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Research on the Innovation Efficiency of China's Blockchain Listed Companies Based on Data Envelopment Analysis

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ABSTRACT : *This study examined the innovation efficiency of Chinese blockchain listed companies and its implications for industry development. A sample of 24 companies from 2011 to 2020 was analyzed using data envelopment analysis (DEA). The results reveal a fluctuating and declining trend in innovation efficiency over the period. Factors contributing to this include government investments in science and technology, the impact of the Internet finance industry, and issues related to resource allocation within the blockchain sector. The low technological innovation efficiency is primarily attributed to the prevalence of stable-scale development strategies, resulting in inadequate investment in innovation activities. To address these challenges, recommendations are proposed for enhancing innovation efficiency through government macro-control, comprehensive industry transformation, and self-improvement initiatives by blockchain listed companies. This research provides a theoretical foundation for future investigations, offers insights into the characteristics and trends of the blockchain industry, and presents valuable guidance for the long-term development of blockchain listed companies. By considering the unique business models of the blockchain sector,this study paves the way for cross-domain research and development, empowering managers and developers to achieve sustained growth in the industry. blockchain listed companies.*

KEYWORDS - *Blockchain listed companies, innovation efficiency, data envelopment analysis*

I. Introduction

China's "14th Five-Year Plan" launched in 2021 highlighted blockchain as a key digital industry for development. The Ministry of Industry and Information Technology and the Cyberspace Administration of China issued guidelines to accelerate blockchain technology adoption and industrial growth. The objective is to build a leading blockchain industry system, promote widespread application, and achieve leapfrog development. China's blockchain sector is entering a new phase driven by "trust chain" and "collaboration chain" principles. Policy support has fueled rapid advancements in blockchain technology application and ecosystem, positioning China as a key player in this field.

The concept of blockchain, which originated from Satoshi Nakamoto's groundbreaking article "Bitcoin: A Peer-to-Peer Electronic Cash System"[1] published on a Bitcoin forum in 2008, is the underlying technology supporting Bitcoin. From a protocol perspective, blockchain is essentially an internet protocol like HTTP [2]. Blockchain research covers data, accounting, protocol, economics, and technology perspectives. It serves as a decentralized database, distinct from traditional ones, due to its immutable and decentralized nature. Blockchain is seen as a distributed ledger technology, with each node acting as an independent bookkeeper. Like HTTP, blockchain operates with decentralization, immutability, and non-repudiation. Economically, blockchain supports the Internet of Value and the sharing economy, shifting the internet from information-centric to value-centric. Technologically, blockchain integrates multiple technologies. Overall, blockchain revolutionizes data storage, accounting, protocols, economics, and technology, leaving a significant impact.

Regarding the impact of blockchain on enterprises, some scholars have focused on the influence of blockchain technology on finance [3]. Blockchain technology emerged from encrypted digital currencies to facilitate payments and disrupt the industry through decentralized electronic transactions and fund custody. Researchers have explored its applications extensively, including shopping system architectures, electronic currency rewards, and rental item platforms. Management transformation in blockchain enterprises focuses on the "decentralized intelligent management and control" model, reducing costs and improving efficiency. Its potential to enhance operational and asset management capabilities in enterprises has also been investigated.

Integrating the Gartner Technology Hype Cycle helps identify research bottlenecks, offering insights for future studies.

With the continuous development of science and technology, various blockchain listed companies are innovating their technologies. The efficiency of their technological innovation serves as an important indicator to measure their technological development and progress. This paper reviews the research on enterprise innovation efficiency both domestically and internationally to seek methods suitable for studying the innovation efficiency of blockchain listed companies in China.At present, there is extensive research on the efficiency of technological innovation in enterprises internationally. For example, Alonso et al.(2019) explored the impact of a company's technological innovation efficiency on its growth and development based on the research background of family business management[4] . Claudio et al.(2013) proposed an innovation management approach based on input-output models, emphasizing the importance of technological innovation efficiency from the perspective of company managers [5]. Karmaker et al.(2012) examined the impact of environmental taxes on the innovation efficiency of environmentally innovative firms, considering external factors such as national taxation that affect enterprise innovation efficiency[6]. Ferrier (2017) analyzed and evaluated innovation efficiency using a two-stage DEA model for 1,074 US surgical hospitals from 2011 to 2016[7]. Justin et al. (2019) investigated the role of internal R&D and external knowledge in innovation in small and medium-sized enterprises in Ireland from the perspective of measuring innovation efficiency[8] . Kang et al. (2012) combined the concept of the national innovation system with the innovation value chain and found that government subsidies and R&D cooperation have a positive impact on the innovation efficiency of biotechnology companies in South Korea [9]. Tahizadeh et al. (2017) divided the innovation activities of enterprises into three stages and studied the impact of innovation strategies on innovation efficiency based on this framework[10] . This will also help provide recommendations and suggestions regarding the improvement of innovation efficiency in Chinese listed blockchain companies with respect to the external environment.

