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Efficiency Performance of China Brand Automobiles: The Role of Innovation Systems

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Abstract

This research aims to examine and investigate the efficiency performance and its influencing factors of China brand automobiles' innovation system using both theoretical and empirical approaches. Initially, the study applies the DEA model to assess the technical efficiency, pure technical efficiency, and scale efficiency of the innovation system of China brand automobiles. The results reveal a general upward trend in the innovation system's efficiency of China brand automobiles. Subsequently, a panel regression model is employed to analyze the determinants impacting the efficiency of the innovation system. The findings of the research suggest that economic development, openness to international markets, and marketization enhance the technical efficiency of the innovation system of the domestic automobile industry. However, an increase in enterprise size tends to negatively affect this technical efficiency. While economic growth, openness, and marketization positively impact pure technical efficiency, the expansion of enterprise size exerts a detrimental effect. Conversely, enterprise size growth positively influences scale efficiency, whereas openness and marketization present some negative implications. Lastly, this study proposes policy recommendations from both governmental and enterprise viewpoints, aimed at promoting the sustainable advancement of the automobile industry.

Keywords: Efficiency, China Brand Automobiles, Innovation System, DEA.

1 Introduction

Research Background

In recent times, Chinese automobile brands have exhibited a robust growth trajectory and a clear trend toward innovation. As the domestic automotive market continues to expand and consumer demand

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evolves, China brand cars are also constantly improving in terms of technology, quality, design, and performance.

In this context, examining the efficiency of China brand automobiles' innovation system holds significant importance. Firstly, the swift evolution and innovative trajectory of China brand automobiles epitomize the advancement of the Chinese automotive industry (Li, 2019). Amidst intensifying global competition within the automotive market, nations are hastening the transformation and enhancement of their automotive sectors to align with shifting market dynamics and confront international competitive pressures. Being one of the globe's largest automotive markets, China is similarly expediting the transition and enhancement of its automotive industry. Governmental authorities have released a series of industry standards, including the development plan for new energy vehicles and supporting the construction of intelligent network connected systems. With the support of favorable policies, the Chinese automotive industry is accelerating its transformation and upgrading, aiming to reach a high ground in the future of "low-carbon, informatization, and intelligence" (Gao, 2021). In this process, the innovation ability and competitiveness of China brand cars have gradually emerged, becoming an important force in promoting the transition and enhancement of China automobile industry.

Secondly, the innovation efficiency of Chinese brand automobiles significantly influences the competitiveness and long-term viability of enterprises. In the face of escalating market competition and evolving consumer preferences, companies must possess efficient innovation capabilities and swift market responsiveness to maintain their competitive edge. Consequently, investigating the innovation efficiency of Chinese brand automobiles not only enhances enterprise innovation and market competitiveness but also fosters the sustainable advancement of the Chinese automotive industry (Zhang, 2022).

Finally, China automobiles' innovation efficiency significantly impacts the nation's economic development and industrial security. The automotive industry, strategically crucial, influences economic growth, employment, and industrial stability. Therefore, analyzing the innovation efficiency of China brand automobiles not only advances the industry's development and modernization, but also helps to enhance the comprehensive strength and industrial security of the country (Klink et al., 2014).

Therefore, This research focuses on examining the efficiency performance of China brand automobile industry's innovation system. By conducting a comprehensive literature review on innovation efficiency in both domestic and international automotive industries, this study employs theoretical and empirical methodologies to analyze innovation efficiency and its influencing factors specific to Chinese automobile industry. The goal is to pinpoint the key factors contributing to the enhancement of innovation efficiency. Subsequently, based on these findings, policy recommendations will be formulated to foster innovation and advancement of China brand automobiles, thereby offering effective strategies for their long-term sustainable development.

Significance of Study

The primary objective of this research is to conduct an in-depth investigation into the efficiency performance of China brand automobile industry's innovation system and identify the key influencing factors. By employing systematic analysis and empirical research methods, this study aims to offer theoretical insights and policy recommendations aimed at enhancing the innovation capabilities of China brand automobiles, optimizing the allocation of innovation resources, and bolstering market

competitiveness. The significance of this research can be categorized into four main dimensions: theoretical, practical, social, and academic.

