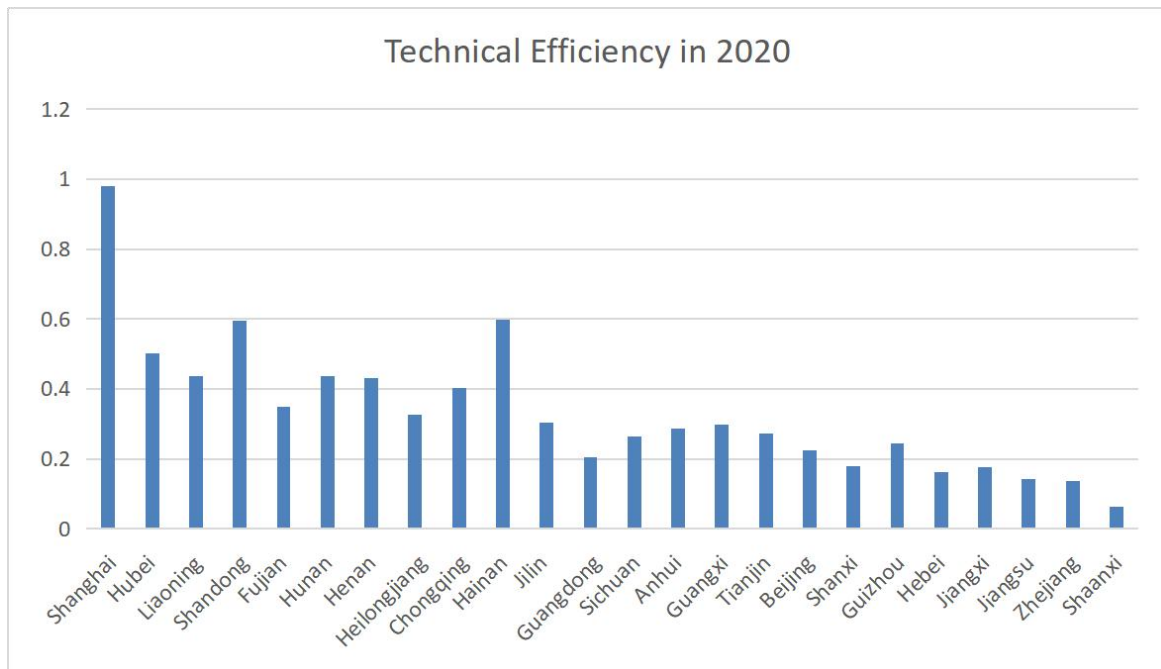
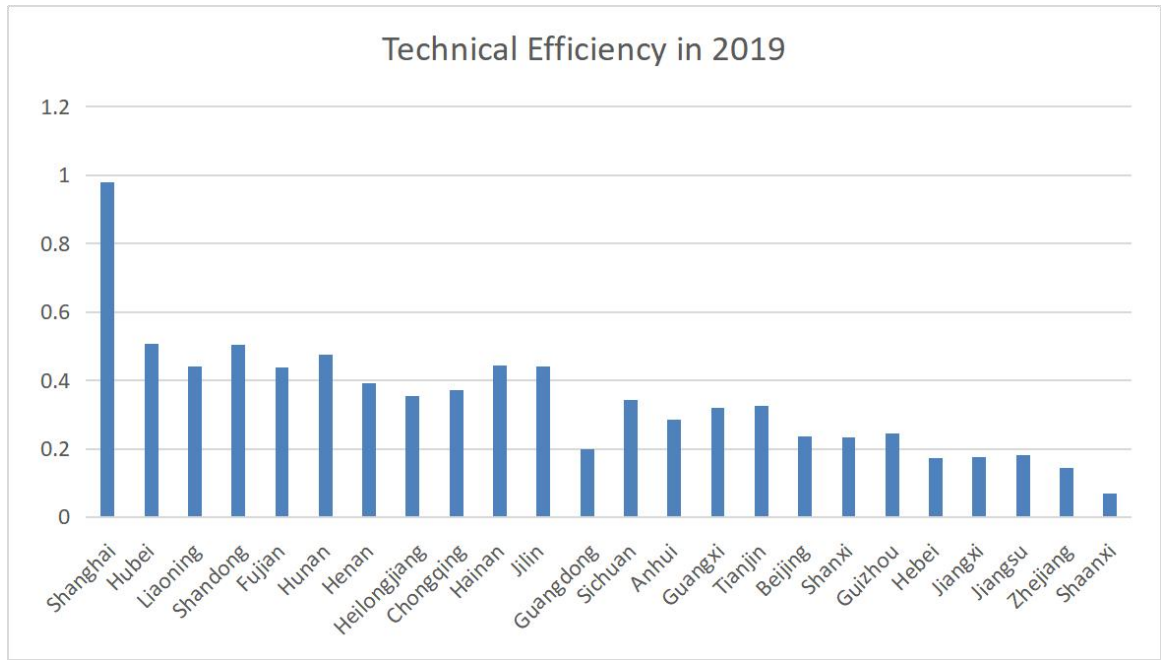
Appendix M: The Full Results of Technical Efficiency

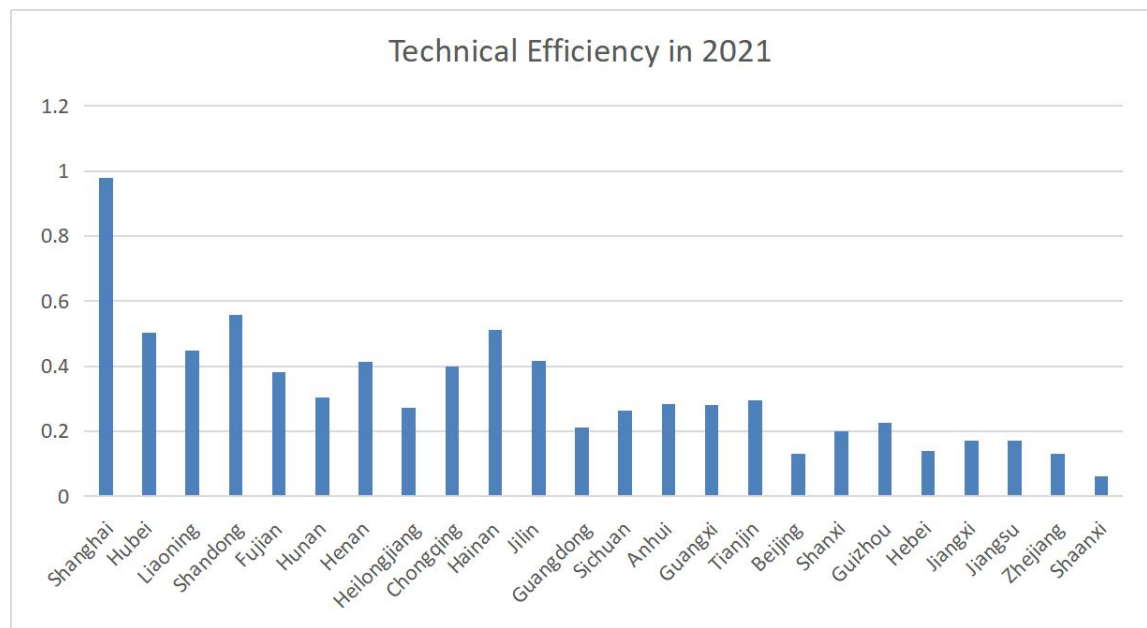




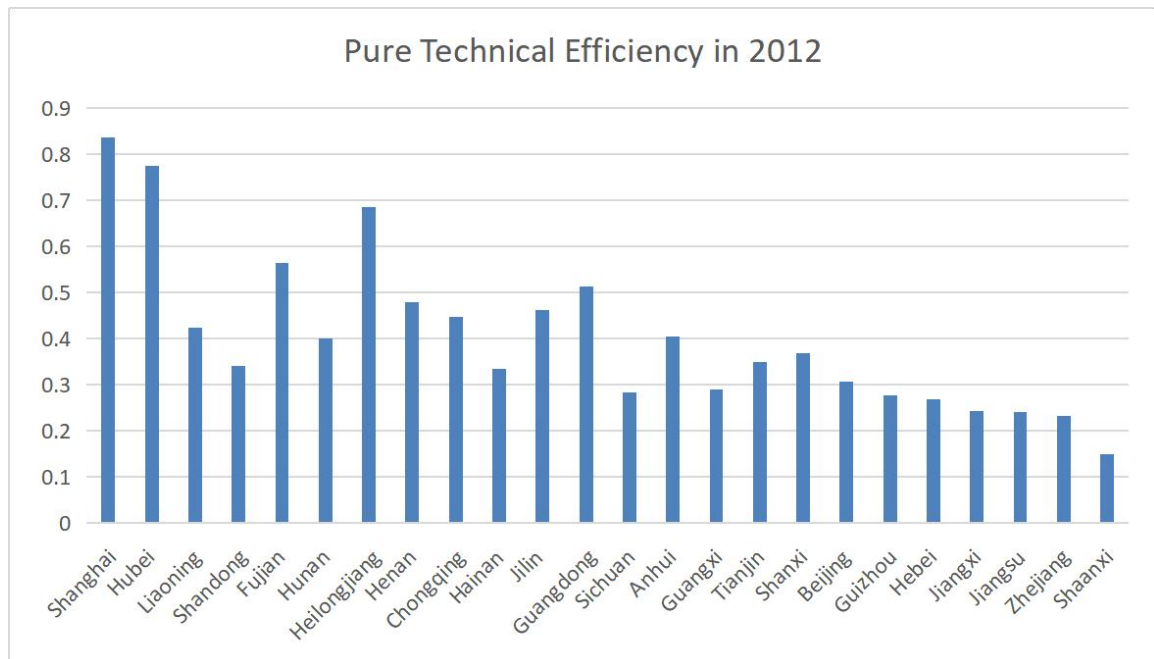
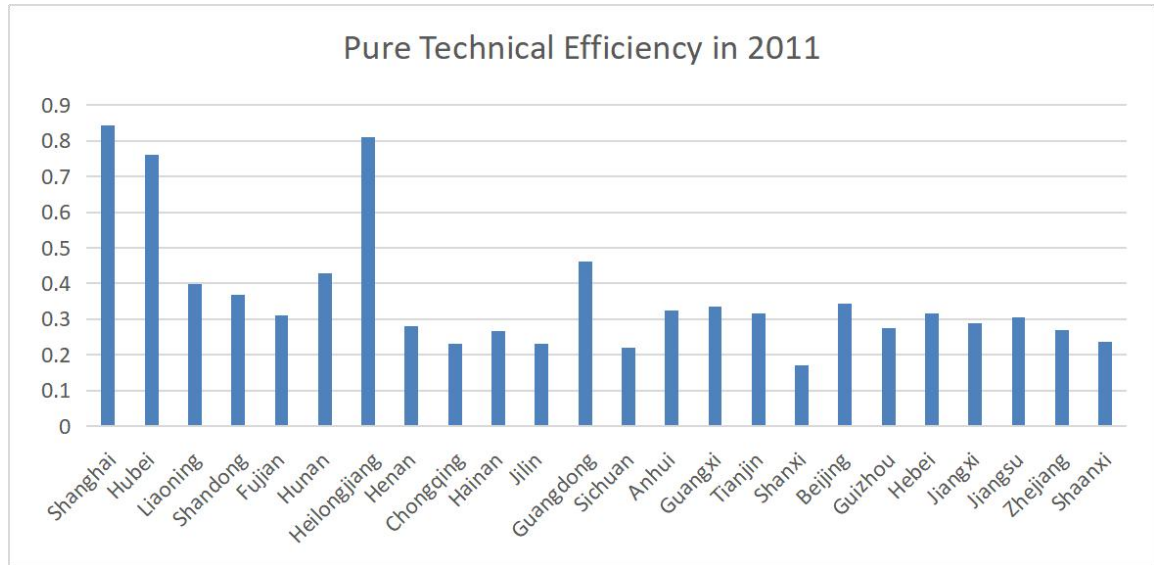


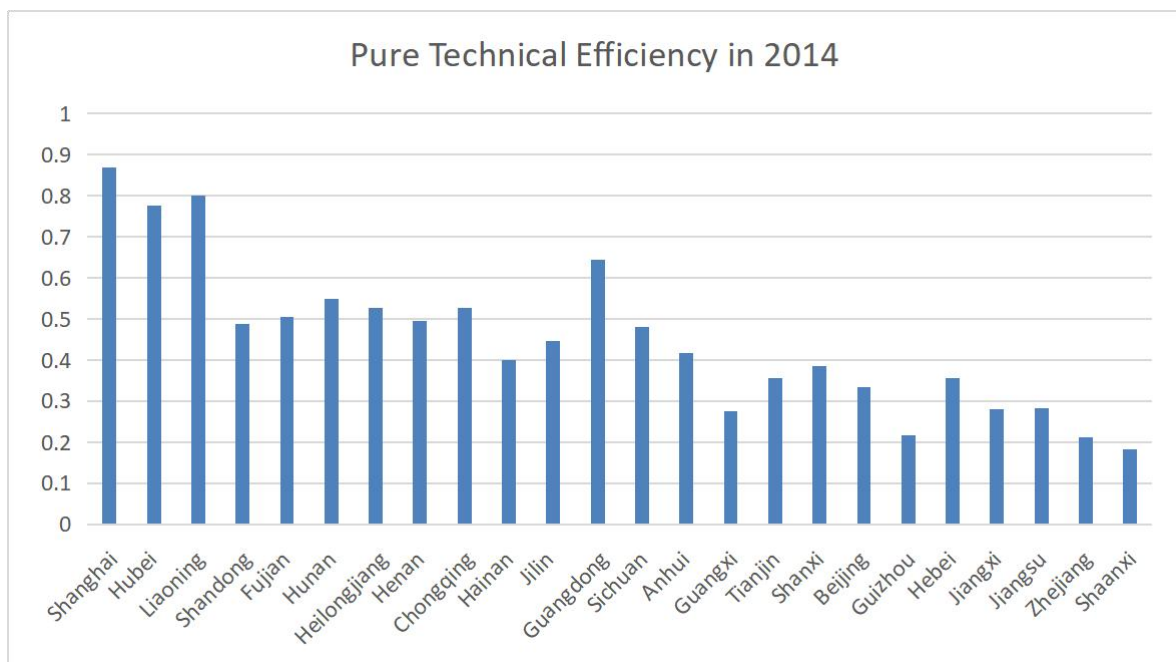
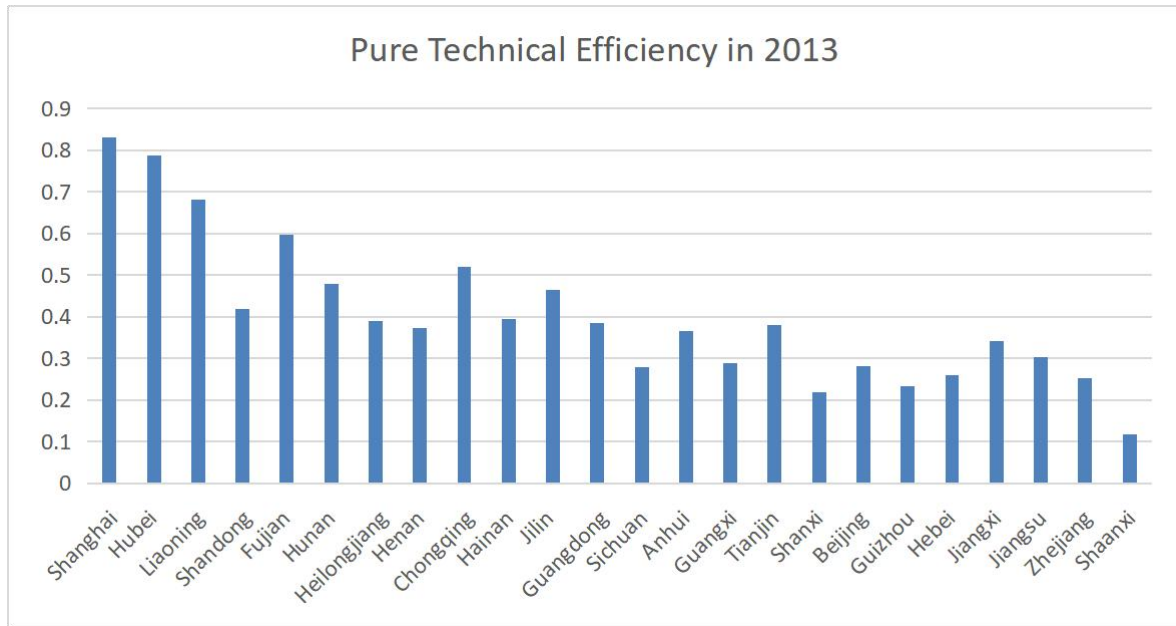