Chinese blockchain listed companies are experiencing strong growth, leveraging their advantages and motivation in the current social landscape. However, there is still a significant gap compared to international counterparts. To excel in competitive markets, Chinese blockchain listed companies need to optimize resource allocation and enhance innovation efficiency. Technological innovation drives economic and enterprise development, reflecting investment intensity and resource capabilities. Despite the increasing emphasis on innovation, China's technological innovation level, particularly in technology-intensive sectors, lags developed countries, primarily in terms of innovation efficiency. Shareholders and management play a pivotal role in driving technological innovation efficiency, especially in blockchain enterprises. This study aims to analyze the innovation efficiency of Chinese blockchain listed companies, crucial for overall innovation performance. Many companies in China's blockchain industry focus solely on independent innovation, overlooking the need for sufficient external investments. This approach hampers the research and development process, impacting long-term economic benefits and hindering sustainable development. Addressing these challenges and implementing effective measures is crucial. Given the limited availability of innovative resources, studying practices to enhance blockchain technology's innovation efficiency becomes imperative to support innovation efforts of Chinese listed companies. This research holds significant scientific, theoretical, and practical implications.

II. Research Design and Model Construction

2.1 Model Design

Based on the literature review conducted on Data Envelopment Analysis (DEA) for enterprise efficiency, it has been observed that many traditional Chinese companies often establish multiple input-output indicators for capital investment and business output in their linear management models. However, in the complex daily operations and management activities of most companies, it is rare for them to simultaneously involve multiple capital inputs and business output indicators. Therefore, solely relying on such linear management models may not be suitable for traditional enterprises. To address this issue, this study extensively explores and reviews the management capabilities of information technology innovation in Chinese enterprises by referring to a significant number of relevant academic papers. During the research on how Chinese enterprises can effectively enhance their information technology innovation management capabilities, Data Envelopment Analysis (DEA) was found to be the most typical and effective method for problem-solving. Building upon previous research and combining it with their own research experience, the authors summarize and consolidate the frontier theories and application technologies in this field. Furthermore, they apply these findings to practical case studies, providing reference and guidance for future researchers. DEA, which was initially proposed by enterprises in 1978, is the most used performance evaluation method for multi-input, multi-output assessments of human resources and management capabilities required by various strategic decision units.

Given that blockchain listed companies belong to emerging industries and have business models distinct from traditional companies, the analysis method for their innovation efficiency needs to be adjusted accordingly. To address the uncertainty in marginal returns in the research and development field, this study reconstructs the traditional DEA BCC model based on the DEA CCR model. It conducts data envelopment analysis (DEA) on the validity of decision-making units under the circumstances of changing scale and continuous benefit generation, as well as uncertain marginal efficiency, and analyzes the results. Overall, the DEA-based approach provides a suitable framework for assessing the innovation efficiency of blockchain listed companies, considering the unique characteristics of their industry, and addressing the uncertainty in marginal returns. By applying this method, researchers can gain insights into the effectiveness of decision-making units and contribute to the advancement of knowledge in this field. The formula is as follows：

$$\min \theta \tag{2-1}$$

$$s.t.\sum_{1}^{n}\lambda_x + s^+ = \theta x_0 \tag{2-2}$$

$$\sum_{1}^{n}\lambda \approx 1 \tag{2-3}$$

$$\sum_{1}^{n}\lambda y - s^- = y_0 \tag{2-4}$$

$$\lambda \geq 0, s^+ \geq 0, s^- \geq 0 \tag{2-5}$$

2.2 Variable and Indicator Selection

To measure the technological innovation efficiency of a company, it is often necessary to consider indicators related to both innovation inputs and technological outputs. In this study, we have considered the indicators of innovation inputs and outputs that have been selected by domestic experts and scholars, as well as the input-output models in the blockchain industry, such as blockchain technology industry innovation input-output models. Based on these considerations, we have constructed a model using input-output indicators to analyze the technological innovation efficiency and scale efficiency of blockchain listed companies. Table 2-1 lists the specific indicators.