When referring to theoretical significance, this study can enrich and develop the innovation theory of China automotive industry, furnishing essential theoretical underpinnings and strategic guidance for its innovative evolution. Simultaneously, a profound investigation into innovation efficiency and its determinants holds significant implications for the metamorphosis, enhancement, and innovative progress of the Chinese automobile sector.

As to practical significance, this study holds significant practical implications for the advancement of the Chinese automobile industry. Through the assessment and comparative analysis of the efficiency of China's automotive sector's innovation system, the study aims to help enterprises identify innovation bottlenecks and clarify development directions, provide a decision-making basis for formulating innovation strategies, optimize resource allocation, and improve market competitiveness. At the same time, providing policy recommendations to relevant government departments, promoting the improvement and development of industrial and technological policies, and making the sustainable development of the automotive sector in China.

Regarding social benefits, this research endeavor is poised to enhance the innovation prowess and global competitiveness of the Chinese automotive sector, fostering technological advancements and facilitating the industry's transformation and elevation. Such efforts will contribute to bolstering the nation's overall economic robustness and international prominence, it also brings positive social benefits to promote employment and regional economic development.

Regarding academic value, the results of this study will provide valuable empirical research information and perspectives for the domestic and international academic community, and help promote the development and improvement of related disciplines such as innovation, economics, and industrial economics. At the same time, this study holds the potential to furnish essential theoretical underpinnings and pragmatic directives for the government and enterprises to cultivate more innovative talents and promote technological innovation.

2 Literature Review

Research on Efficiency Measurement

Farrell, (1957) proposed a measurement method for the forefront of technical efficiency, which was widely recognized in the academic community. The core idea of this theory revolves around delineating the production possibility frontier by analyzing input-output data. This method ensures that all outputs are within the boundary and all inputs are outside the boundary, and the distance between the observed values and the boundary forms the efficiency level of the corresponding production unit. The techniques for gauging the efficiency frontier can be categorized into parametric analysis approaches and non-parametric analysis approaches. The parameter analysis methods mainly include three methods: random frontier analysis, thick frontier analysis, and free distribution analysis. Non parametric analysis methods mainly determine the production frontier and measure technical efficiency by solving linear programming, with data envelopment analysis as the main method.

In terms of data envelopment analysis, Charnes et al., (1978) introduced the DEA method, which is extensively employed for estimating efficiency in systems with multiple input and output indicators.

This method uses data planning and statistical data to determine relatively effective production frontiers, and its effectiveness is determined based on the distance between decision units and effective production frontiers. Banker et al., (1984) pointed out that the DEA method does not require prior parameter estimation, thus effectively avoiding subjective factors and minimizing errors. Mozaffari et al., (2014) improved the DEA model, and Nikolaus, (2015), Ioannis & Vincent, (2014) utilized the DEA model to assess efficiency across various sectors and domains.

Research on Factors Influencing Innovation Efficiency

Regarding the determinants of innovation efficiency, scholarly investigation predominantly centers on two dimensions: firm-specific factors and industry-specific factors.

From the perspective of enterprises, the main influencing factors include three categories: first, the size of the enterprise. Pavitt et al., (1987) observed a curvilinear association between innovation efficiency and firm size. Conversely, Scherer & Ross, (1990) posited that the expansion of bureaucracy within larger firms hampers the enhancement of innovation efficiency. Nevertheless (Zhang, 2013) contended that there exists a favorable relationship between firm size and innovation efficiency, and that firm size has a cost sharing advantage, thereby improving innovation efficiency. The second is the absorption and digestion ability of innovation. Cohen & Levinthal, (1990) pointed out that absorptive capacity is a company's capacity to identify, assimilate, and leverage external technologies and information to yield economic outcomes. Zahra & George, (2002) defined absorptive capacity as the organizational capability to enhance innovation efficiency by acquiring, assimilating, transforming, and applying knowledge. The research of (Wen et al., 2024) demonstrated that absorptive capacity significantly fosters innovation performance. Ihsen et al., (2015) obtained similar results through research on Germany. The third is corporate governance and financial condition. James & Sevin, (2012) discovered that the character of corporate property rights influences innovation efficiency, while (Liu et al., 2015) discovered that innovation efficiency is influenced by corporate governance, operational effectiveness, and financial status.