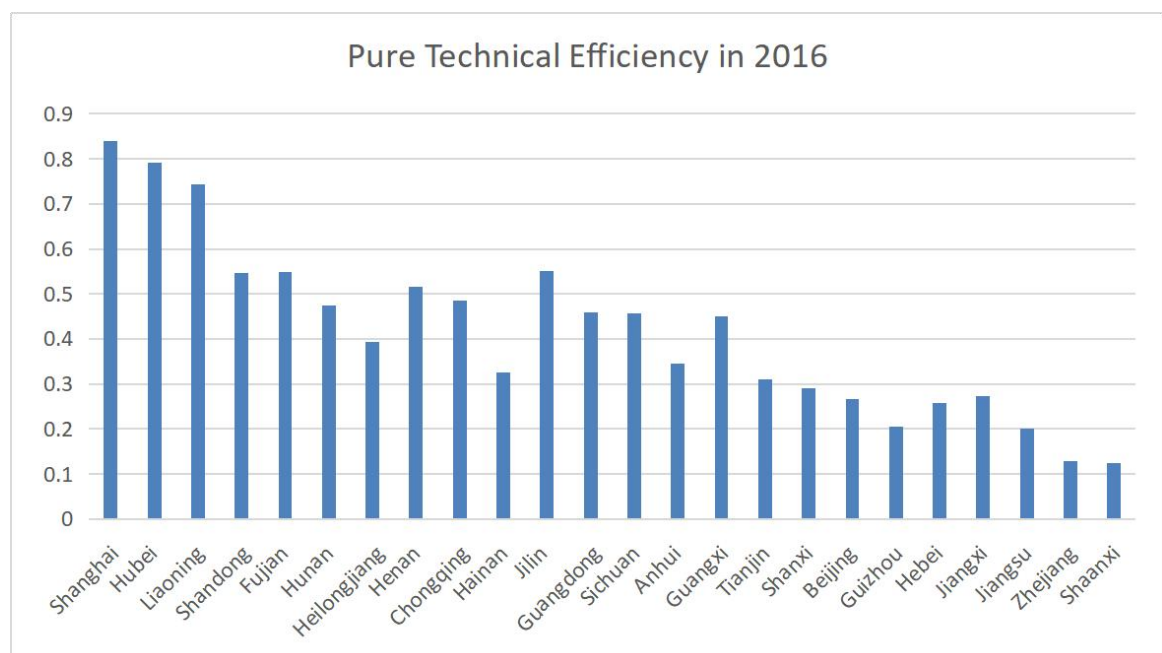
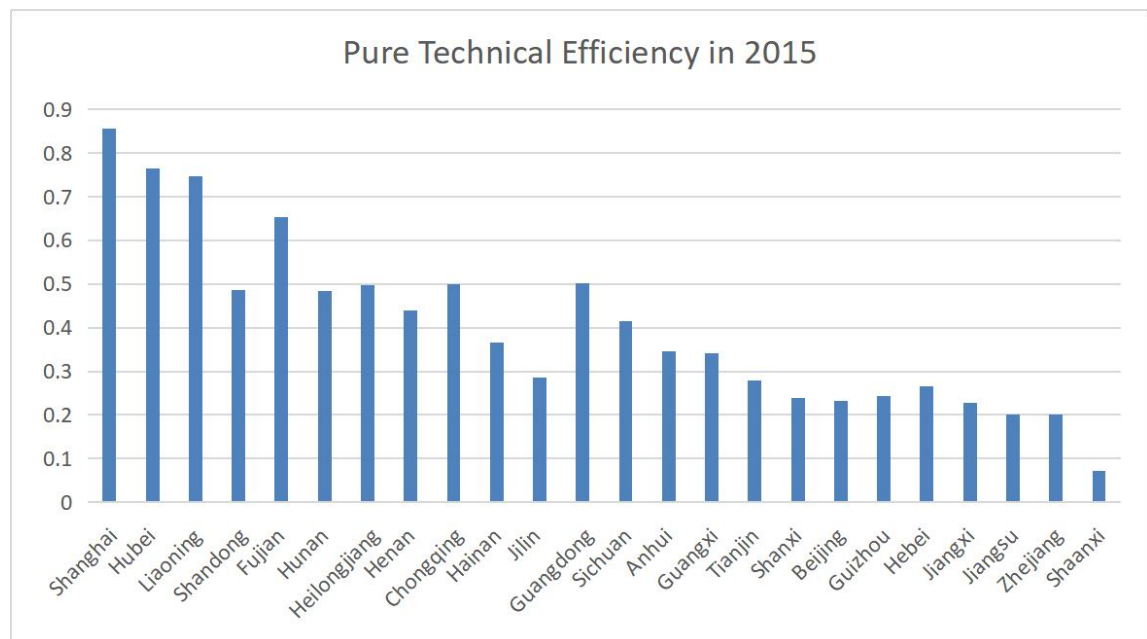


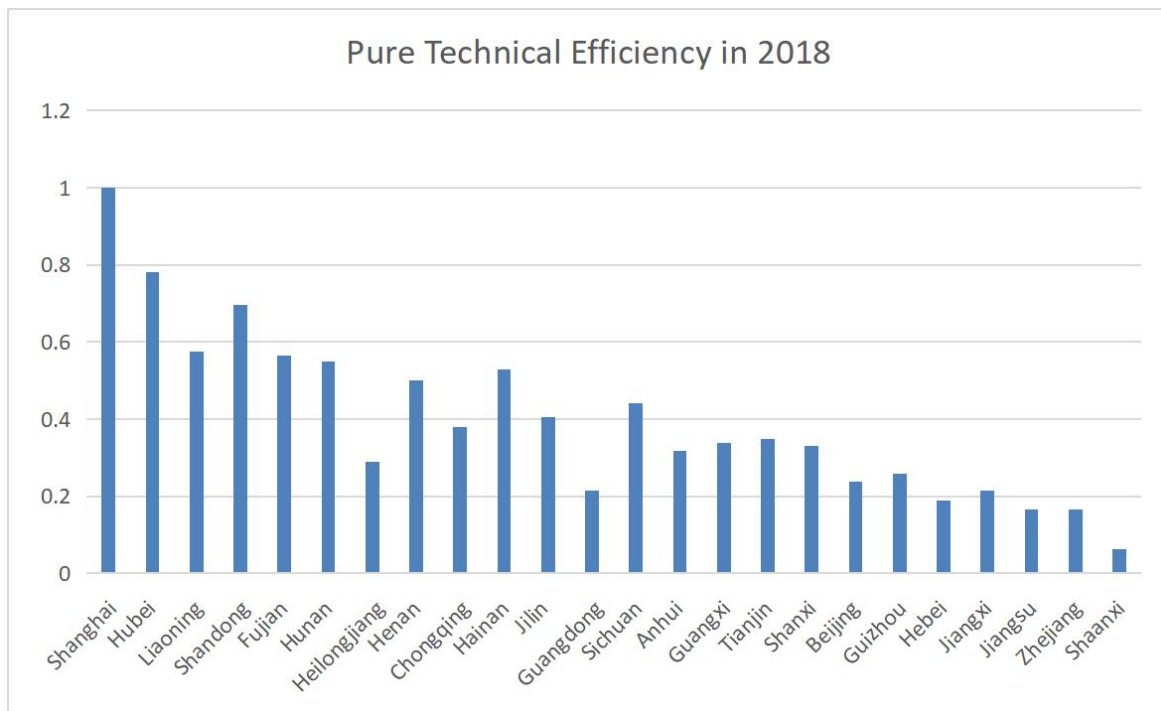
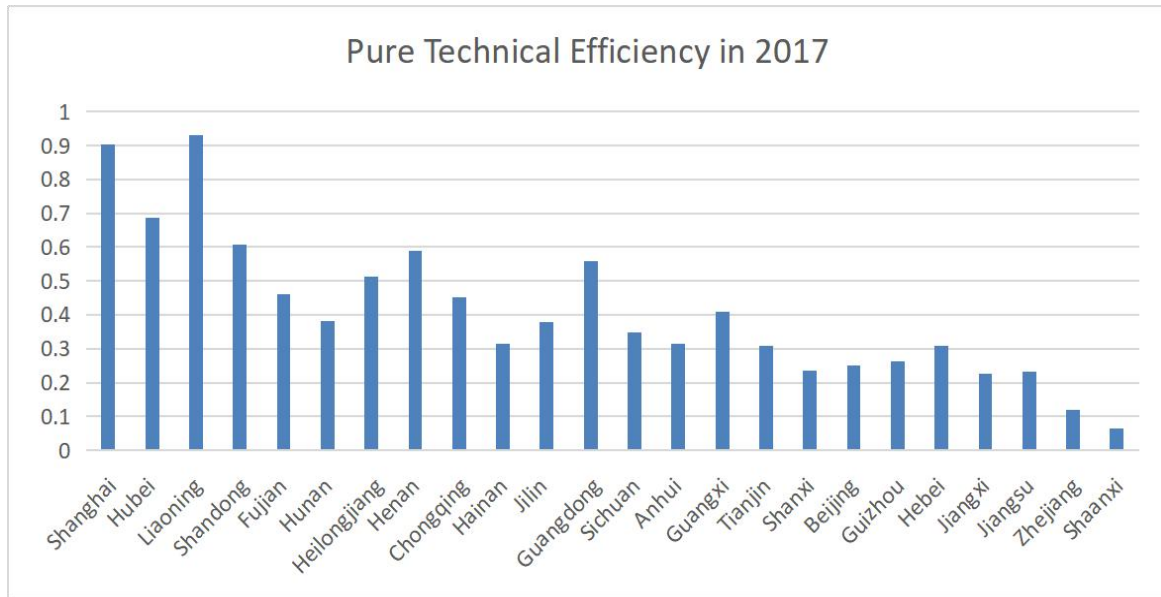


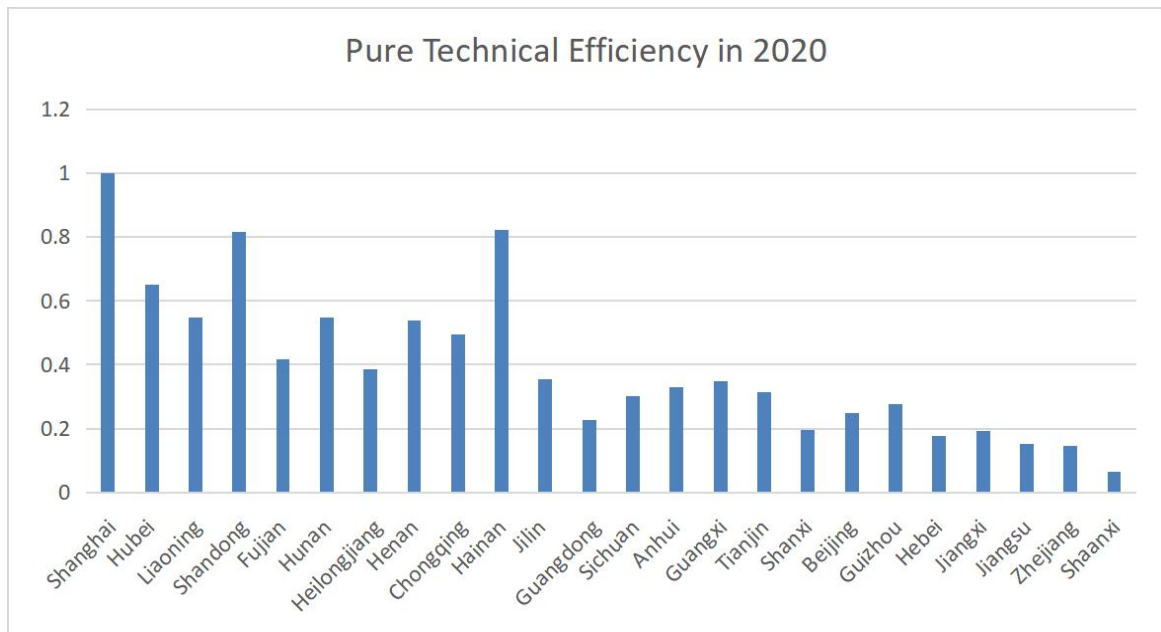
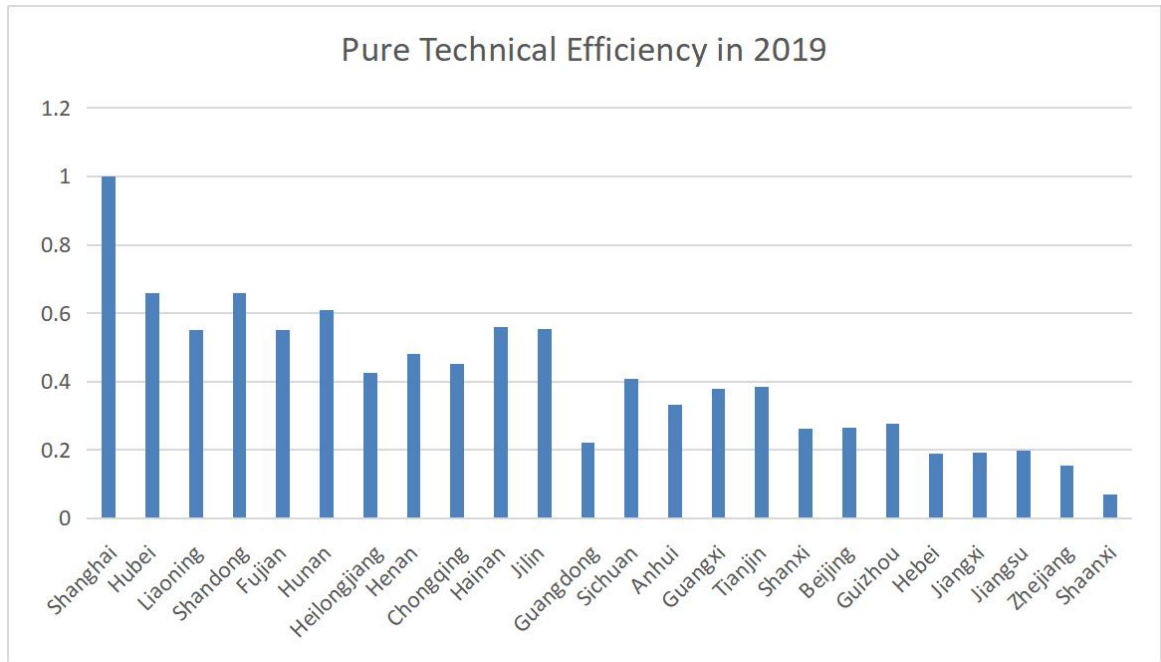
Appendix N: The Full Results of Pure Technical Efficiency