Table 2-1 Innovation efficiency index system of blockchain listed enterprises

Primary indicator	Secondary indicator	Tertiary indicator	Symbol
input indicator	labor input	R&D personnel count	X1
	capital input	R&D investment funding	X2
output indicator		fixed assets	X3
	operating income	operating revenue	Y1
	research achievements	number of patents	Y2

In terms of selecting input indicators, this study considers two perspectives: business operations and research and development (R&D). Three specific indicators of research input are chosen, namely the number of research personnel, the amount of research investment, and fixed assets. Existing literature often uses the input of R&D personnel and expenditure on research and development as indicators reflecting innovation output. To provide a more comprehensive evaluation of innovation efficiency and enable the evaluation of scale efficiency and comparative analysis of comprehensive efficiency, this study includes the indicator of fixed assets to jointly evaluate innovation efficiency. By combining these three indicators, it is possible to better reflect the level of technological innovation investment and the overall scale of blockchain listed companies. Regarding output indicators, this study selects the operating income and research achievements of blockchain listed companies, specifically the number of patents and revenue. Operating income represents the commercialization of innovation outcomes and can economically reflect the number of innovative outcomes, making it suitable as an indicator of innovation output. Patents cover a substantial amount of technological information and represent direct innovation outcomes. They can objectively reflect the innovation capacity and comprehensive technological strength of a listed company. Relevant data can be accessed from patent office websites to facilitate the assessment of innovation status among different listed companies. By combining these two indicators, it is possible to better reflect the operational and profitability capabilities of blockchain enterprises while directly reflecting their actual development status and research and technological innovation level.

2.3 Sample and Data

This study targets 258 blockchain listed companies in China, based on the blockchain-related concepts listed on Sohu Securities. Considering the significant differences between listed private enterprises and state-owned enterprises, a total of 201 private listed companies were selected. To obtain data for a continuous period of ten years, further screening was performed based on the year of listing, resulting in 64 companies that went public before 2010. After excluding 6 abnormal operating status samples such as ST, *ST, and S*ST, a total of 58 companies' sample data were obtained. Subsequently, the companies were further screened based on the input-output indicators, resulting in a set of 29 listed companies that continuously disclosed R&D investment funds for ten years. Among the 29 companies, 5 companies with missing output indicator data on the number of patents were removed. Finally, a representative set of 24 domestic listed companies engaged in the blockchain field, with a duration of more than 10 years, was obtained.

The paper obtained the following variables from the annual reports of 24 blockchain companies in the sample from 2011 to 2020: research and development (R&D) investment amount (X2) of listed companies, the number of R&D personnel (X1) from 2015 to 2020, fixed assets (X3), and operating income (Y1) from company financial statements. Additionally, the paper searched and compiled the number of blockchain patents (Y2) from various sources such as PatentStar, Wanfang Data, Guotai and Database, and CCER Database.

It is worth mentioning that due to the significant lack of data on the number of R&D personnel from 2011 to 2014, the variable for R&D personnel (X1) was excluded from the input indicators for those years. Furthermore, as data envelopment analysis is based on cross-sectional data, this approach is deemed feasible.

The paper presents descriptive statistics for the indicator data of the 24 listed blockchain companies in the period of 2011-2020. Table 2-2 lists the details. Driven by the increasing demand for scientific research and the overall national strength, the number of R&D personnel, R&D investment amount, and fixed assets of domestic blockchain listed companies have shown a rising trend year by year. However, due to the uneven pace of development, there is a significant standard deviation among the company data. Additionally, in terms of output indicators, there is a considerable difference between the maximum and minimum values of operating income and research output. This deviation can result in a potential bias in the mean value and a relatively large standard deviation.

Table 2-2 Descriptive statistics of related indicators of blockchain listed enterprises

Indicator	Number of observations	Mix	Max	Mean	Standard Deviation
X1	144	54	5749	758	904.5781407
X2	240	1885588.99	1560031918	156700988.7	218858488.1
X3	240	99231497.35	6981385182	1643625929	1450074304
Y1	240	357151889.6	53787719147	6027297060	7927227634
Y2	240	0	247	34	37.69379347

The paper conducted an analysis using the SPSS software to examine the correlation between the selected input and output indicators. Table 2-3 lists the results. From the data in the table, it can be observed that R&D investment is significantly and moderately correlated with the number of patents. It is weakly and significantly correlated with operating income. The number of R&D personnel is weakly and significantly correlated with the number of patents. Fixed assets are moderately and significantly correlated with the number of patents, and they are highly and significantly correlated with operating income.