From the perspective of industry influencing factors, the main influencing factors include technological level, market structure, government support, and financial support. Xu, (2000) believed that developing countries lack technological resources, foreign finance has not formed strong technical support. Research conducted by scholars indicates that the technological level plays a crucial role in determining innovation efficiency. According to (Arrow, 1962), a competitive market environment fosters enterprise research and development (R&D) activities, thereby positively influencing innovation efficiency. Moreover, due to the evident externalities associated with innovative R&D, government subsidies and other forms of support contribute positively to innovation efficiency. Leyden & Link, (1991) and Mamuneas & Nadiri (1996) based on research in the United States, Guellec & Pattinson, (2001) based on research in OECD countries, and Gonzalez & Pazo (2008) based on research in Spain all supported this conclusion. However, certain scholars argue that government funding may have a crowding-out effect on innovation efficiency. This assertion is supported by studies conducted (Wallsten, 2000) in the United States and (Gorg & Strobl, 2007) in Ireland. In addition (Guan & Chen, 2010) argued that government subsidies only have an auxiliary effect and have little impact on innovation efficiency. Tadesse, (2002) believed that the support of financial institutions forms support for innovation efficiency through financing channels, and the research of (Sullivan, 2005) on Southeast Asian countries also supported this conclusion.

Researchers have extensively investigated innovation efficiency, primarily concentrating on the measurement of innovation efficiency (Smith & Cannan, 1977), factors influencing it (Zhang, 2011; Zayas-Márquez & Ávila-López, 2022), and strategies to improve efficiency (Gu & Feng, 2018). Although these studies have provided many valuable insights, there are still some shortcomings. Currently, most of the research is focused on a specific field or industry, and research on the innovation efficiency of Chinese own brand cars is still in the initial stage. This is mainly because the development of China own brand cars has achieved preliminary development through market exchange technology during the process of reform and openness. However, in these 20 years, China has taken proactive steps to advance new energy vehicle technology, which represents a departure from the conventional automotive industry's innovation efficiency. This shift has prompted a reorientation in research towards the innovation efficiency of China brand automobile industry. Focusing on the innovation efficiency of China brand automotive industry, this study employs sector-specific measurement methodologies. Its objective is to assess innovation efficiency, scrutinize its determinants, and devise policy recommendations to steer the future innovation trajectory of China brand automobile industry. It is of great significance from both theoretical and practical perspectives.

3 Data and Methods

Model Construction

This study constructs a basic model for empirical analysis of the determinants of the efficiency of China brand automobile industry's innovation system. Key determinants encompass various factors such as the stage of economic development, the extent of global engagement, levels of foreign direct investment, degree of market liberalization, governmental support for scientific and technological endeavors, as well as the scale of enterprises. Leveraging this framework, the basic econometric model for determining the efficiency of China brand automotive industry's innovation system is as follows the equation (1) is given as:

$$ine_{i,t} = \alpha_0 + \alpha_1 gdp_{i,t} + \alpha_2 do_{i,t} + \alpha_3 fdi_{i,t} + \alpha_4 mal_{i,t} + \alpha_5 tf_{i,t} + \alpha_6 sca_{i,t} + \varepsilon_i + \mu_{i,t} \quad (1)$$

Among them, $ine_{i,t}$ is the efficiency of the China brand automotive industry's innovation system in the period t of province *i*, $gdp_{i,t}$ is the economic development level in the period t of province i, $do_{i,t}$, in province i during period t, it denotes the extent of external openness, $fdi_{i,t}$ is the foreign direct investment in the period t of province i, $mal_{i,t}$, within period t of province i, it represents the level of marketization, $tf_{i,t}$, it pertains to the technological and financial assistance rendered by province i throughout period t, $sca_{i,t}$ represents the enterprise scale of China brand automotive industry during the period t of province i.

Variable Description

Input and Output Variables of Innovation System's Efficiency

Efficiency investment is divided into capital investment and personnel investment. The R&D capital stock serves as the metric for R&D investment during the technology research and development phase. Meanwhile, the R & D personnel investment index during this phase gauges the intensity of R & D personnel investment, quantified by the per capita full-time equivalent of R&D personnel in the

automotive sector. Transitioning to the achievement transformation phase, investment indicators are gauged by expenditure on technological transformation funds, while personnel investment indicators are measured by the workforce count within the proprietary automotive industry.