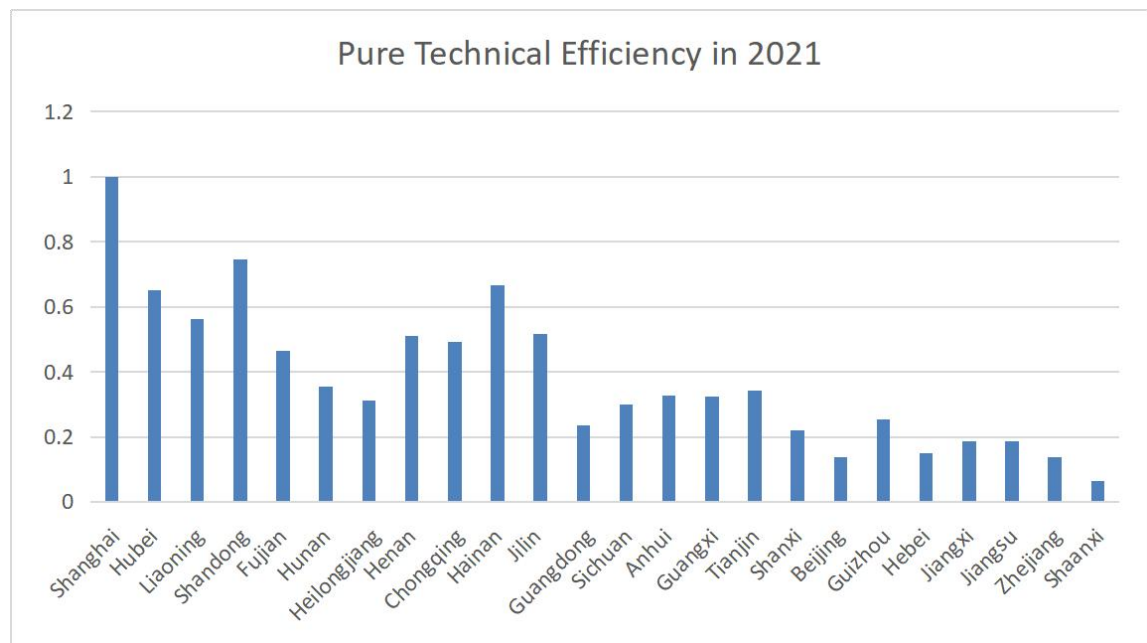




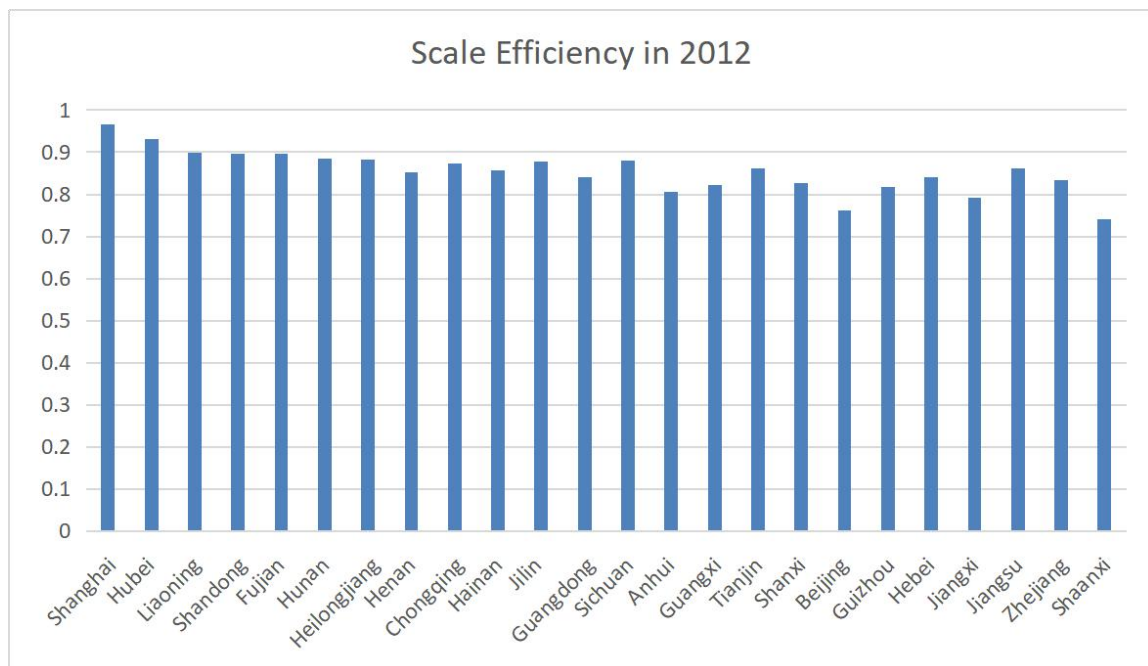
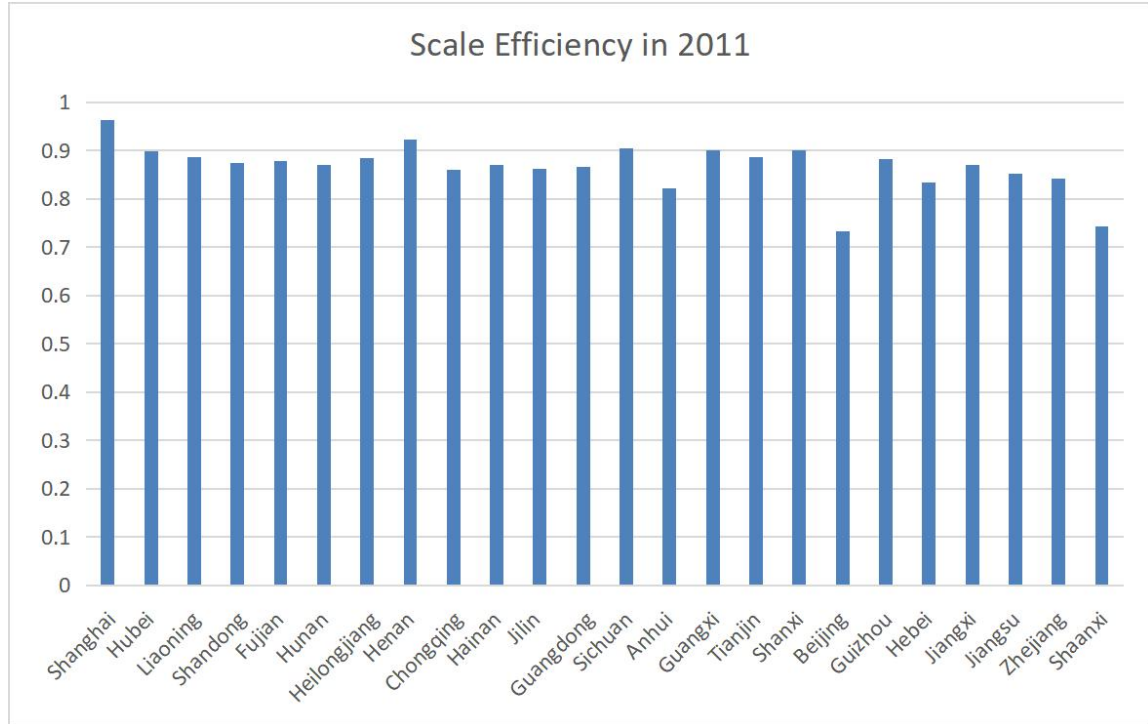


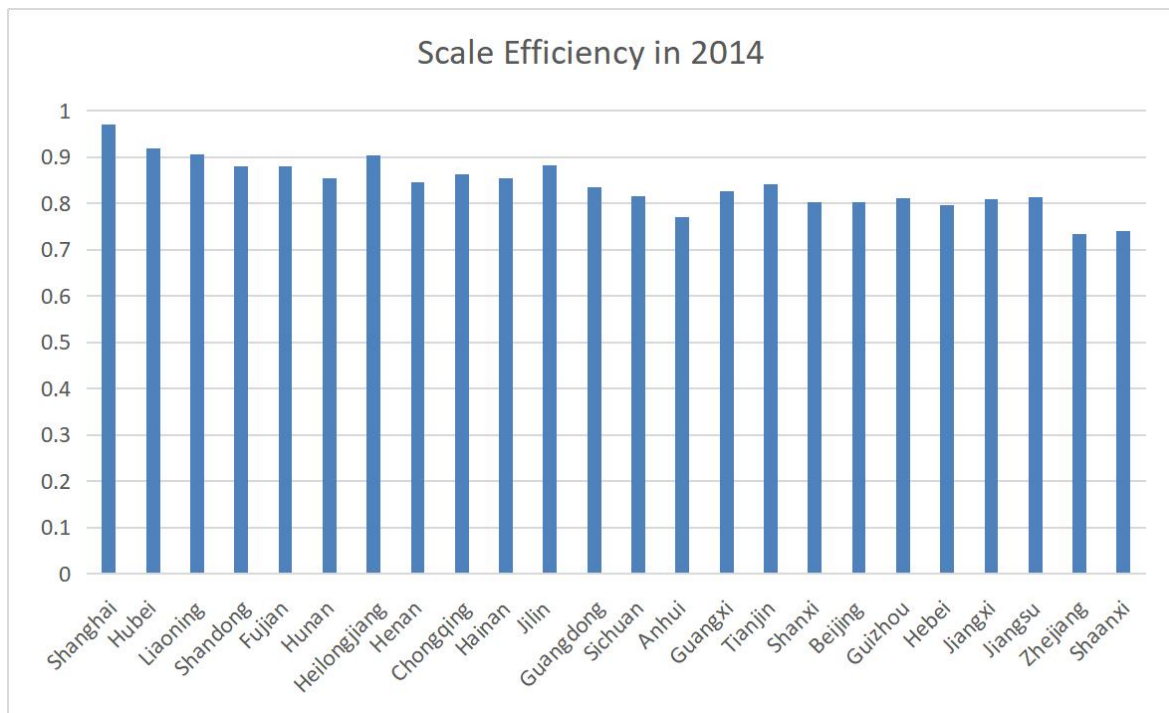
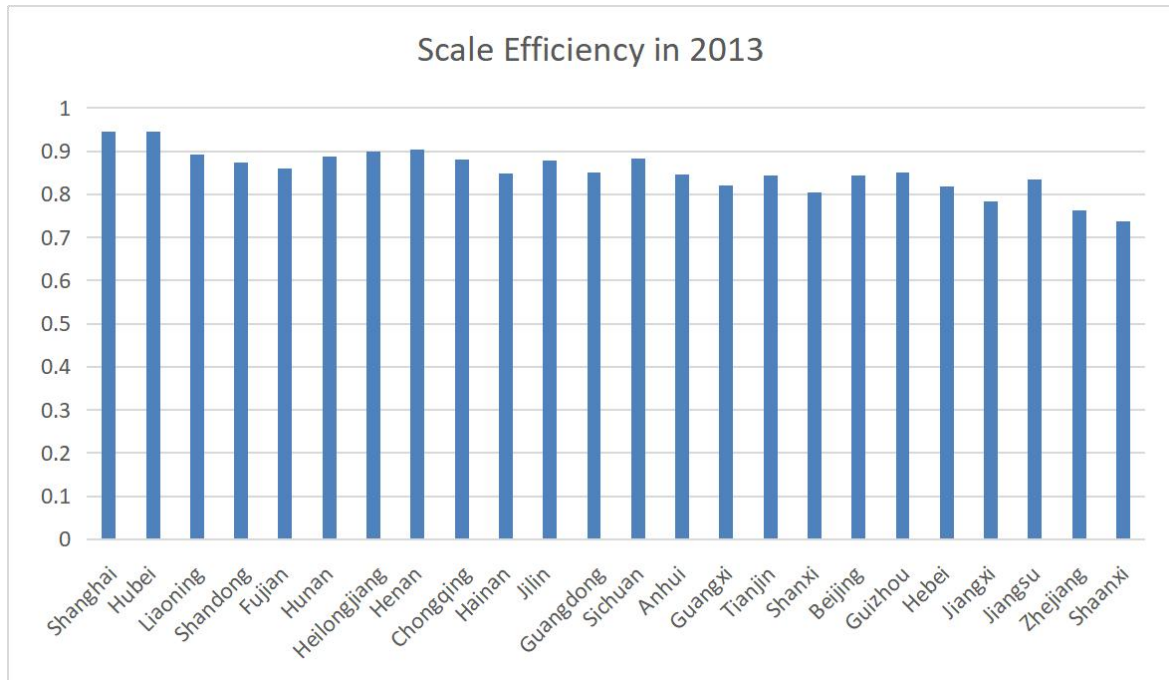


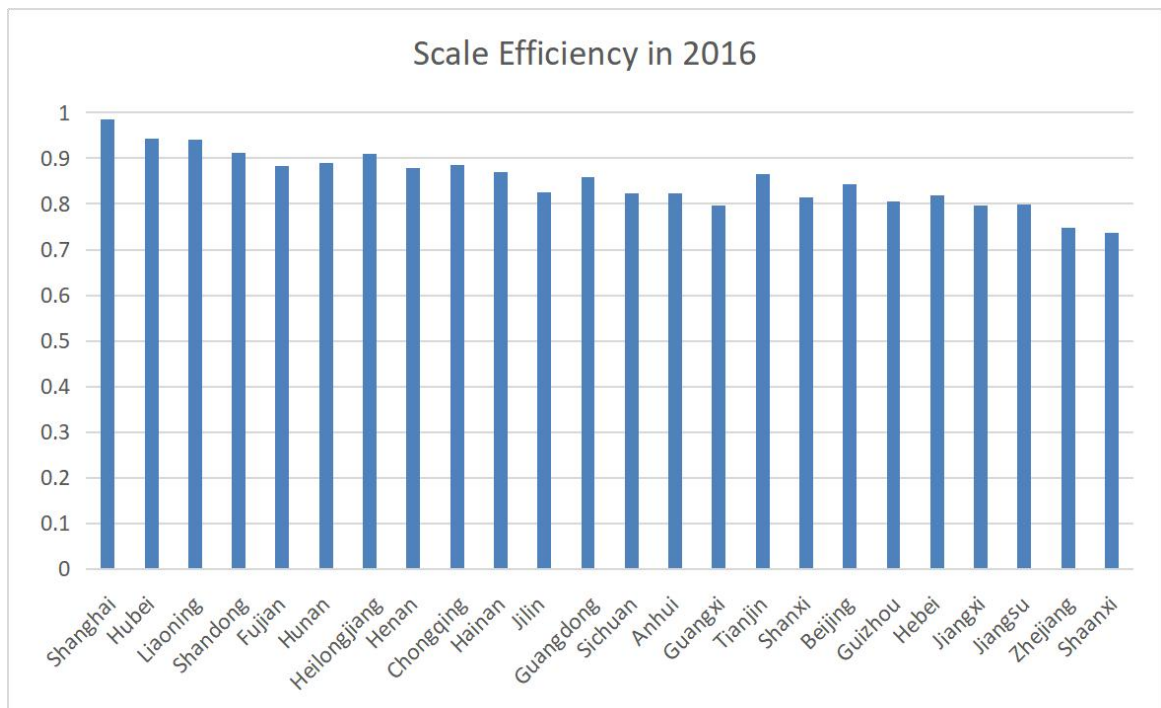
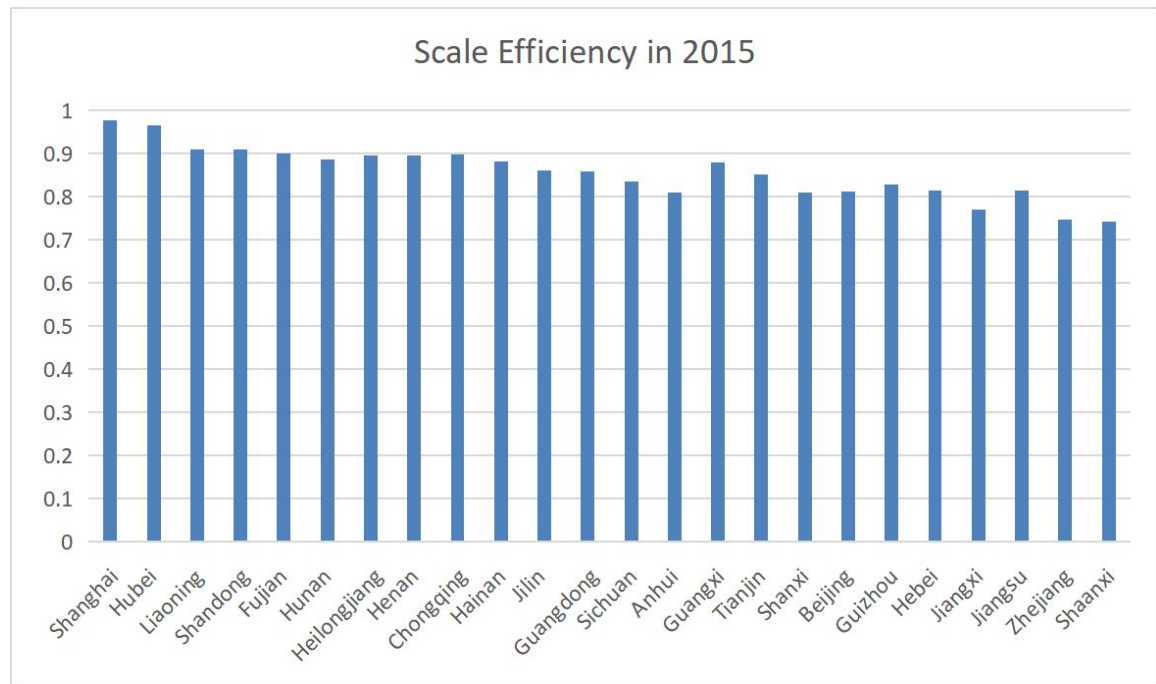


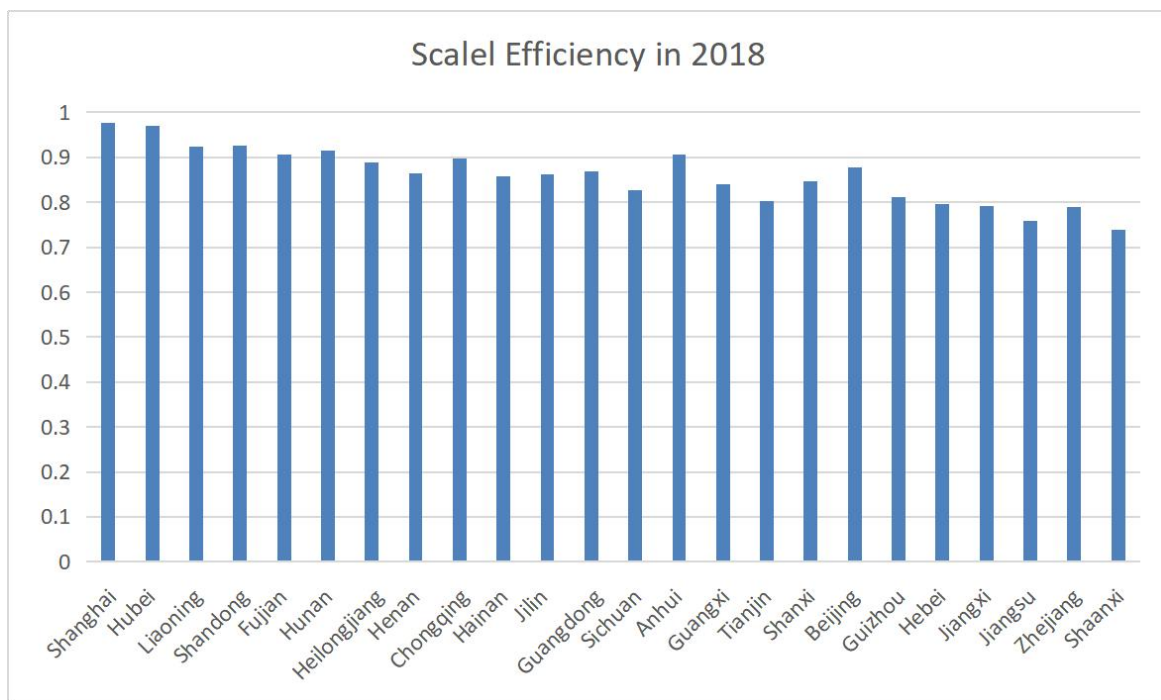
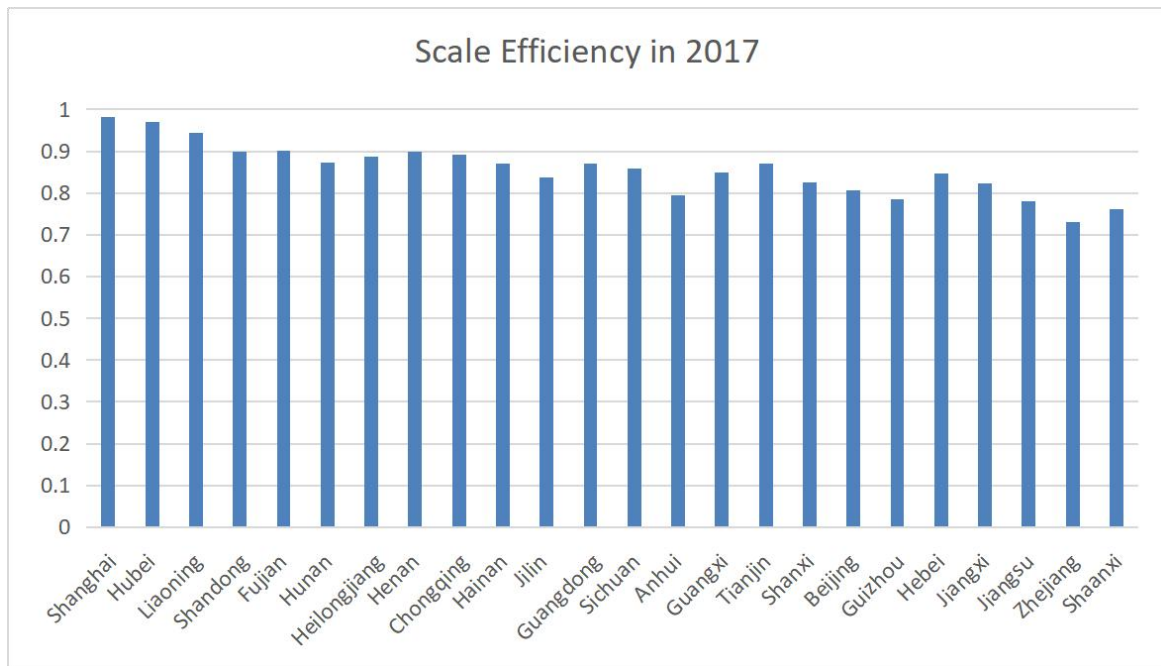