Table 2-3 Correlation analysis of input-output indicators of blockchain listed enterprises

Indicator	R&D investment	R&D personnel	Fixed assets
patent	0.372**	0.185*	0.427**
business income	0.174*	0.143	0.649**

Note: **. At level 0.01 (two-tailed), the correlation was significant. *. At level 0.05 (two-tailed), the correlation was significant.

III. Empirical Analysis

3.1 Innovation Efficiency Evaluation

The DEA-Solver5.0Pro software was used to apply the Data Envelopment Analysis (DEA) BCC model from the input perspective to calculate the comprehensive efficiency, pure technical efficiency, and scale efficiency of the 24 collected companies over a period of ten years from 2011 to 2020. Table 3-1 shows the result.

Table 3-1: Enterprise Comprehensive Efficiency Values from 2011 to 2020

Code	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
000810	0.462	0.617	0.214	0.877	1.000	0.730	0.850	0.742	0.838	0.757
002010	0.694	0.596	0.314	0.691	0.634	0.527	0.963	1.000	0.935	0.873
002049	0.175	0.311	0.276	0.201	0.569	0.788	0.497	1.000	1.000	0.957
002063	0.325	0.328	0.324	0.239	0.234	0.312	0.503	0.326	0.513	0.479
002103	0.566	1.000	0.586	1.000	1.000	0.980	1.000	1.000	1.000	1.000
002104	0.323	0.254	0.154	0.257	0.446	0.229	0.346	0.448	0.616	1.000
002115	0.406	0.271	0.688	0.407	0.475	0.291	0.192	0.404	0.595	0.935
002123	0.330	0.283	0.409	0.412	0.535	0.545	0.406	0.498	0.624	0.821
002131	0.471	0.814	0.385	0.915	1.000	1.000	1.000	1.000	1.000	1.000
002137	1.000	1.000	0.246	0.994	0.843	1.000	1.000	1.000	1.000	1.000
002168	0.143	0.201	0.074	0.344	0.416	1.000	0.655	1.000	0.792	0.527
002177	0.321	0.359	0.488	0.786	1.000	0.526	0.216	1.000	1.000	1.000
002191	0.342	0.665	0.499	0.723	1.000	0.893	0.336	0.547	0.579	0.762
002224	0.442	0.476	0.244	0.594	0.527	0.431	0.355	1.000	0.473	0.278
002276	0.581	0.828	1.000	0.605	1.000	0.661	0.822	0.814	0.687	0.432
002296	0.650	0.322	0.539	0.350	1.000	0.783	1.000	0.842	0.585	0.415
002303	0.437	0.945	0.542	0.812	0.712	0.525	0.363	0.517	0.369	0.239
300002	0.382	0.414	0.590	0.414	0.423	0.479	0.431	0.259	0.270	0.466
300007	1.000	1.000	0.544	1.000	0.551	0.443	0.220	0.323	0.372	0.728
300018	0.522	0.358	1.000	0.645	1.000	0.707	0.508	0.872	0.702	0.700
300020	0.702	1.000	1.000	1.000	1.000	0.560	0.808	0.647	0.532	0.738
300036	0.170	0.153	0.074	0.083	0.146	0.220	0.500	0.366	0.535	0.332
600410	1.000	1.000	1.000	1.000	1.000	0.506	0.903	0.625	0.787	0.519
600570	0.543	0.382	0.469	0.547	0.152	0.361	0.597	0.432	0.543	0.414

Through the study of the visual line chart in Table 3-1, it can be observed that the comprehensive efficiency of companies in the blockchain industry fluctuated significantly from 2011 to 2020. It indicates that these companies are generally experiencing stable development, but their innovation efficiency and company scale have not yet reached an optimal state of development, Specifically, as shown in Tables 3-2 and 3-3. Among them, Company A demonstrates relatively good performance in terms of comprehensive efficiency. Except for the year 2013 with a comprehensive efficiency of 0.246, the company's comprehensive efficiency remained above 0.8 for the rest of the years, with 7 years achieving a comprehensive efficiency of 1.