During the technology research and development stage, the output of the innovation system predominantly pertains to industrial research and development outcomes. Typically, the quantity of patent applications serves as a key metric for assessing the extent of innovation output. Hence, this research employs the volume of granted patents and invention patents within the proprietary automotive industry as proxies. The output of the innovation system during the achievement transformation stage is reflected in the production of new products in the industry. The study evaluates the product sales revenue within the proprietary automotive sector (Dong et al., 2014; Zhao et al., 2019).

Determinants of Innovation System's Efficiency

Economic Development Level (GDP)

Typically, regions with advanced economic development tend to attract a greater influx of highly skilled talent and substantial financial investments towards industrial technological innovation endeavors, thereby affecting the efficiency of the industrial innovation system (Yan et al., 2023). The study employs regional per capita GDP as a metric to gauge the degree of economic development.

Degree of Openness to the Outside World (DO)

Regions exhibiting greater degrees of openness to global markets can engage in independent research and development innovation activities through innovative entities that accumulate capital and profits, and have more exchanges with other international regions, thereby improving the innovation efficiency of local industrial systems (Feng et al., 2011). Therefore, this research utilizes the ratio of total regional imports and exports to GDP as an indicator of trade openness.

Foreign Direct Investment (FDI)

Foreign direct investment serves as a barometer of a region's capacity to draw in overseas capital, and the more foreign direct investment, the more technology spillovers it can achieve to the local area, thereby affecting the efficiency of industrial system innovation (Dunning, 2008). In this investigation, the ratio of foreign direct investment to GDP is employed to depict the extent of foreign direct investment within the region.

The Degree of Marketization (MAL)

MAL serves as an indicator of resource allocation efficacy within a region's market structure (Zhang, 2011). This research employs the ratio of non-state-owned enterprise personnel to assess the extent of marketization across various regions.

Technology Financial Support (TF)

Government support is integral to the functioning of the industrial innovation system. The allocation of fiscal resources towards science and technology initiatives serves as a key indicator of regional government policy priorities in fostering industrial development (Fang, 2022). Hence, this research

utilizes the ratio of regional government expenditure on science and technology to GDP to gauge the level of fiscal support for technological advancements.

Enterprise Scale (SCA)

The influence of firm size on the efficiency of the industrial innovation system is mainly reflected in the fact that larger enterprises have stronger available funds and can improve innovation efficiency by purchasing advanced machinery and hiring more advanced technical talents (Wakasugi & Koyata, 1997; Gayle, 2001). In this study, the size of regional self-owned brand enterprises is quantified by the ratio of total industrial output value to the number of enterprises.

Research Data

This study adopts data from 24 provinces or municipalities directly under the central government in China that have their own brand cars for analysis. Due to the missing data in regions such as Hong Kong, Macao, and Taiwan, as well as the Tibet Autonomous Region, some regions do not have their own brand cars, therefore, these areas were excluded. Information concerning R&D capital stock, technical personnel count, patent applications, and sales revenue originates predominantly from sources such as the "China Automotive Industry Yearbook", "China Science and Technology Statistical Yearbook", and the statistical publications of diverse provinces and municipalities. In terms of data sources for determining the efficiency of innovation system, information regarding the level of economic development, openness to international markets, foreign direct investment, marketization level, technological and financial support, and enterprise scale is primarily sourced from publications such as the "China Statistical Yearbook", "China Population and Employment Statistical Yearbook", and the statistical yearbooks of various provinces and municipalities. In terms of input-output data processing for innovation system efficiency, the index of R&D investment during the technology research and development phase is gauged through the R&D capital stock, employing the perpetual inventory method for estimation. In terms of data processing for the determining factors of innovation system efficiency, certain data regarding the level of external openness and foreign direct investment undergo conversion, primarily achieved by translating the aggregate import and export volumes and the US dollar value of foreign direct investment at the median annual exchange rate of the RMB.

4 Empirical Analysis

Evaluation of Efficiency of China Brand Automobile's Innovation System

The analysis entails the computation of various statistical measures such as the mean, standard deviation, minimum, median, and maximum values across variables. Assessing technical efficiency, pure technical efficiency, and scale efficiency, it is observed that the average scale efficiency is the highest at 0.857, followed by the average pure technical efficiency at 0.403, while the average technical efficiency ranks the lowest at 0.339, which is shown in Table 1.