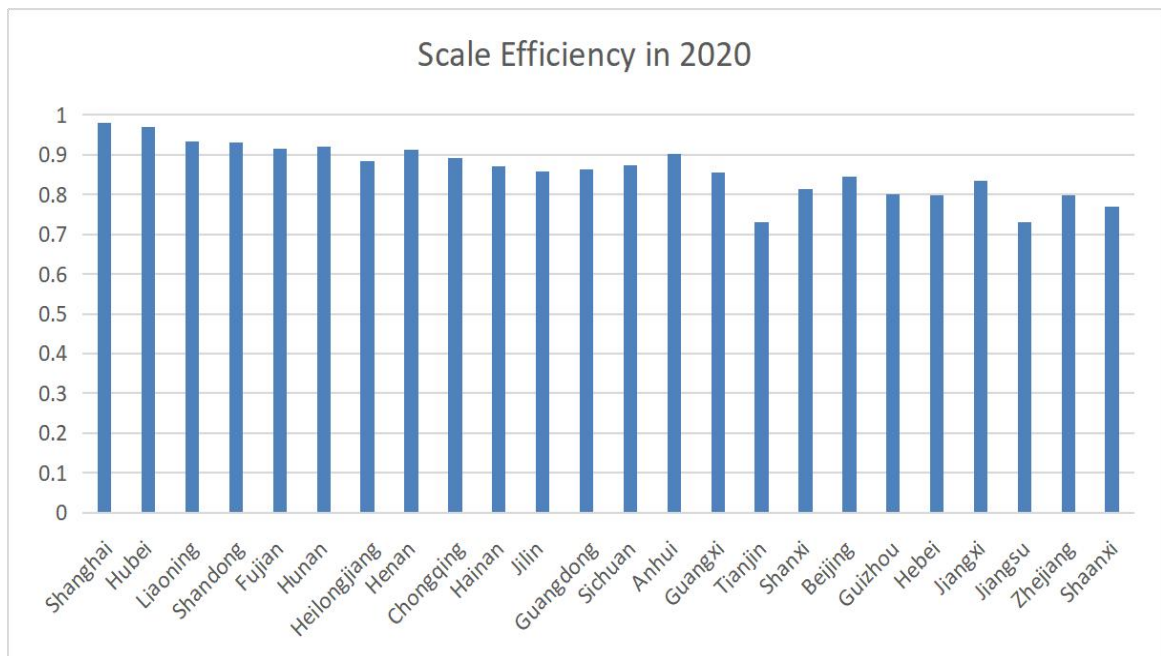
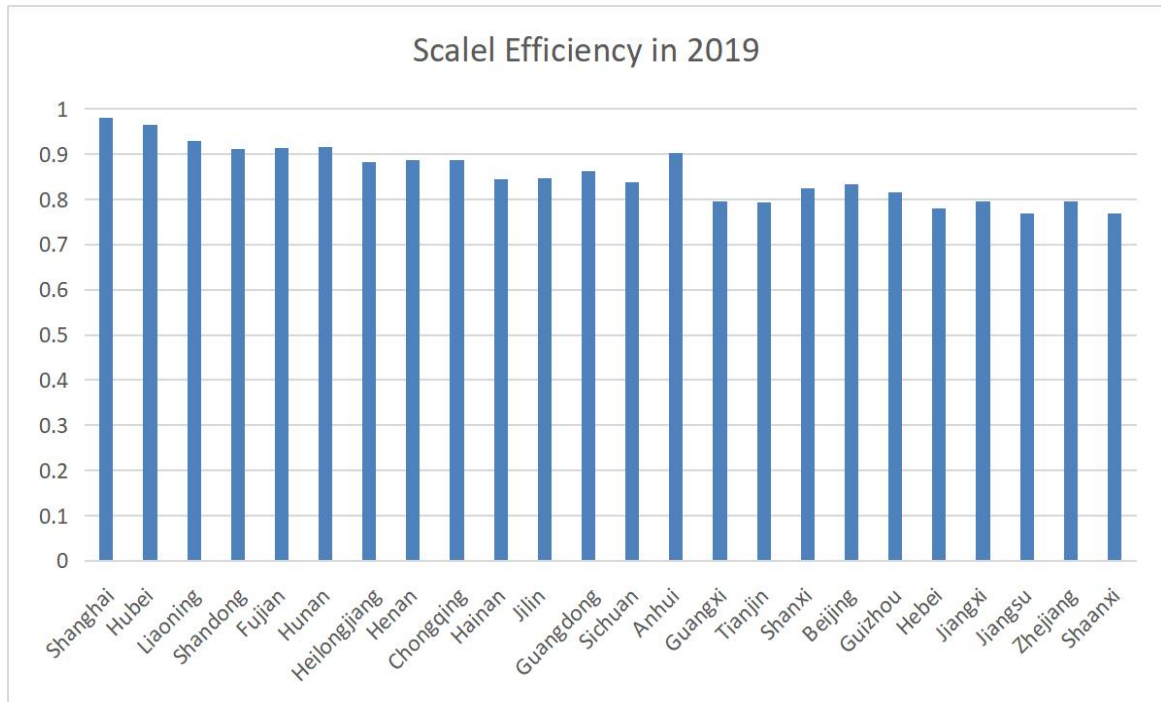
Appendix O: The Full Results of Scale Efficiency

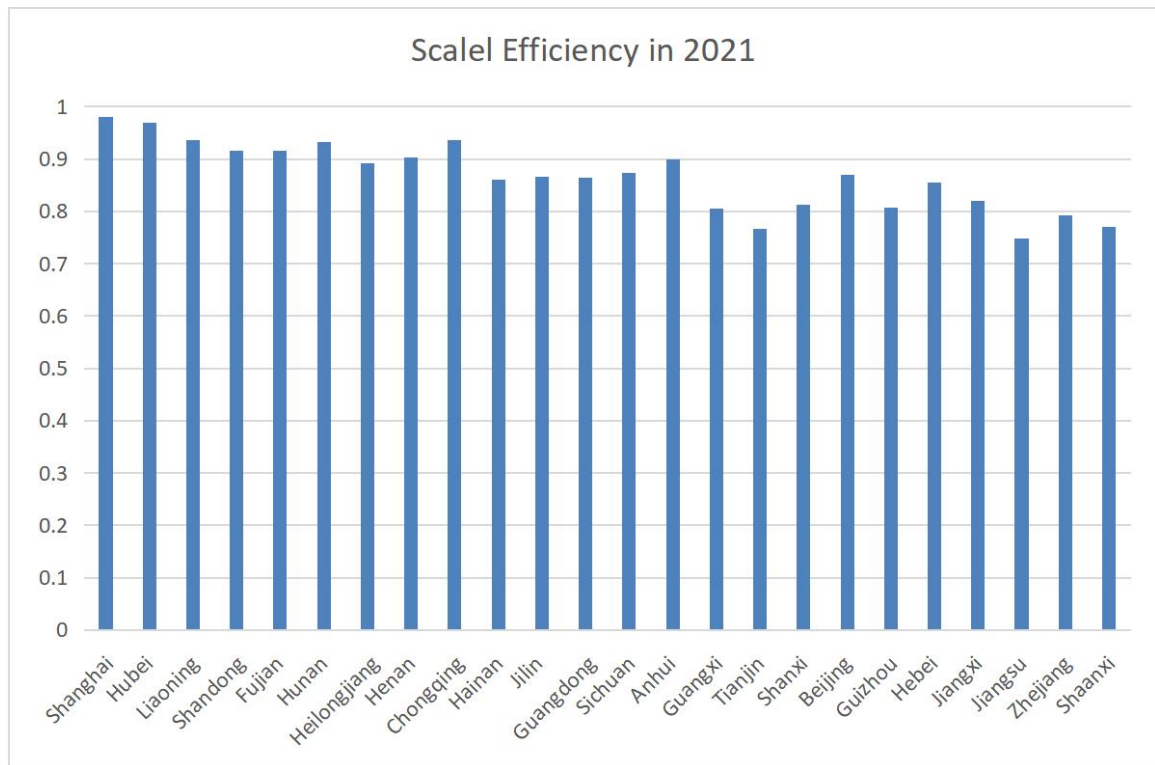




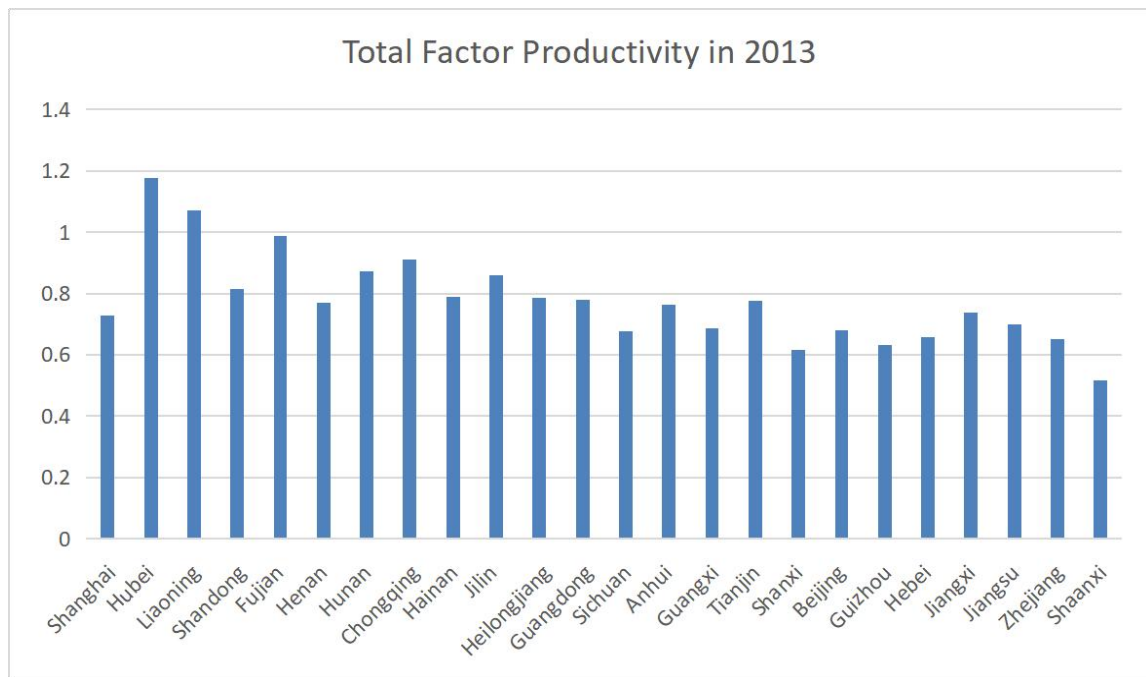
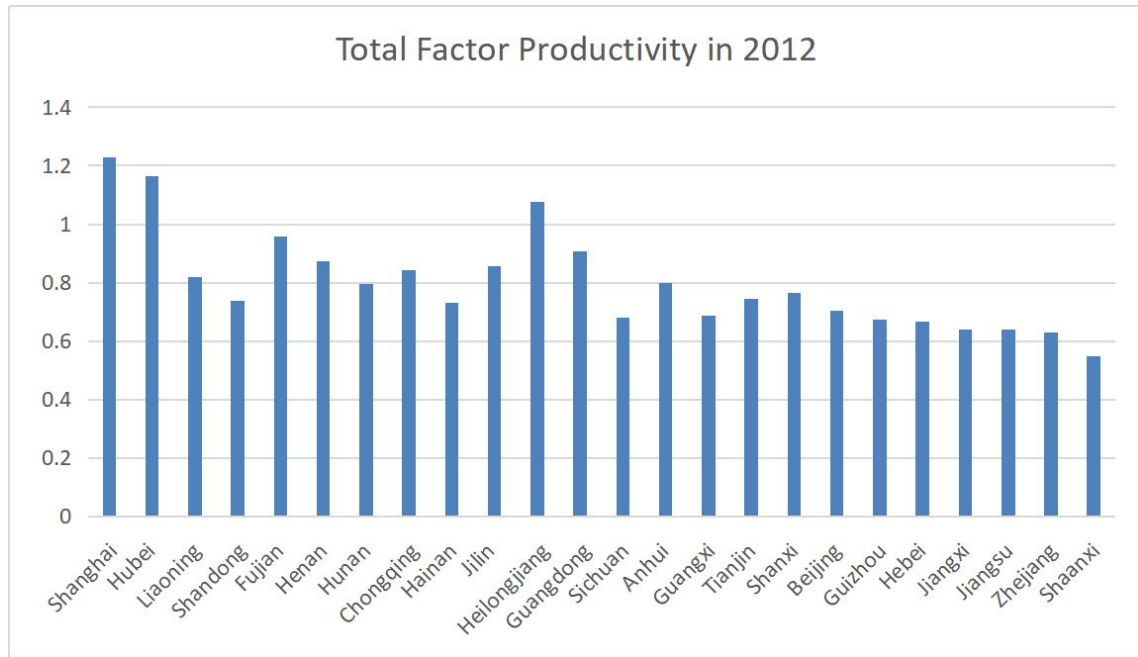


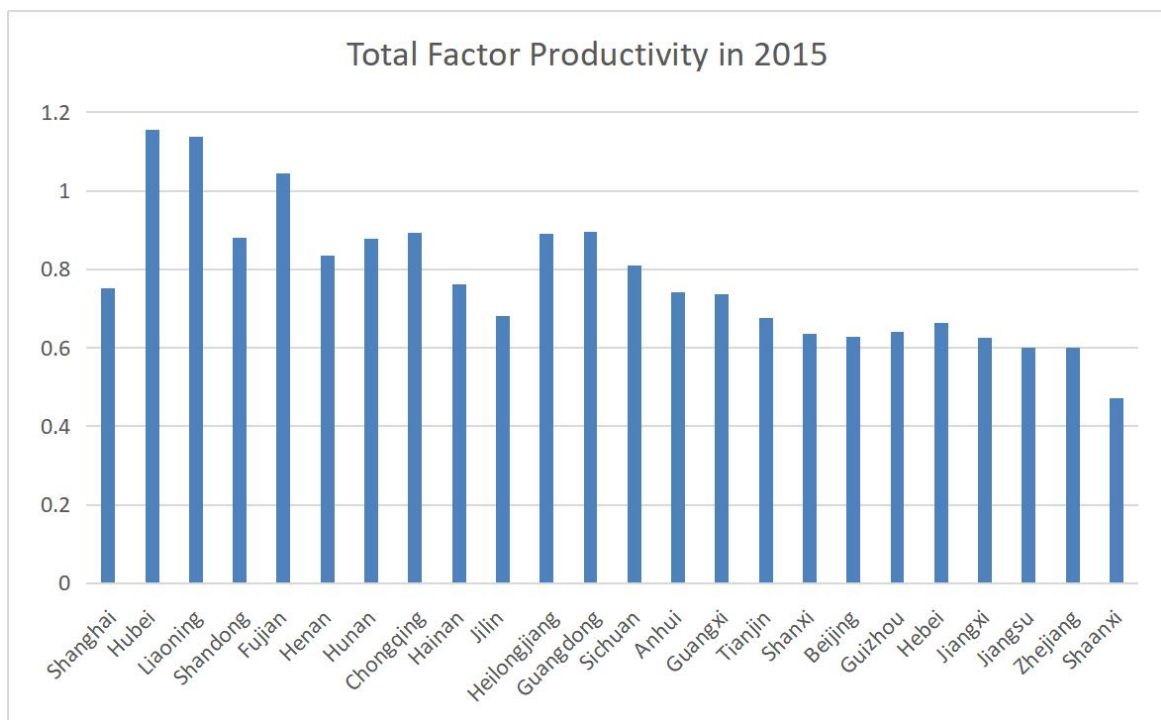
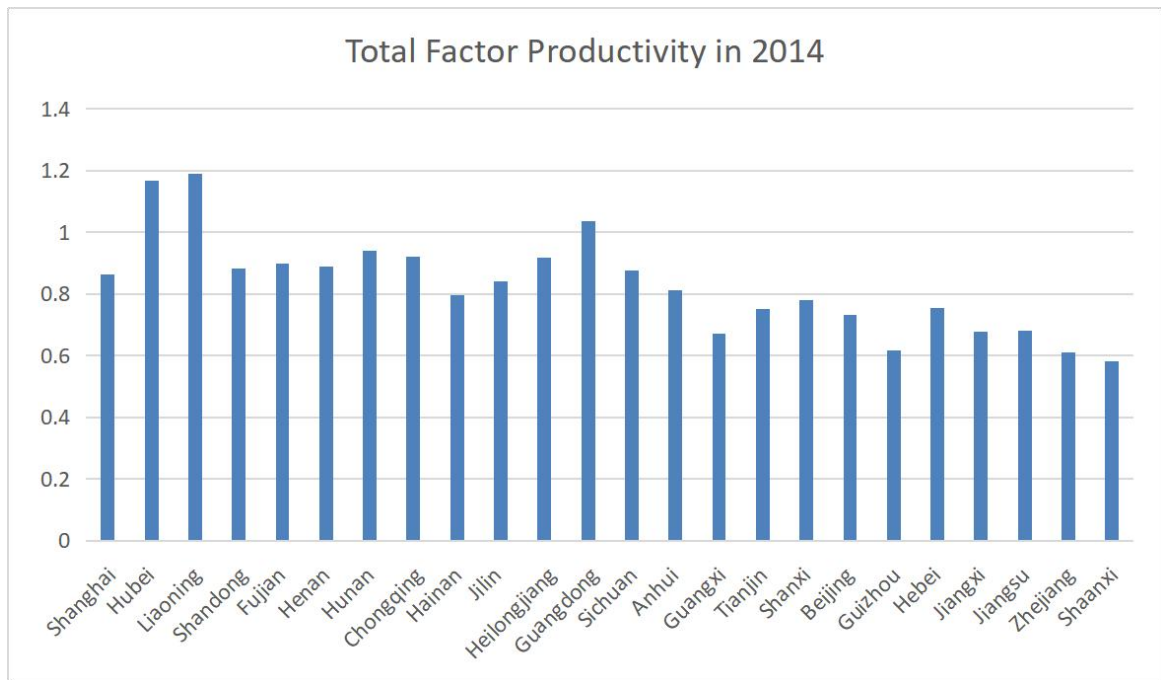