Table 3-2: Enterprise Pure Technical Efficiency Values from 2011 to 2020

Code	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
000810	0.618	0.617	0.654	1.000	1.000	0.737	0.860	1.000	1.000	1.000
002010	0.720	0.620	0.332	1.000	0.902	0.799	1.000	1.000	1.000	1.000
002049	1.000	0.570	0.322	0.231	0.688	0.803	0.558	1.000	1.000	1.000
002063	0.542	0.466	0.457	0.474	0.326	0.428	0.608	0.473	0.610	0.547
002103	0.918	1.000	0.856	1.000	1.000	1.000	1.000	1.000	1.000	1.000
002104	0.507	0.450	0.301	0.352	0.486	0.295	0.412	0.508	0.624	1.000
002115	0.500	0.333	1.000	0.489	0.600	0.413	0.313	0.477	0.619	1.000
002123	0.389	0.633	0.554	0.419	0.605	0.582	0.445	0.554	0.652	0.880
002131	0.512	1.000	0.398	1.000	1.000	1.000	1.000	1.000	1.000	1.000
002137	1.000	1.000	0.743	1.000	1.000	1.000	1.000	1.000	1.000	1.000
002168	0.597	0.574	0.392	0.412	1.000	1.000	1.000	1.000	0.942	0.763
002177	0.535	0.508	0.541	0.833	1.000	0.605	0.720	1.000	1.000	1.000
002191	0.628	0.834	1.000	1.000	1.000	0.908	0.395	1.000	0.739	0.973
002224	0.627	0.739	0.591	0.683	0.693	0.568	0.805	1.000	0.998	1.000
002276	0.606	0.910	1.000	1.000	1.000	0.665	0.832	0.907	0.691	0.472
002296	0.965	0.777	0.602	0.705	1.000	1.000	1.000	0.885	0.610	0.609
002303	0.724	0.957	0.572	0.972	0.738	0.549	0.409	0.673	0.442	0.353
300002	1.000	1.000	1.000	0.424	0.450	0.523	0.470	0.278	0.310	0.493
300007	1.000	1.000	0.661	1.000	0.679	0.454	0.242	0.340	0.438	1.000
300018	1.000	1.000	1.000	1.000	1.000	0.962	1.000	1.000	1.000	1.000
300020	1.000	1.000	1.000	1.000	1.000	0.684	0.902	0.682	0.643	0.785
300036	0.448	0.418	0.357	0.320	0.438	0.378	0.613	0.502	0.614	0.384
600410	1.000	1.000	1.000	1.000	1.000	0.525	0.924	0.722	0.813	0.543
600570	0.814	0.501	0.674	0.840	0.201	0.426	0.647	0.517	0.546	0.435

Table 3-3: Enterprise Scale Efficiency Values from 2011 to 2020

Code	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
000810	0.748	0.999	0.327	0.877	1.000	0.992	0.989	0.742	0.838	0.757
002010	0.964	0.961	0.947	0.691	0.704	0.660	0.963	1.000	0.935	0.873
002049	0.175	0.547	0.858	0.870	0.826	0.981	0.891	1.000	1.000	0.957
002063	0.599	0.703	0.709	0.503	0.717	0.729	0.827	0.689	0.840	0.874
002103	0.617	1.000	0.685	1.000	1.000	0.980	1.000	1.000	1.000	1.000
002104	0.637	0.564	0.511	0.731	0.918	0.778	0.840	0.883	0.987	1.000
002115	0.812	0.814	0.688	0.832	0.792	0.705	0.615	0.848	0.961	0.935
002123	0.848	0.448	0.738	0.984	0.883	0.936	0.911	0.899	0.957	0.933
002131	0.920	0.814	0.967	0.915	1.000	1.000	1.000	1.000	1.000	1.000
002137	1.000	1.000	0.331	0.994	0.843	1.000	1.000	1.000	1.000	1.000
002168	0.240	0.351	0.190	0.836	0.416	1.000	0.655	1.000	0.841	0.691
002177	0.600	0.707	0.902	0.944	1.000	0.869	0.301	1.000	1.000	1.000
002191	0.544	0.797	0.499	0.723	1.000	0.983	0.851	0.547	0.785	0.783
002224	0.705	0.644	0.413	0.870	0.761	0.758	0.441	1.000	0.474	0.278
002276	0.959	0.909	1.000	0.605	1.000	0.994	0.988	0.898	0.993	0.914
002296	0.673	0.415	0.895	0.496	1.000	0.783	1.000	0.951	0.959	0.682
002303	0.604	0.988	0.947	0.836	0.965	0.956	0.888	0.768	0.834	0.676

300002	0.382	0.414	0.590	0.976	0.941	0.915	0.916	0.932	0.870	0.945
300007	1.000	1.000	0.823	1.000	0.811	0.977	0.910	0.951	0.849	0.728
300018	0.522	0.358	1.000	0.645	1.000	0.736	0.508	0.872	0.702	0.700
300020	0.702	1.000	1.000	1.000	1.000	0.819	0.896	0.948	0.828	0.940
300036	0.380	0.367	0.208	0.260	0.333	0.581	0.817	0.730	0.871	0.865
600410	1.000	1.000	1.000	1.000	1.000	0.965	0.976	0.865	0.968	0.956
600570	0.667	0.762	0.697	0.651	0.756	0.848	0.922	0.836	0.995	0.952