Table 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
SCA	264	2.766	0.072	2.598	2.758	2.950

Technical Efficiency

Figure 1 primarily illustrates the temporal evolution of technical efficiency. The visual representation indicates fluctuating trends in overall technical efficiency over the specified period. The initial value in 2011 was 0.3129, followed by a slow increase in fluctuation, and reached its maximum value of 0.3738 in 2014. This is also the peak value during the entire time period. After reaching the maximum value, it continued to fluctuate and decrease, continuing until 0.3226 in 2021. The annual average growth percentage is approximately 0.3058%. It can be reviewed that during the sample period, the efficacy of technological innovation in the proprietary automotive sector has exhibited variability rather than consistent growth over time. Overall, it shows a fluctuating upward trend. The factors that cause this phenomenon are diverse, and the main influencing conditions are fluctuations in technological level, changes in industrial environment, and government regulations. Currently, the level of China's independently developed automotive industry is still some way off compared to advanced foreign countries.

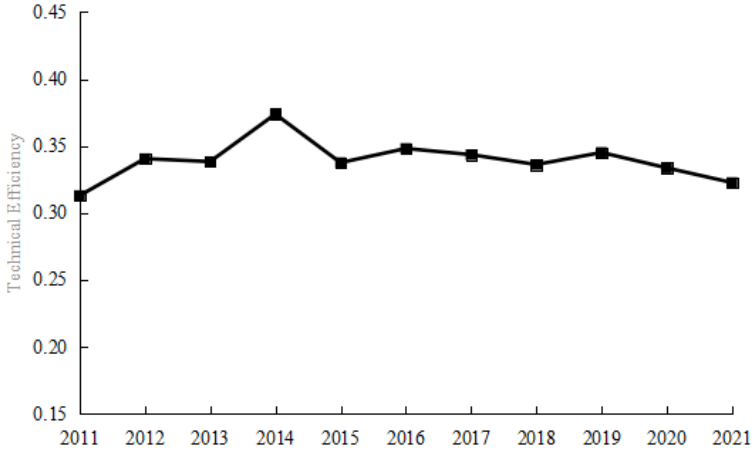

Figure 1: The Evolution Trend of Technical Efficiency of China Brand Automobile Industry's Innovation System

Pure Technical Efficiency

Figure 2 primarily illustrates the trajectory of pure technical efficiency at the national level. Observing the graph reveals a similar pattern between pure technical efficiency and overall technical efficiency, both exhibiting fluctuations over time. From the figure, it can be reviewed that the efficiency in 2011 was 0.3662, and then the fluctuation increased. Finally, in 2014, it reached the maximum value of 0.4508 for the entire sample period. After reaching its peak, the fluctuation began to decrease and continued to reach the minimum value of 0.3811. The annual average growth percentage was approximately 0.3996%. From the above analysis, it can be deduced that, similar to technical efficiency, the advancement of pure technical efficiency in the self-owned automotive industry encounters obstacles. This impediment arises due to foreign capital's dominance over technology, which prioritizes its own industrial interests over fostering independent research and innovation in China's automotive sector, making it difficult for related industries in China to master key technologies, and the level of innovation is also stagnant.

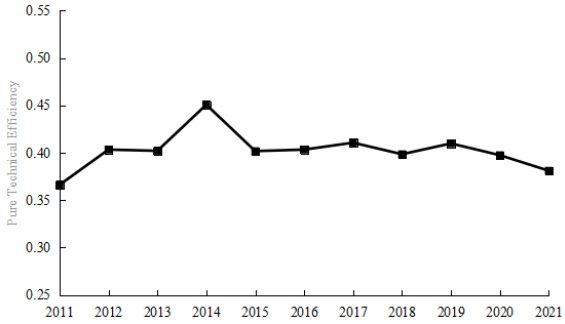

Figure 2: The Evolution Trend of Pure Technical Efficiency of China Brand Automobile's Innovation System

Scale Efficiency

Figure 3 illustrates the evolution of scale efficiency of the innovation system of China's automotive industry over the observed timeframe. Unlike the above two figures, it is evident that the overall trend of scale efficiency is relatively stable with little change. Commencing at 0.8665 in 2011, this metric exhibited a consistent upward trajectory, reaching 0.8668 by the conclusion of the sampling period in 2021. Within the time shown in the figure, the values are all higher than 0.8, indicating that overall, the resource allocation for innovation and R&D in China brand automotive industry is close to the optimal combination.