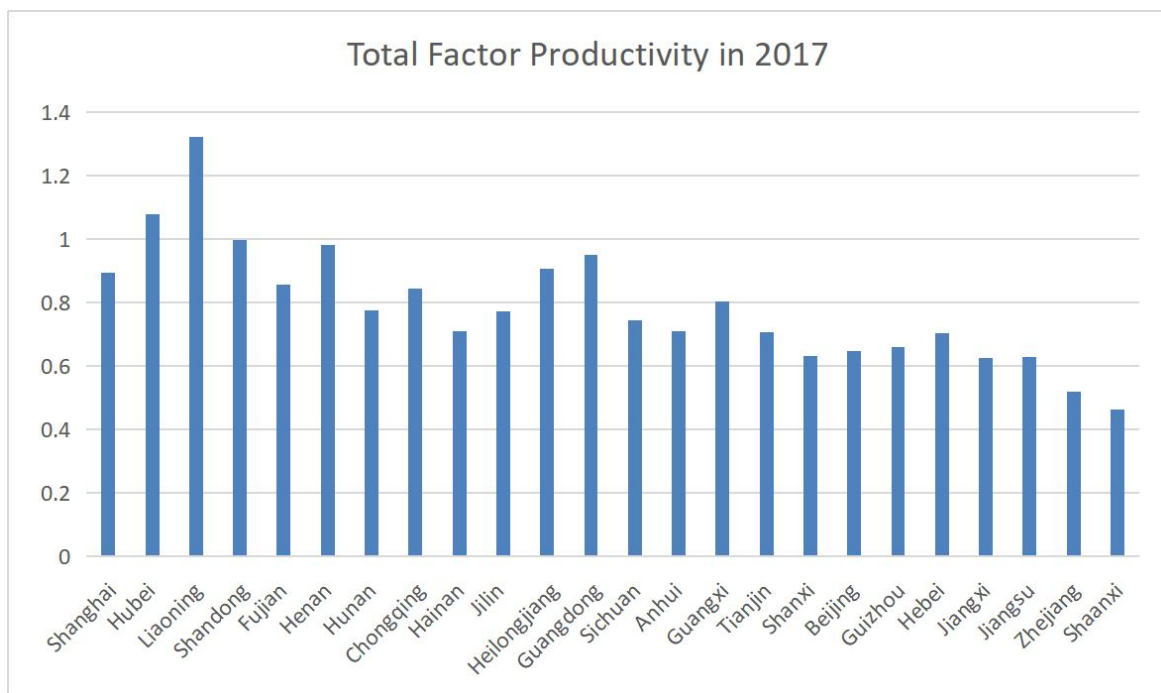
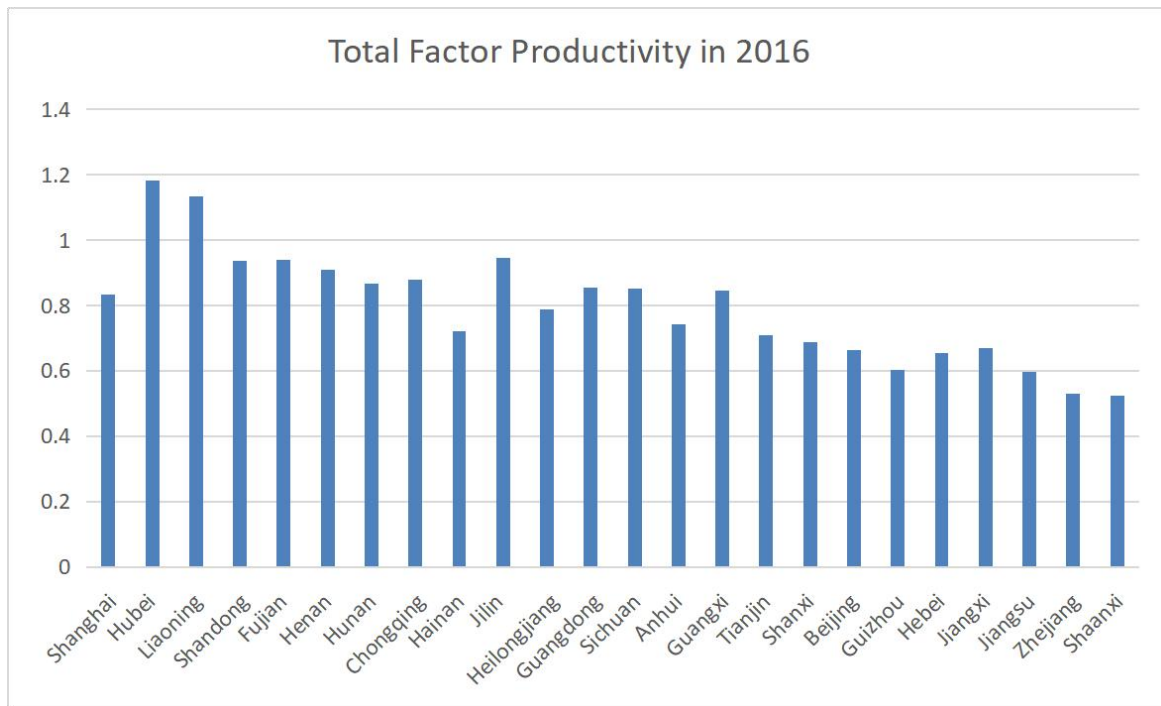


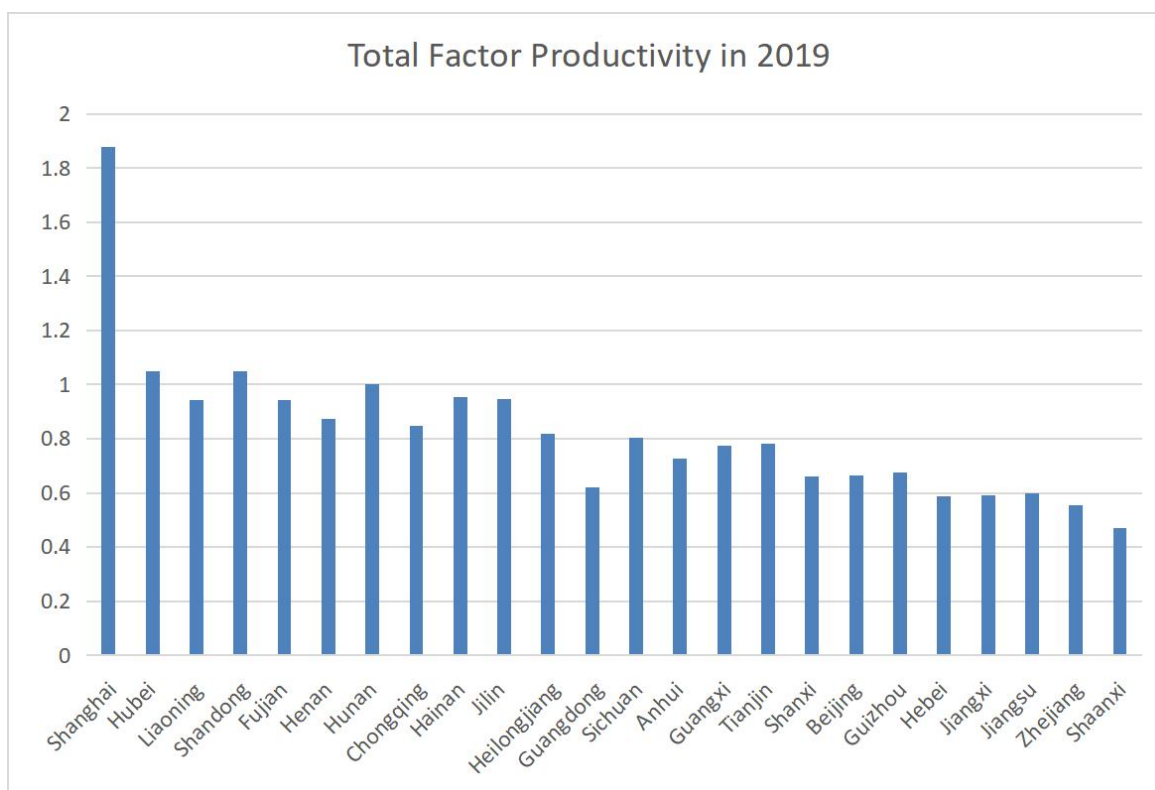
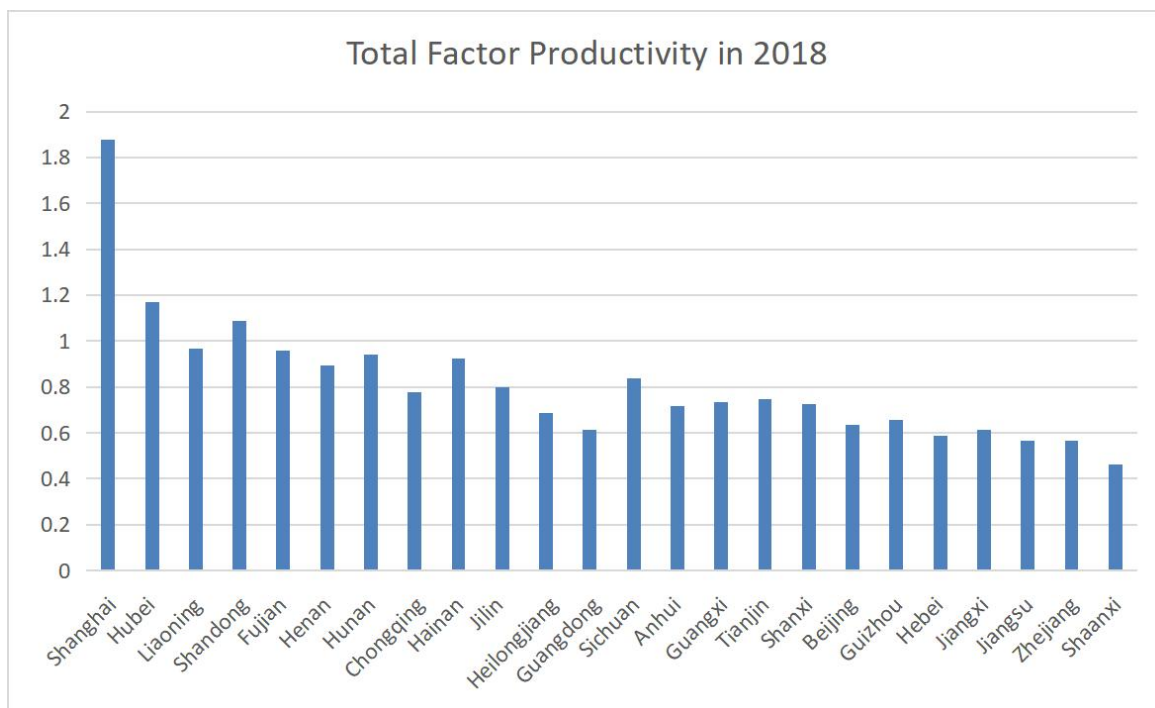


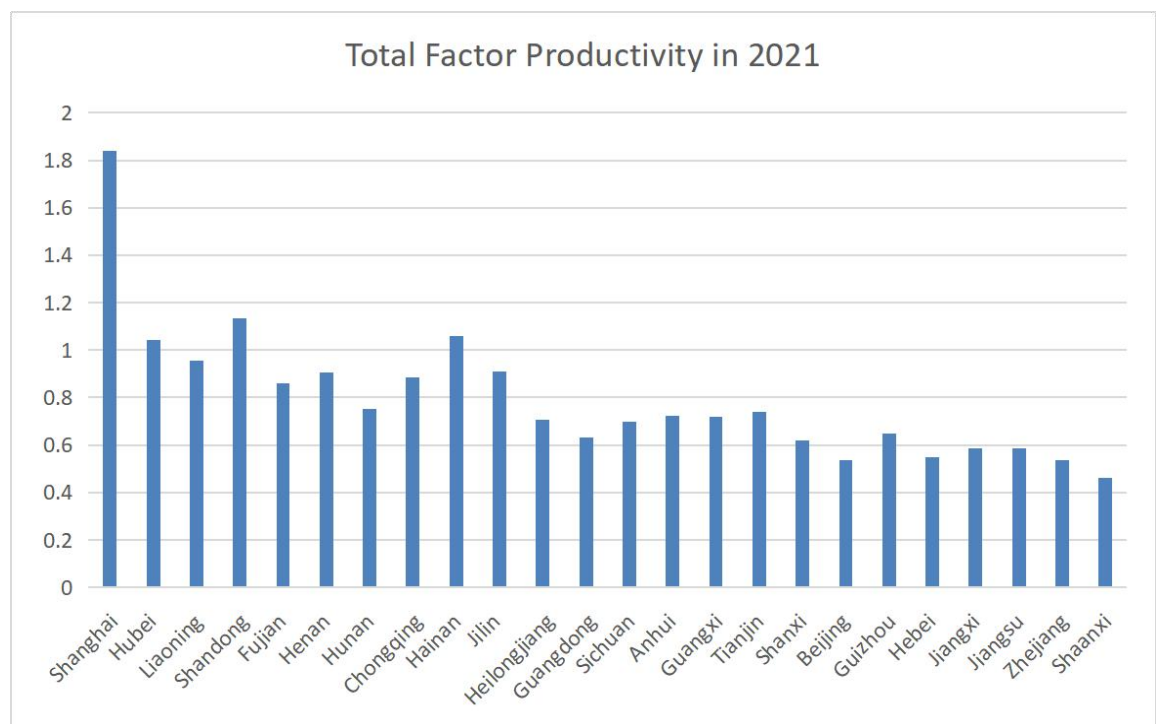
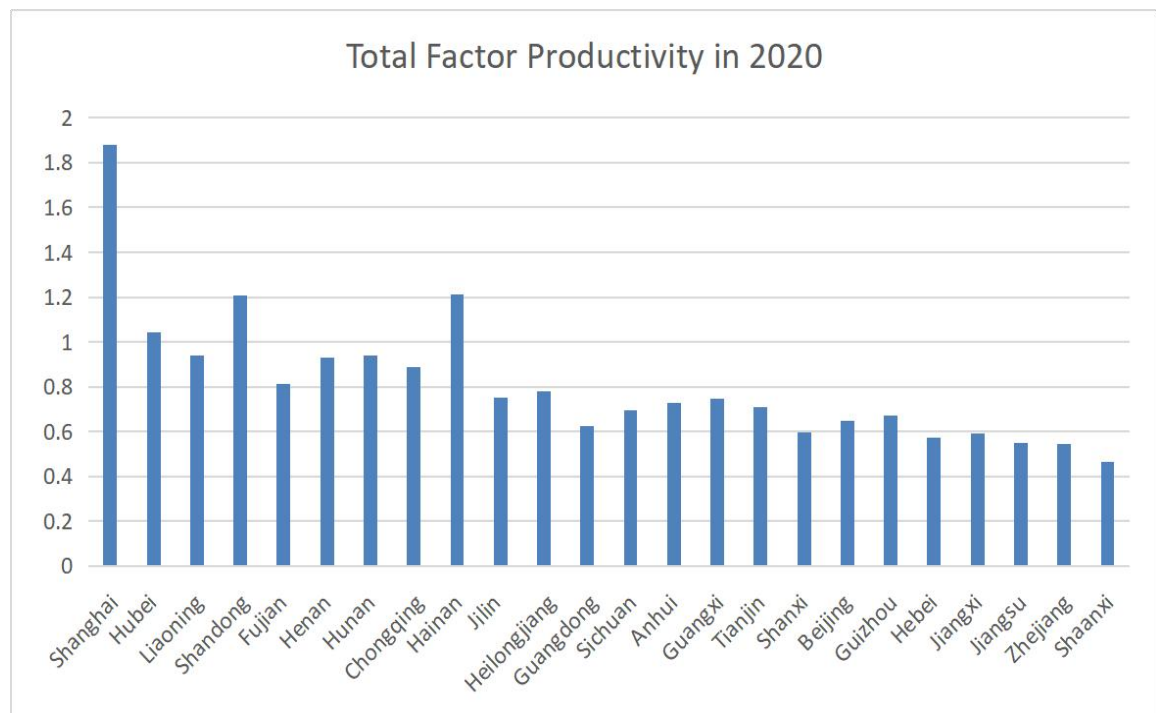
Appendix P: The Full Results of Total Factor Productivity