To provide companies with a better understanding of the overall situation in the blockchain industry, the paper calculates the average values of the DEA data envelopment analysis results for each year from 2011 to 2020. The paper also provides a detailed description of the comprehensive efficiency, pure technical innovation efficiency, and scale efficiency for each year. The average values of the three measurement values are shown in Table 3-4. It is evident that there is significant fluctuation in the average values for each measure during the period from 2011 to 2020. This further confirms that companies in the blockchain sector are experiencing overall stable development, but the innovation efficiency and company scale have not yet reached the optimal state of development.

Table 3-4 Average efficiency results

Year	Average comprehensive efficiency	Average technological innovation efficiency	Average scale efficiency
2011	0.500	0.735	0.679
2012	0.566	0.746	0.732
2013	0.486	0.667	0.705
2014	0.621	0.756	0.802
2015	0.694	0.784	0.861
2016	0.604	0.679	0.873
2017	0.603	0.715	0.838
2018	0.694	0.772	0.890
2019	0.681	0.762	0.895
2020	0.682	0.802	0.852

The paper conducted a horizontal comparison of the three columns of data in table 3-4 and found that, except for the first two years, the average technical innovation efficiency of each company during the period from 2011 to 2020 was lower than their average scale efficiency.

From this, we can conclude that the current low technical innovation efficiency of listed blockchain companies is mainly due to their tendency to prioritize stable scale development, resulting in insufficient investment in innovation activities and lower average technical innovation efficiency. Given the current social and technological conditions, this decision is not correct.

Blockchain is a new network information technology known for its openness. The rapid development of science and technology has brought about tremendous changes in society. As leaders in the technological era, listed blockchain companies typically possess advanced technology and ample development potential. Therefore, for these companies, loosening the reins on innovation activities and continuously improving their technical innovation efficiency are essential to promote their own stable development and progress in society.

3.2 Technical Innovation Efficiency Analysis

Based on the calculation model and referring to previous literature and empirical data, the paper classified the sample blockchain companies into four levels: "Excellent," "Good," "Fair," and "Poor," based on their innovation efficiency values. and Table 3-5, Table 3-6, Table 3-7 and Table 3-8 are sorted out.

From table 3-5,it can be observed that the distribution of companies achieving excellent innovation efficiency (DEA effective) was uneven from 2011 to 2020. The peak was reached in 2015, with 10 companies able to achieve DEA effectiveness, accounting for 41.7% of the selected sample for that year. However, in 2011 and 2016, there were only three DEA effective companies, accounting for only 12.5% of the selected sample for those years.

Table 3-5 Innovation efficiency evaluation of 2011-2020 as "excellent" statistical table

Innovation efficiency value	Innovation efficiency evaluation	Year	Number	Proportion（%）
1	Excellent	2011	3	12.5
		2012	5	20.8
		2013	4	16.7
		2014	4	16.7
		2015	10	41.7
		2016	3	12.5
		2017	4	16.7
		2018	8	33.3
		2019	5	20.8
		2020	5	20.8

From table 3-6, it can be concluded that the number of listed blockchain companies with a "good" level of innovation efficiency measurement is relatively small. In 2011 and 2015, there were only 0 and 1 company respectively, and the highest number was 5 companies in 2017, which accounts for a small proportion.

Table 3-6 The evaluation of innovation efficiency in 2011-2020 is "good"

Innovation efficiency value	Innovation efficiency evaluation	Year	Number	Proportion（%）
[0.8,1.0)	Good	2011	0	12.5
		2012	3	20.8
		2013	0	16.7
		2014	4	16.7
		2015	1	41.7
		2016	3	12.5
		2017	4	16.7
		2018	8	33.3
		2019	5	20.8
		2020	5	20.8

Table 3-7 The evaluation of innovation efficiency in 2011-2020 is "good"

Innovation efficiency value	Innovation efficiency evaluation	Year	Number	Proportion（%）
[0.4,0.8)	General	2011	12	50
		2012	5	20.8
		2013	10	41.7
		2014	10	41.7
		2015	10	41.7
		2016	14	58.3
		2017	8	33.3
		2018	9	37.5
		2019	14	58.3
		2020	12	50

Table 3-8 The evaluation of innovation efficiency in 2011-2020 is "good"

Innovation efficiency value	Innovation efficiency evaluation	Year	Number	Proportion（%）
(0,0.4)	Poor	2011	9	37.5

	2012	11	45.8
	2013	10	41.7
	2014	6	25
	2015	3	12.5
	2016	5	20.8
	2017	7	29.2
	2018	4	16.7
	2019	3	12.5
	2020	3	12.5

Form table3-7, it can be observed that most of the listed blockchain companies' innovation efficiency measurements are at a "moderate" level from 2011 to 2020. Therefore, the current innovation efficiency of blockchain listed companies is generally not high.