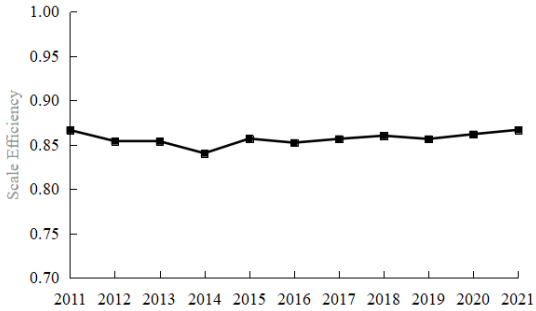

Figure 3: The Evolution Trend of Scale Efficiency of China Brand Automobile Industry's Innovation System

Factors Influencing the Efficiency of China Brand Automobile's Innovation System

Model Verification

Before conducting regression analysis, this study undertakes a likelihood ratio test to ascertain the significance of model construction. Subsequently, a Hausman test is executed to juxtapose the outcomes of the random effects model against those of the fixed effects model, while a VIF test is employed to scrutinize potential multicollinearity issues within the model. Both the LR test and the Hausman test from the results of the random effects and fixed effects tests, reject the original hypothesis at a significance level of 0.05. This implies that the fixed effects model's estimation method outperforms the random effects model in each instance, thus advocating for the adoption of the fixed effects model in subsequent empirical investigations. Additionally, the multicollinearity test reveals that the VIF values for all model variables remain below 10, underscoring the efficacy of the model's test outcomes.

Factors Affecting Technical Efficiency

The content presented in Table 2 is the regression results that affect technical efficiency. In the table, the contents in columns (1) to (6) are the regression results obtained by gradually adding influencing factor variables through experiments. As the sixth column contains the largest amount of information, this article focuses its analysis on the sixth column. The regression analysis reveals that the coefficients of various influential factors, including the level of economic development, the extent of external openness, and the degree of industrial marketization, all surpass 0. Nevertheless, the regression coefficients of the influencing factor of company size are clearly negative values less than 0. This implies that elevated economic and societal standards, heightened external openness, and increased industrial marketization all contribute to advancing independent innovation efficiency of the automotive sector. However, as company size increases, there is typically a decrease in innovation efficiency. This trend can be attributed to several factors. Firstly, as the economic and social development of a country advances, it tends to foster greater openness and exchange with the global community. Additionally, increased levels of marketization of the industry facilitate access to a wider array of production factors. Consequently, industries are presented with expanded opportunities for growth and development. These conditions naturally contribute to the enhancement of pure technical efficiency. However, expanding a company's size means that management will become rather difficult, the essential elements of innovation will be scattered, hard to allocate, and decision-making will be difficult to cover all aspects. The research results are consistent with those of (Ding, 2022; Tan, 2022).

Table 2: Regression Results of Factors Affecting Technical Efficiency

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

					(1.790)	(1.292)
ln_sca						-1.660***
						(-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
* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

Factors Affecting Pure Technical Efficiency

Table 3 displays the regression findings pertaining to the determinants affecting pure technical efficiency. In this table, the contents of columns (1) to (6) are the regression results obtained by gradually adding influencing factor variables through experiments. Therefore, column (6) contains the largest amount of information, and this article focuses analysis on column (6). It can be reviewed that the regression coefficients of the economic development level, degree of openness, and degree of marketization are all greater than 0. In order to ensure the precision of the data, this study conducted a validity examination, verifying that all values conform to established criteria. The observed regression coefficients demonstrate a positive correlation. This suggests that heightened levels of economic development, regional openness, and marketization of the automotive sector tend to enhance pure technical efficiency. Primarily, the economic condition correlates directly with consumption levels. As economic development escalates, so does the demand for automobiles, reflecting an increase in people's purchasing power, and the purchasing power is also sufficient. As a result, companies have more opportunities for profitability, and their efforts are more likely to receive corresponding returns. Therefore, enterprises will naturally increase their investment in innovation in order to make profits; Secondly, the strengthening of cooperation and exchange with foreign countries has improved the level of openness, allowing enterprises to attract more foreign investment and obtain more resources. In addition, opening up external exchanges and cooperation will inevitably lead to intensified industry competition, and enterprises will feel a sense of crisis, which will force them to self innovate and ultimately achieve the improvement of pure technical efficiency; Finally, the improvement of marketization level means that the own brand automobile industry can compete in a relatively fair and orderly market environment. In order to expand its market share and form its unique competitiveness, enterprises will explore how to improve pure technical efficiency to achieve their goals. These results are similar to the research findings of (Tang, 2021; Wei, 2020).