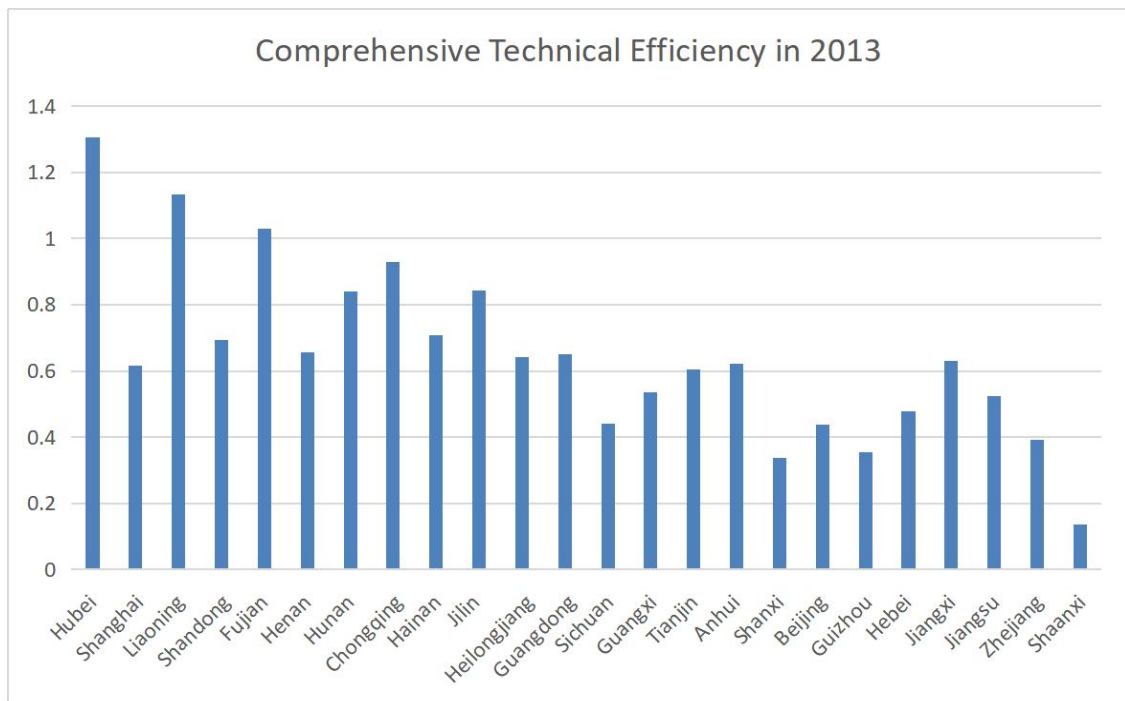
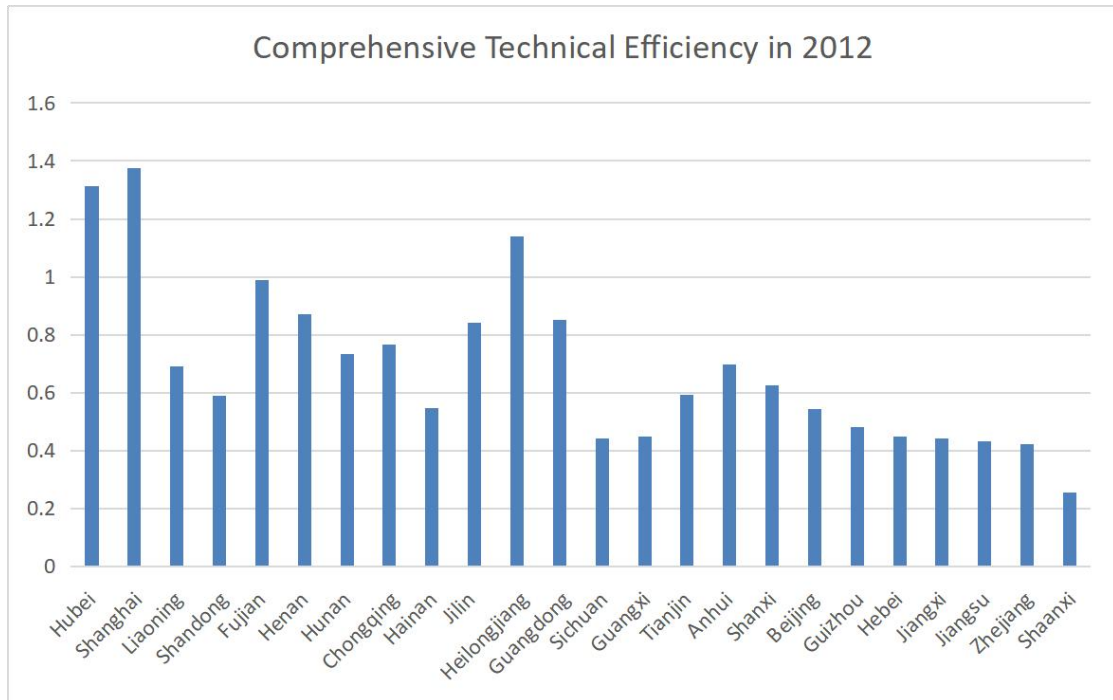


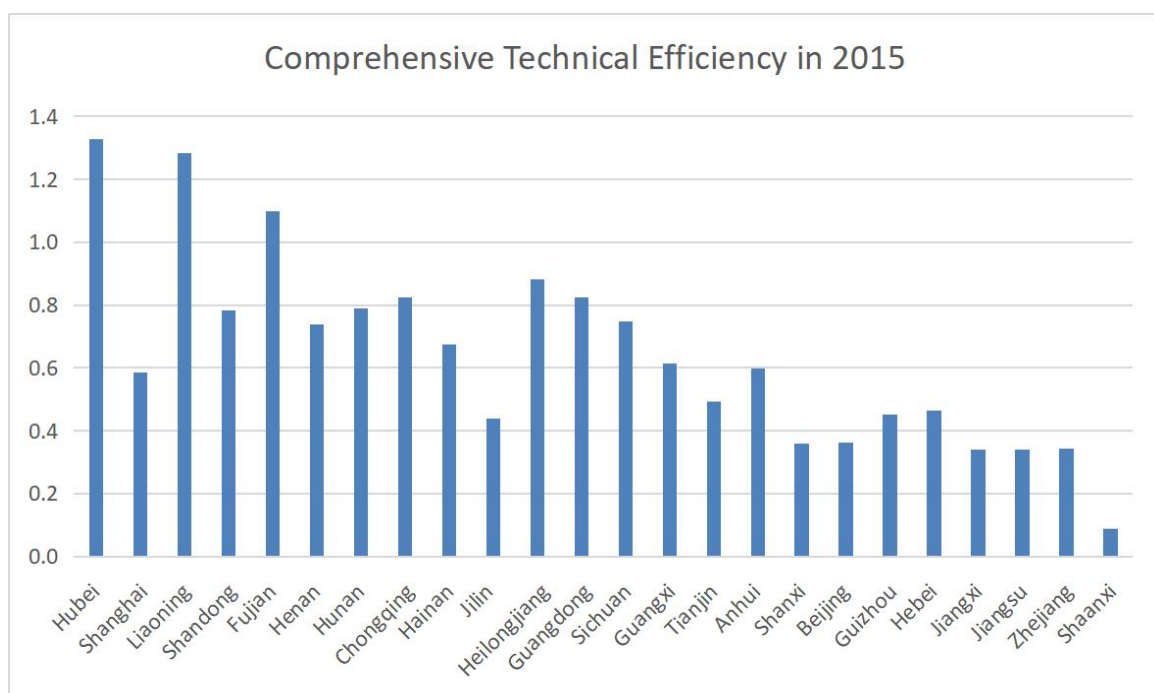
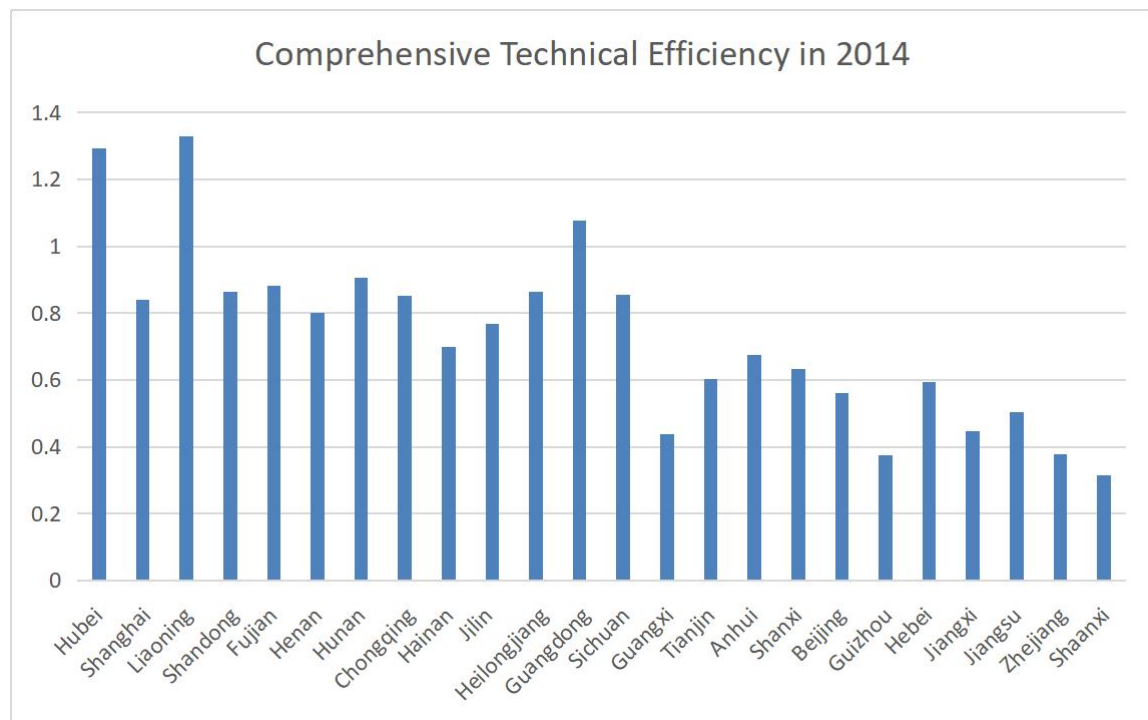


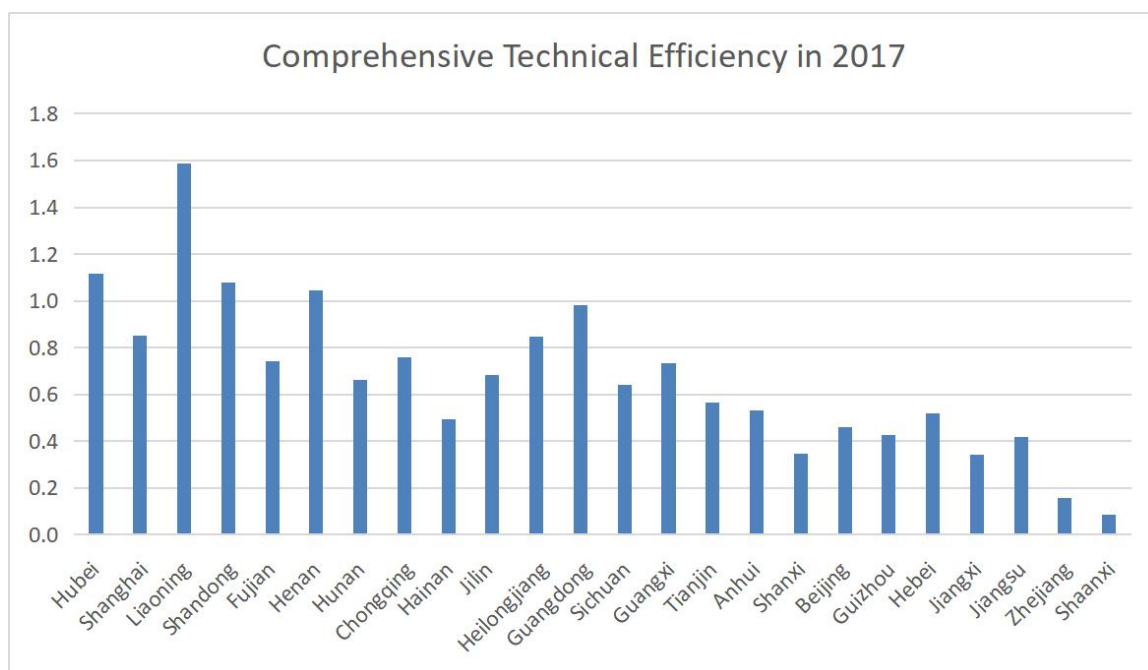
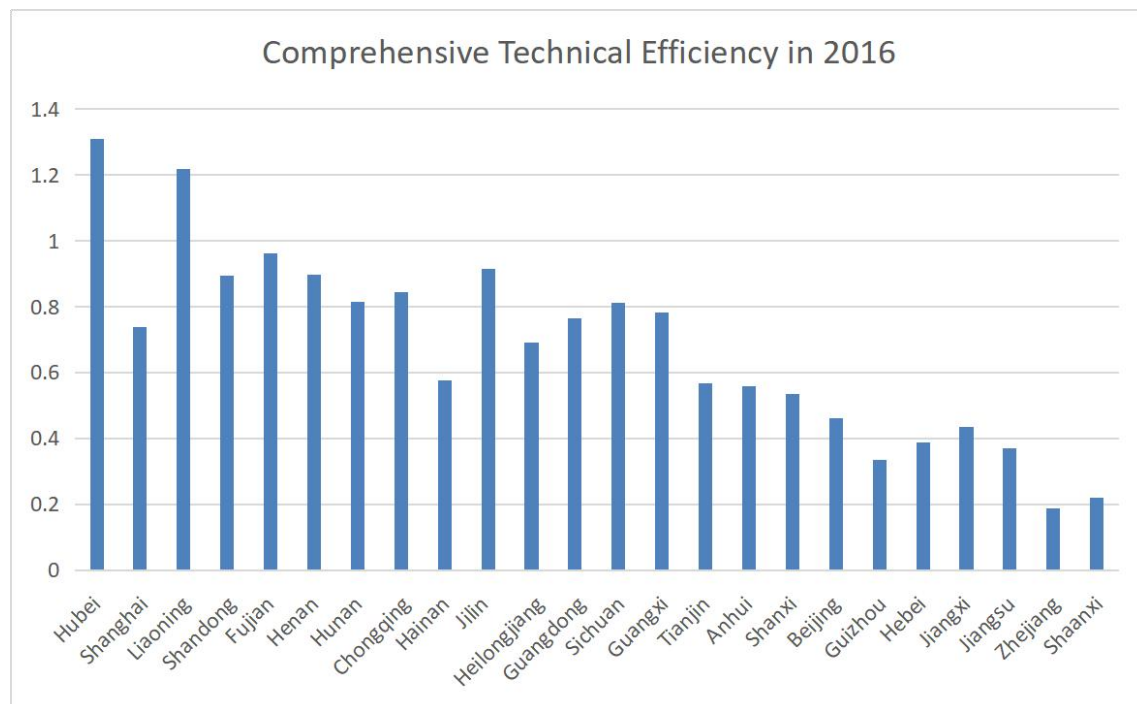