Furthermore, As shown in Table 3-8, the number of companies with "poor" innovation efficiency, indicated by a comprehensive efficiency score between 0 and 0.4, shows a decreasing trend over the 10-year period. This trend reflects the gradual improvement in innovation efficiency in the blockchain industry in China due to the deepening research efforts.

However, during the study, when the data for the four types of companies were integrated, it was found that only a small proportion of companies achieved excellent or good overall innovation efficiency. Therefore, the overall comprehensive innovation efficiency of blockchain listed companies remains at a relatively low level each year, indicating that there is still room for improvement in the comprehensive innovation efficiency of the blockchain industry.

3.3 Scale Efficiency Analysis

In-depth analysis of the technological innovation efficiency of blockchain-listed companies in China requires ensuring that these companies have robust corporate mechanisms and relatively healthy revenue models while undertaking innovation activities. To achieve this, the research combines DEA analysis with empirical analysis evaluation results, incorporating the scale efficiency measurement values obtained from both the BCC input perspective and the CCR input perspective. This analysis examines the development of the selected sample of blockchain-listed companies in terms of their scale and operational profitability. It enables these companies to have a clear understanding of their operating environment and effectively plan their innovation input-output models, ultimately achieving improved innovation efficiency.

Table 3-9 Analysis results of innovation scale return of blockchain listed enterprises

Enterprise	Number				Proportion			
Returns to scale	Increase	Constant	Decrease	Total	Increase	Constant	Decrease	Total
2011	18	4	2	24	75	16.7	8.3	100
2012	13	6	5	24	54.2	25	20.8	100
2013	1	15	8	24	4.2	62.5	33.3	100
2014	11	5	8	24	45.8	20.9	33.3	100
2015	11	13	0	24	45.8	54.2	0	100
2016	7	14	3	24	29.2	58.3	12.5	100
2017	13	10	1	24	54.2	41.7	4.2	100
2018	5	14	5	24	20.8	58.3	20.9	100
2019	4	17	3	24	16.7	70.8	12.5	100
2020	6	12	6	24	25	50	25	100

According to the content analysis in Table 3-9, during the period of 2011-2020, the number of blockchain-listed companies with increasing scale efficiency measurement values fluctuated. For these companies, they have sufficient financial and human resources to support the development of their scale. Therefore, they need to focus on both business growth and appropriate increases in investment in science and technology to maintain a competitive position in the current and future market. On the other hand, the number of blockchain-listed companies with decreasing scale efficiency measurement values fluctuated and increased. This indicates that these companies still face challenges related to their manufacturing and large-scale operations. To improve scale efficiency, they need to optimize their independent innovation capabilities and allocate various types of human resources effectively. Additionally, a significant proportion of companies in the scale efficiency analysis show relatively stable measurement values, and this trend is on the rise. In-depth research and comparison reveal that most companies with effective DEA analysis are included in the group of companies with unchanged scale efficiency. This reflects that these companies, which maintain stable scale efficiency, have rational resource allocation. They not only maintain their competitiveness in innovation activities but also steadily develop their business scale. Overall, these companies are in a good developmental state.

3.4 DEA Effectiveness Analysis

Before analyzing the results obtained from Data Envelopment Analysis (DEA), it is important to provide an explanation. In DEA, the comprehensive efficiency of a company is typically decomposed into two components: pure technical efficiency and scale efficiency. The product of these two measurement values is equal to 1, representing the DEA effective state where the company demonstrates outstanding performance in both innovation activities and scale development. If the product of the measurement values of pure technical efficiency and scale efficiency is not equal to 1, and one of these values reaches 1, it is referred to as the DEA weakly effective state. This indicates that although the company has achieved a high level of pure technical efficiency or scale efficiency, improvements are needed in the other aspect of non-technical efficiency in terms of innovation and scale development. Lastly, if none of the three measurement values (comprehensive efficiency, pure technical innovation efficiency, and scale efficiency) reach 1, the company is considered to be in the DEA ineffective state, reflecting unfavorable conditions in both technological innovation activities and scale development.