Table 3: Regression Results of Factors Affecting Pure Technical Efficiency

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

ln_fdi			1.374***	1.316***	0.744	0.214
			(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 numerical regression coefficient of the enterprise scale is -2.033, which is less than 0, and it meets the significance level standard after testing, which confirms the negative correlation between the expansion of enterprise size and the improvement of pure technical efficiency. Zhang, (2018) research conclusion is consistent with the conclusion of this study. There are many possible factors that can cause this situation. It can be deduced that as the company expands, it will face management problems, communication of instructions will not be convenient enough, decision-making will also be difficult, and the execution process will be hard to supervise. Therefore, the operation of the innovation system will be delayed, resulting in the inefficient utilization of production factors required for innovation and a decrease in pure technical efficiency.

Factors Affecting Scale Efficiency

Table 4 presents the regression outcomes concerning the determinants of scale efficiency. In this table, the contents of columns (1) to (6) are the regression results obtained by gradually adding influencing factor variables through experiments. Therefore, the sixth column contains the largest amount of information, and this article focuses its analysis on the sixth column. As shown in the table, the regression coefficients related to the degree of external openness and marketization exhibit negativity and have been validated to comply with standards. This indicates that the higher the degree of these two factors, the more unfavorable it is for the improvement of the scale efficiency of the innovation system. This is due to the concurrent process of international integration, enhanced marketization, and the entry of foreign capital into the domestic market, which inevitably leads to significant competitive pressure on the domestic automotive industry. Therefore, the focus will be on how to earn short-term profits and will be more inclined to occupy more market share, rather than focusing on improving innovation levels. Moreover, due to the spread of this pressure, loose management and unreasonable allocation of production factors may occur, over time, this will exert a detrimental influence on the advancement of innovation levels.

Table 4: Regression Results of Factors Affecting Scale Efficiency

	(1) SE	(2) SE	(3) SE	(4) SE	(5) SE	(6) 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)
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 table illustrates that the regression coefficient for enterprise size is 0.601, having met the statistical criteria, suggesting that larger enterprise size correlates with enhanced innovation levels. This is because as the scale of the enterprise expands, it obtains relatively more production factors, such as human resources, material resources, production efficiency, etc., the status of resources will be improved, and the returns obtained will also be greater, which will increase innovation investment. The results are consistent with the research conclusions of (Guo, 2017; Huang, 2017; Zhu, 2019). From the above analysis, it can be inferred that a positive correlation between the comprehensive scale of the innovation system of the own-brand automotive industry and enterprise size. The larger the scale, the more substantial the innovation system scale is. However, the higher the level of openness and marketization towards external domains, the less conducive it becomes for the enlargement of the innovation system's scale.

5 Discussion

There appears to be no discernible upward or downward trajectory in the technical efficiency, pure technical efficiency, and scale efficiency of the industrial innovation system of China brand automobiles. This suggests that over the observation period, the overall technical efficiency, pure technical efficiency, and scale efficiency of the proprietary automobile industry remained relatively constant, with no significant advancement or decline noted. Consequently, continued emphasis on enhancing technological innovation, research and development investments, and production efficiency is deemed necessary. By improving the technological level, optimizing production processes, and improving resource utilization efficiency, pure technical efficiency, the technical efficiency, and scale efficiency of the China brand automotive industry's innovation system can further be enhanced.

Regarding influencing factors, the degree of economic development, extent of external openness, and level of marketization play significant roles in advancing technical and pure technical efficiency of the innovation system of China brand automotive industries (Chen & Zhou, 2020). This is because these factors can provide a better economic environment and policy support, and promote technological innovation and production technology improvement, thereby improving technical and pure technical efficiency. The expansion of enterprise scale has a significant inhibitory effect on it, which is due to the increased management costs and complex organizational structure caused by the expansion of enterprise scale, affecting the innovation and production efficiency of enterprises (An, 2015). In assessing the scale efficiency of the innovation system of the proprietary automotive industry, it becomes evident that the degree of external openness and marketization exerts a notable adverse influence. This phenomenon stems from the heightened competition resulting from increased openness and marketization. In order to survive and develop in competition, companies tend to pursue economies of scale, resulting in a decline in scale efficiency. The expansion of enterprise scale can play a positive driving role to a certain extent, because the expansion of enterprise scale can improve production efficiency and reduce costs, thereby enhancing scale efficiency.