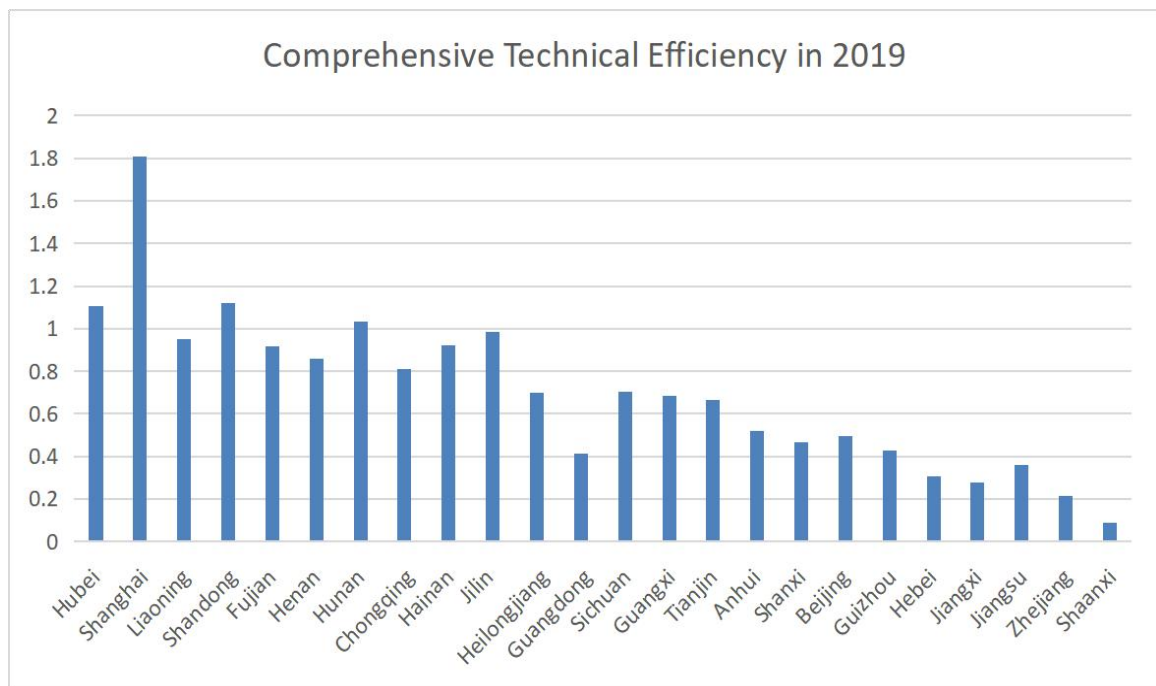
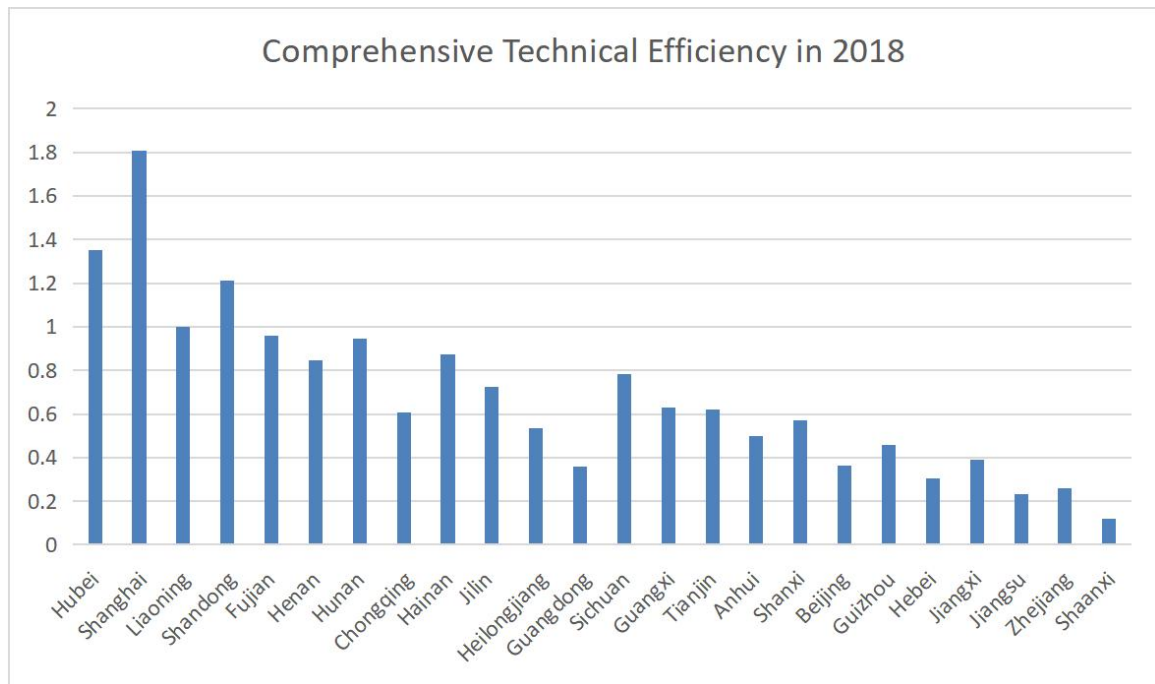


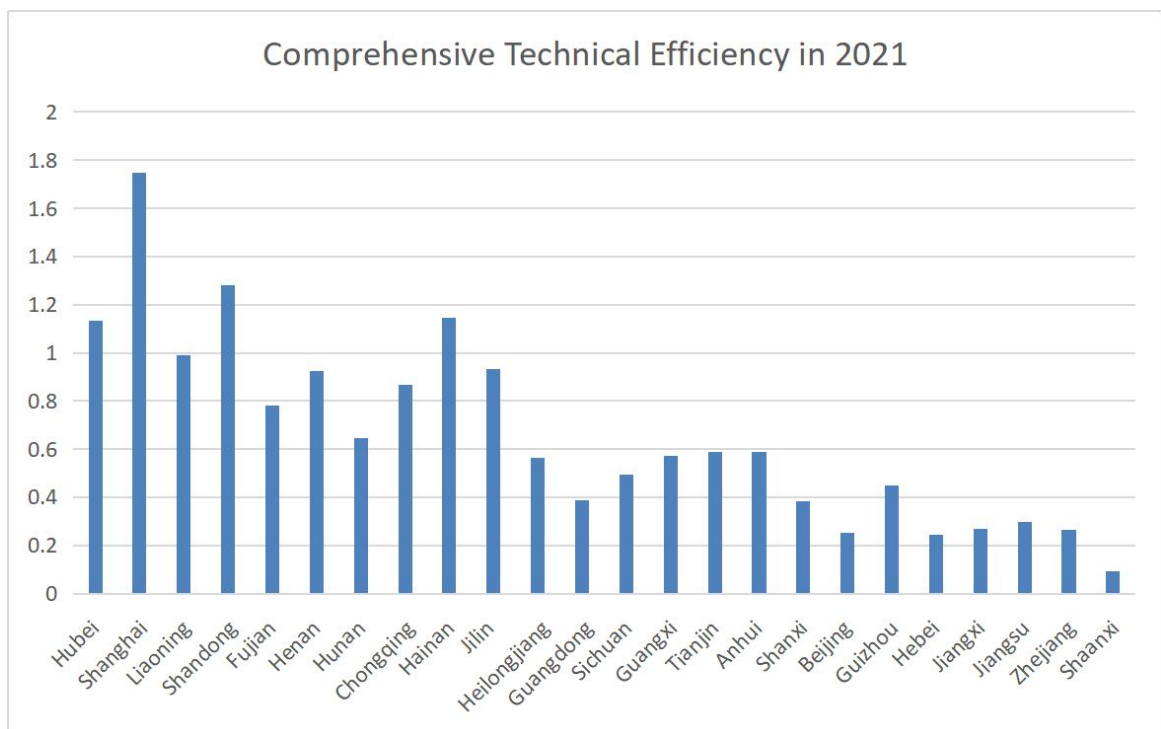
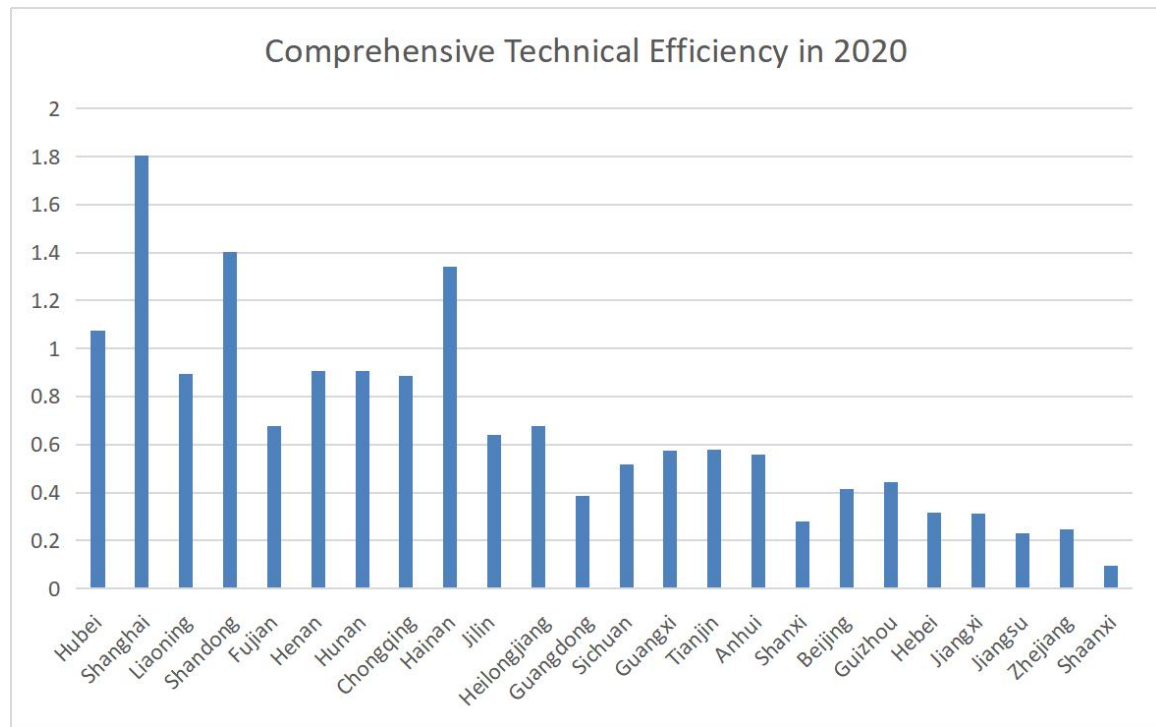
Appendix Q: The Full Results of Comprehensive Technical Efficiency



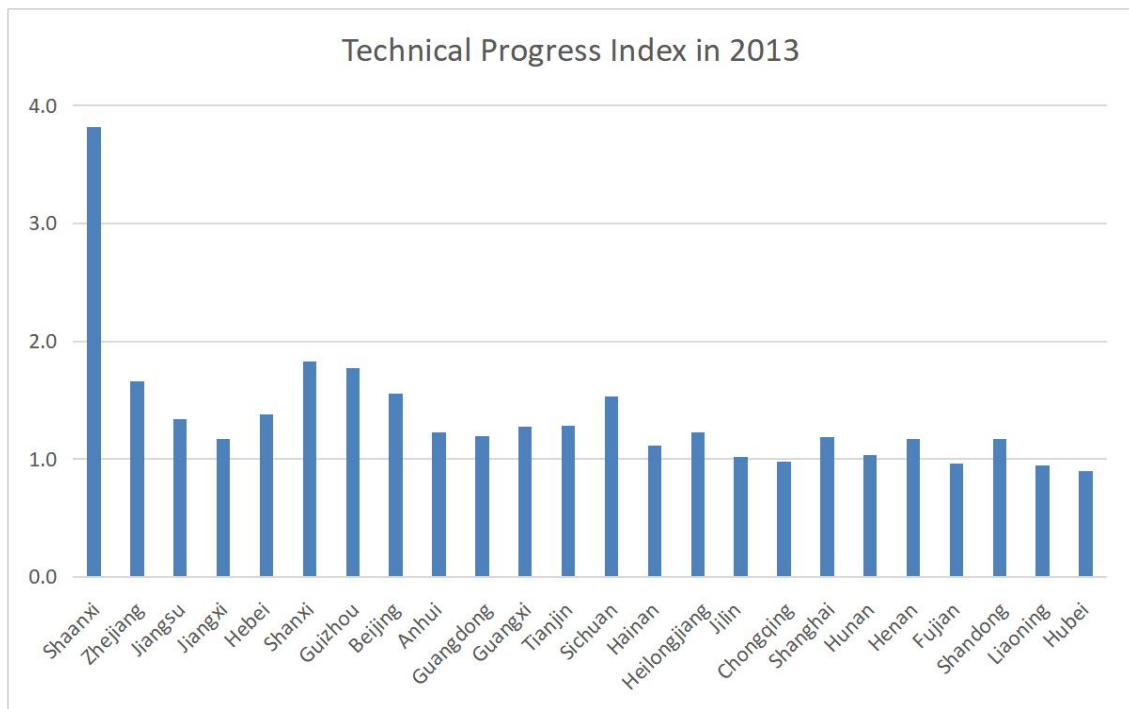
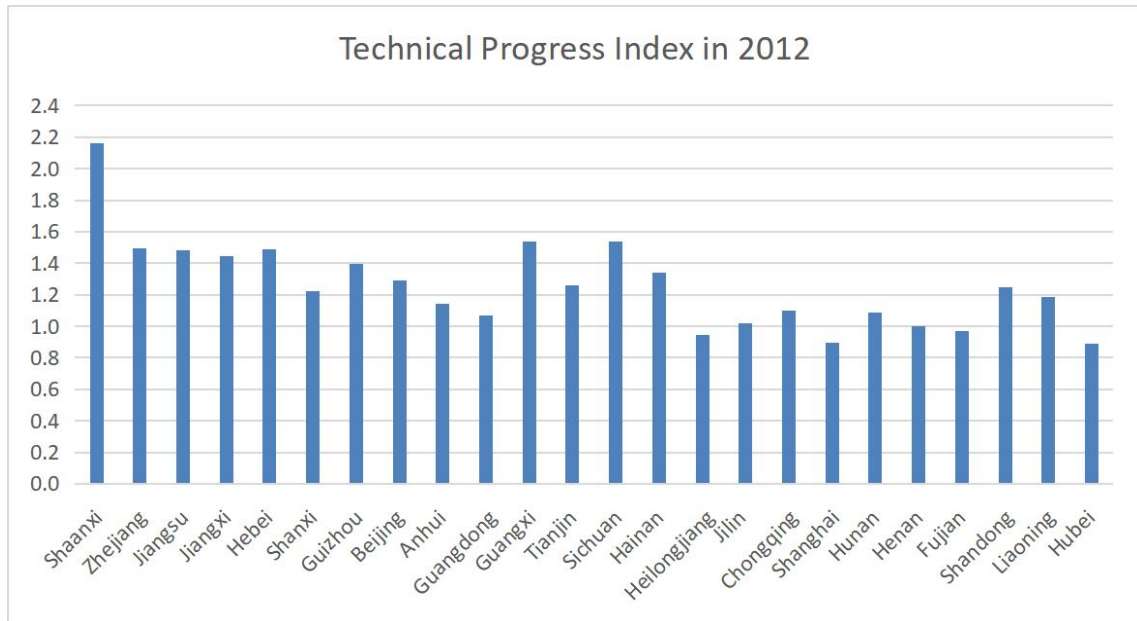


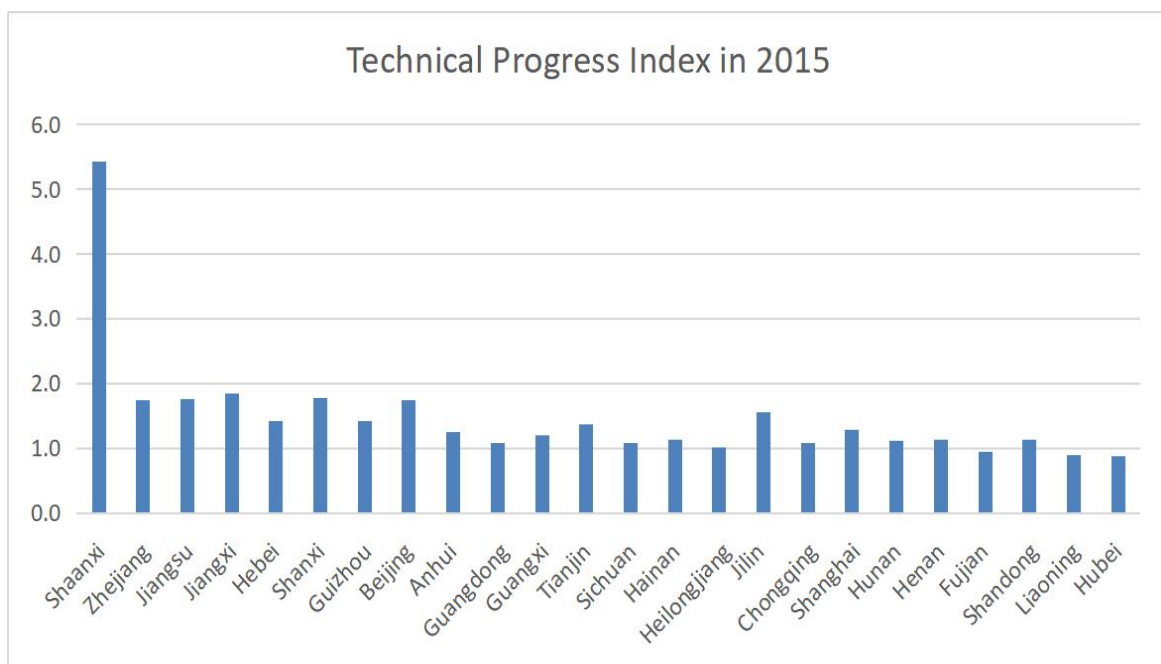
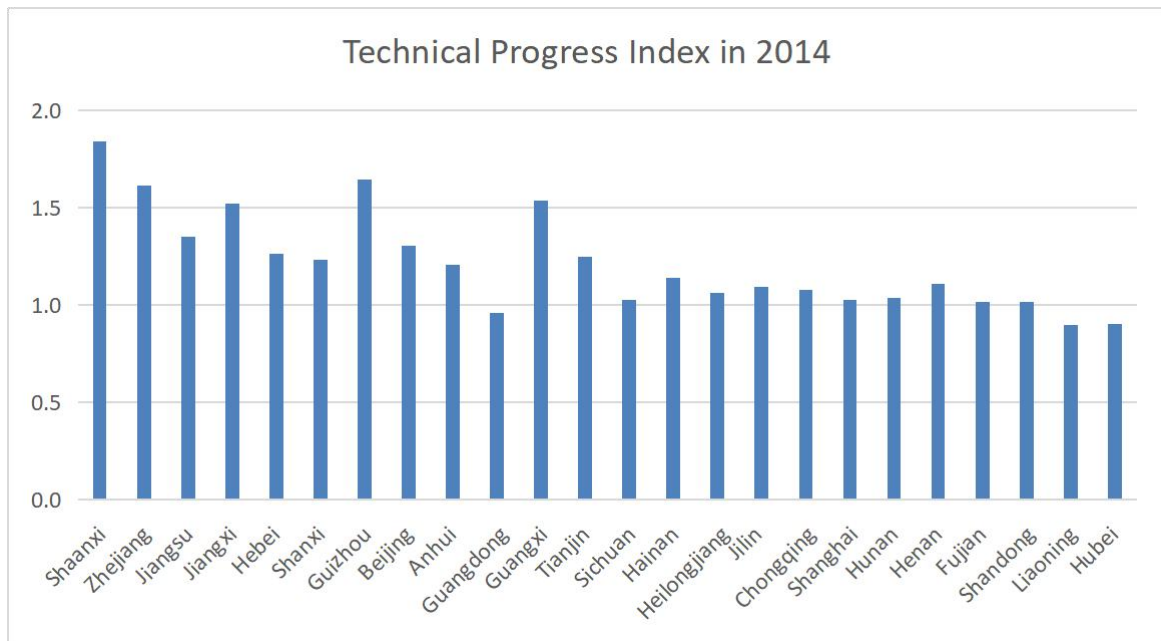