6 Conclusion

The primary focus of this study is to investigate the efficiency of China brand automobile's innovation system. It employs the DEA model to gauge innovation efficiency and utilizes the Tobit model to delve into the factors influencing innovation efficiency. The main conclusions are shown below.

Based on the measurement results of various items for the efficiency of China own brand automotive industry's innovation system, this research investigates the dynamics of technical efficiency, pure technical efficiency, and scale efficiency. Findings suggest that the overall innovation efficiency is on the rise. The technical efficiency of China's automotive industrial innovation system remains volatile, with the enhancement of pure technical efficiency progressing gradually, while scale efficiency demonstrates a comparatively consistent evolution.

The progressive advancement in economic development, external openness, and marketization level serves to enhance the technical efficiency of the innovation system of the indigenous automotive industry. Conversely, the expansion of enterprise scale exerts a detrimental influence on technical efficiency.

Economic development, external openness, and marketization exert a favorable impact on the pure technical efficiency of the indigenous automotive industry's innovation system. However, the enlargement of enterprise scale is associated with a discernible negative impact on pure technical efficiency.

The enlargement of enterprise scale contributes positively to the scale efficiency of the innovation system of the indigenous automotive industry, while advancements in openness and marketization may entail certain adverse effects.

Drawing from extant literature, prospective avenues for enhancing the innovation efficiency of China's indigenous automotive industry encompass the following five dimensions. One is further research on hybrid and electric vehicle technologies, the second is the application research of intelligent and networked technologies, the third is the combination research of automotive lightweight and material science, the fourth is further research on industrial policies and market environment, and the

fifth is to strengthen international cooperation and exchange. Overall, future research needs to continuously explore new technologies and trends, improve relevant policies and market environments, strengthen international cooperation and exchanges, and provide more support and assistance for the innovative development of China own brand automotive industry.

7 Policy Recommendations

With the continuous improvement of economic development, opening up to the outside world, and marketization level, China's automotive industry is undergoing unprecedented transformation and upgrading. The innovative progression of the automotive sector holds paramount importance in augmenting the economic and technological prowess of the nation. Especially for the own brand automotive industry, how to improve its innovation efficiency, fully utilize resources, and achieve sustainable development is a pivotal concern requiring resolution at present. Drawing from the findings of this investigation, the study advances policy suggestions aimed at enhancing the innovation efficiency of China's indigenous automotive sector, addressing both governmental and enterprise dimensions.

At the governmental level, the primary recommendation involves the formulation of policies conducive to fostering innovative strides in the automotive industry (Lu, 2019). The government should formulate long-term and forward-looking industrial policies, clarify the development direction and focus of the automotive industry, and increase support for the own brand automotive industry (Zhu, 2019). The second is to promote opening up and international cooperation, strengthen international trade cooperation and technological exchange, promote deep cooperation between own brand automobile enterprises and international advanced enterprises, introduce international advanced technology and management experience, and improve the innovation effectiveness of the proprietary automotive sector. Another aspect to consider is to strengthen market supervision and law enforcement, establish a sound regulatory mechanism for the automotive market, standardize market order, and prevent the adverse effects of cutthroat competition on industrial innovation efficiency.

From an enterprise standpoint, the primary initiative involves augmenting investment in research and development (R&D) to bolster technological innovation prowess. Enterprises are advised to prioritize R&D investment, augment scientific personnel, and bolster funds allocated for research and development endeavors, thereby fostering ongoing technological innovation and product enhancement (Wu et al., 2019). The second is to optimize the management system and improve the operational efficiency of enterprises. Enterprises ought to bolster the reform and innovation of their internal management structures, fostering the establishment and refinement of contemporary enterprise systems to enhance operational efficiency. The third is to enhance the integration and collaborative innovation of the industrial chain (Cheng & Feng, 2020). Enterprises ought to strengthen their collaboration and coordination with upstream and downstream counterparts to achieve the optimization and advancement of the industrial chain. Additionally, expanding into international markets is vital to enhance international competitiveness. Enterprises should actively expand the international market and enhance their international competitiveness through international trade and cooperation.

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9 Conflict of Interest

The authors declare that the publication of this paper has no conflicts of interest.

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