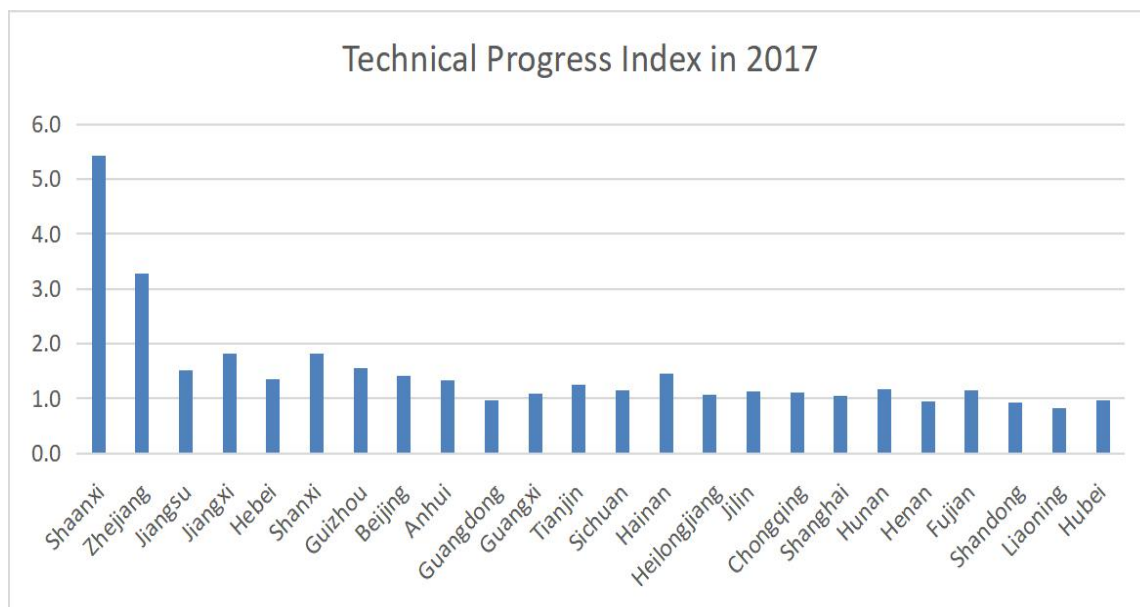
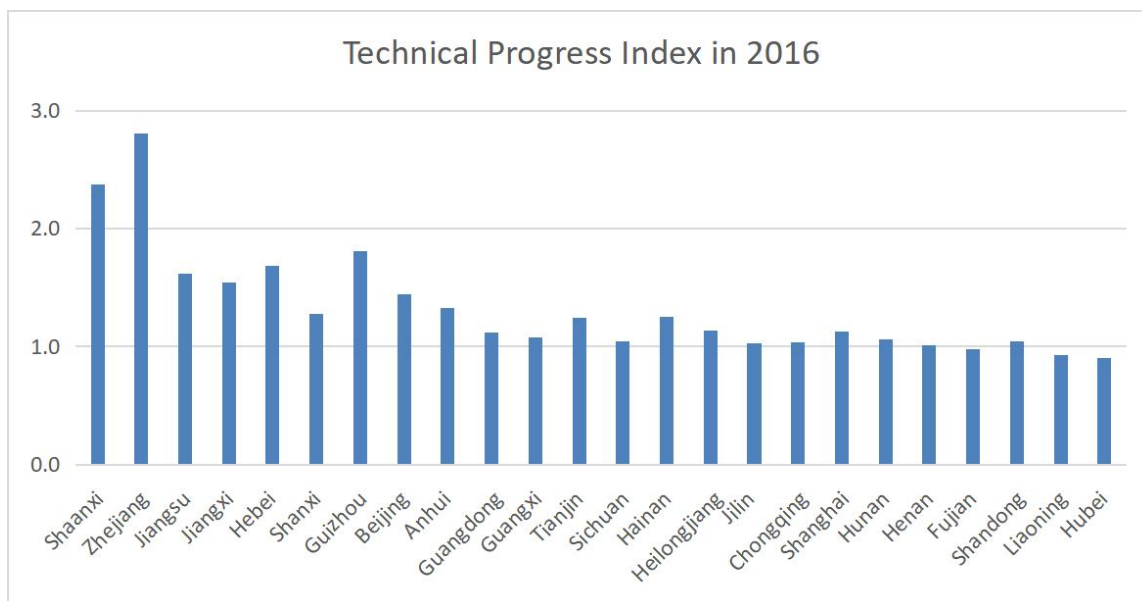


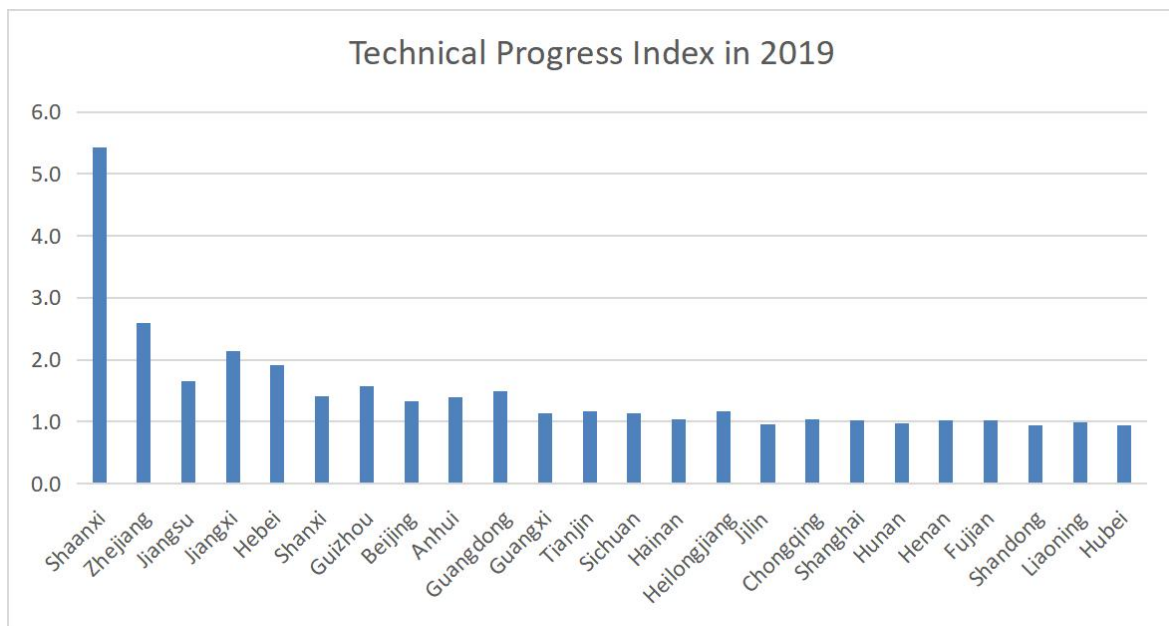
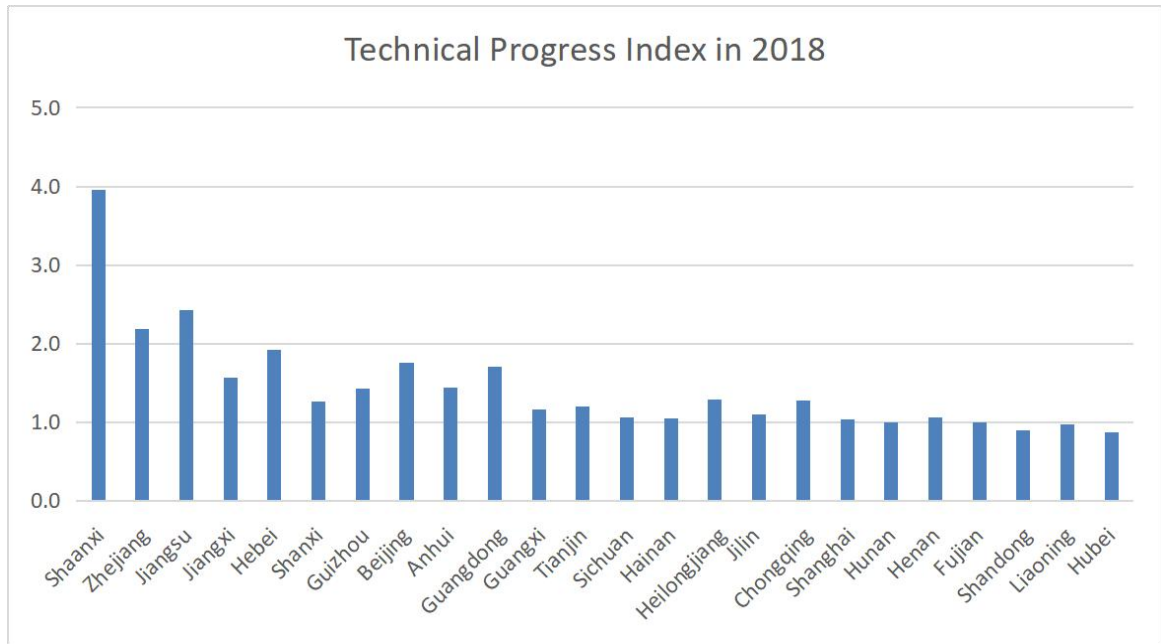


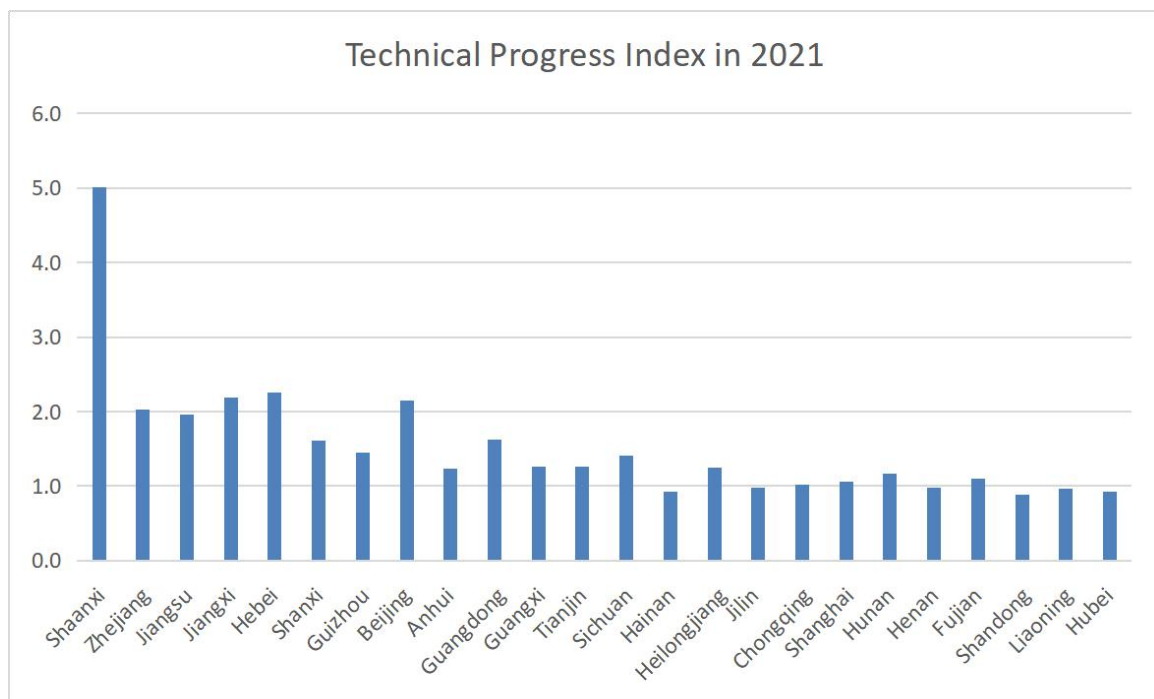
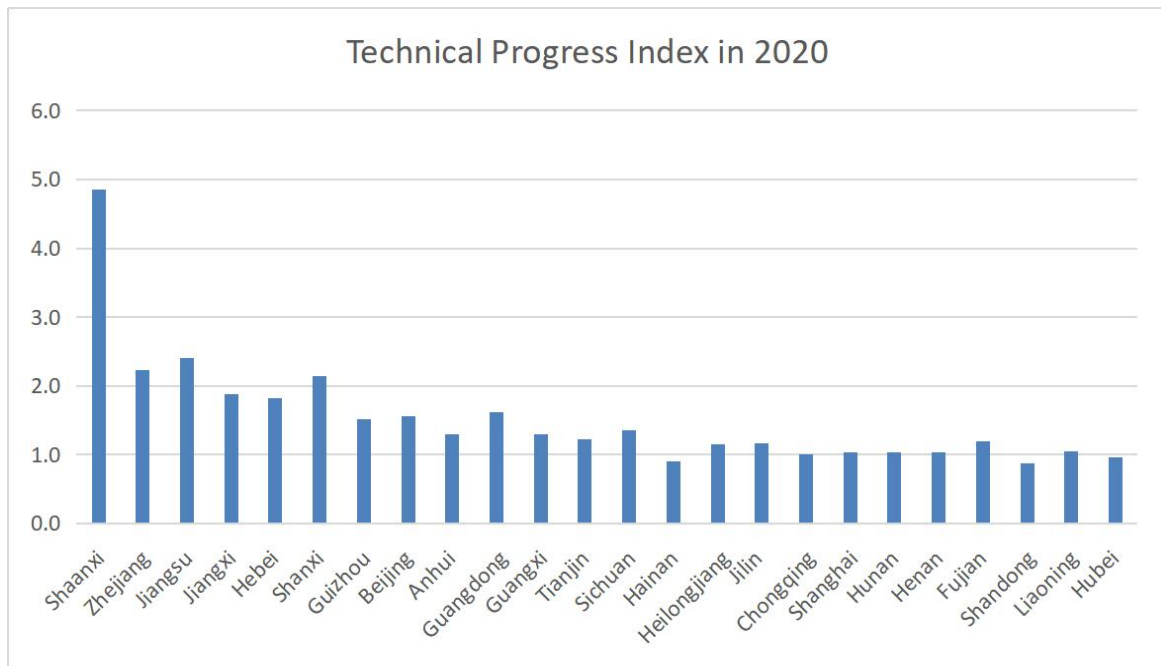
Appendix R: The Full Results of Technical Progress











Appendix S: Brand of China Automobile

Province	Brands
Shandong	Han Ma, Haowo, Yellow River, Tangjun, Fulu, Lichi, Reading, Haigo, Haihui, Shuangchi, Huawo, CT&T, SITRAK, Steyr
Zhejiang	Chery, Kairui, Weilin, Ruiqi, Chongtai, Lingpao, Geely
Jiangsu	Guangzhi, Car and Home, Lixiang,
Beijing	Jihu, Beijing, Futian, Ouake, Aoling, Wise Smurf, Xiangling, Ruiwo, General, Jixiang, Ouhui, Proko, Navigation, Huatai
Hebei	Changcheng, Shuanghuan
Anhui	Chery, Weilai, JAC, Ankai, Xingma
Shanghai	Wuling, Shanghai Shenwo, Mingjue, Rongwei, Weima
Fujian	Jinlong, Soueast
Hunan	Cheetah, Changfeng,
Jiangxi	Jiangling, Landwind, Hanteng
Sichuan	Yema, Nanjun, Sinotruk Ace, Dayun
Chongqing	Dongfeng, EV New Energy, Chenglong, Huashen, Lantu, Fengshen, Fengxing, Lifan, Speed Specific, Qingling, Hafei, Changhe, Lufeng, Chang'an, Chang'an Xingguang, Chang'an Benben, Chang'an Jiexun, Chang'an Zhixiang, Chang'an Ruixiang

Appendix S continued

Hubei	Chitian, Dofeng Special
Guangdong	Trumpqi, Gonoe, Aion, Xiaopeng, BYD, Ruikai, Baoneng
Hainan	Haima
Tianjin	Xiali, Huabei, Sanfeng, Yan, Tieniu, Huali
Henan	Yutong, Suda, Shaolin, Bike
Guizhou	Yunque, Hangtian, Wanren, Guizhou Changjiang, Xinte
Guangxi	Wuling, Hongchi
Heilongjiang	Hafei
Jilin	FAW Jiefang, FAW Sedan, Red Flag, FAW Haima, FAW Pentium
Liaoning	Huacheng, Hunaghai, Shuguang
Shaanxi	Yanan, Delong, Shacman, Xuande, Datong, Sitaier, Aolong, Oushute, Huashan, Tongjia
Shanxi	Dayun, Yuanhang, Yuanzhi, Yuehu