The table 3-10 shows that in 2011, there were 3 DEA effective companies. The number increased to 5 in 2012, remained at 4 for 2013 and 2014, reached a peak of 10 in 2015, dropped to only 3 in 2016, and was 4 in 2017. In 2018, the number rose again to 8. The companies in the DEA effective state for both 2019 and 2020 were Shiyida and other five blockchain-listed companies.

Table 3-10 Statistical tables of DEA effectiveness

Innovation efficiency	Year	Number	Proportion
DEA significant state	2011	3	12.5
	2012	5	20.8
	2013	4	16.7
	2014	4	16.7
	2015	10	41.7
	2016	3	12.5
	2017	4	16.7
	2018	8	33.3
	2019	5	20.8
	2020	5	20.8
DEA Weakly efficient state	2011	4	16.7
	2012	3	12.5
	2013	3	12.5
	2014	7	29.2
	2015	2	8.3
	2016	2	8.3
	2017	3	12.5
	2018	3	12.5

	2019	3	12.5
	2020	7	29.2
DEA invalid state	2011	17	70.8
	2012	16	66.7
	2013	17	70.8
	2014	13	54.2
	2015	12	50
	2016	19	79.2
	2017	17	70.8
	2018	13	54.2
	2019	16	66.7
	2020	12	50

In response to these fluctuating patterns, after conducting a more in-depth analysis and comparing input-output indicators of various companies, it was found that companies such as Ziguang Guowei, which achieved a comprehensive efficiency measurement value of 1 in the previous year, were in a DEA weakly effective state in the following year, with a scale efficiency value less than 1 while maintaining a pure technical innovation efficiency measurement value of 1. Further analysis revealed that these companies had an unreasonable allocation of resources such as manpower and capital, with excessive investment in manpower and capital resources in innovation research, which limited their scale development. Similarly, companies such as Huizhong Technology, which were in the DEA effective state in the previous year, were in a DEA weakly effective state in the following year. Based on the data, Huazhong Technology reduced its R&D investment by 16.8% in 2016 compared to 2015, indicating inadequate resource allocation for innovation. These companies tend to prioritize stability in decision-making and have not fully utilized their innovative advantages. In the future development process, they should increase their investment in innovation resources, take bold actions, and enhance their innovation efficiency to seek better growth opportunities.

3.5 Projection analysis

In the DEA (Data Envelopment Analysis) methodology, projection analysis is a technique used to supplement the efficiency measurement values calculated through DEA. It focuses on inefficient units where both the pure technical efficiency and scale efficiency are not equal to 1. The purpose is to further analyze these units and investigate the phenomena of input redundancy and output insufficiency in terms of input and output, respectively. The objective is to explore the underlying reasons for low innovation efficiency at a deeper level and provide more accurate directions for improving innovation efficiency in such companies.

Taking the projection analysis results for the year 2020 as an example, it is evident that all 12 companies exhibit input redundancy, but there are notable differences among different types of companies. Due to their excessive allocation of innovation resources, their scale efficiency is constrained, indicating that their development scale is not in a highly healthy state. Moreover, these companies also face resource waste in their innovation activities due to improper resource utilization and allocation. Consequently, their innovation efforts encounter significant challenges. As a result of overinvesting in innovation resources without effective utilization, these 12 companies also experience insufficient revenue generation and research patent output. Taking Hang Seng Electronics Company as an example, it ranks high among the 24 listed blockchain companies in terms of developer count and investment amount. However, when considering its output effectiveness, it indeed suffers from output insufficiency. From the table, it is evident that 90% of its investment amount is redundant, and its output level significantly lags the DEA efficient state. Therefore, from these data, it becomes apparent that a substantial amount of human and asset investments inevitably lead to redundancy. This, in turn, decreases the overall efficiency of resource utilization for blockchain listed companies, resulting in significant output gaps. As a result, it becomes challenging to establish a symbiotic pattern of excellent innovation development and balanced corporate management. It is crucial for these companies to address the issue of input redundancy and output insufficiency to improve their overall efficiency and achieve a better balance between resource utilization and output generation.

IV. Discussion and conclusion

4.1 Conclusion

This study empirically analyzes panel data from representative Chinese blockchain listed companies between 2011 and 2020 to investigate the innovation efficiency in this industry. The research employs a Data Envelopment Analysis (DEA) model to explore the factors influencing technological innovation performance. Through a comprehensive DEA analysis of input-output indicators and efficiency measures, the following findings are derived.

Firstly, the overall innovation efficiency of China's blockchain industry exhibits fluctuations but shows a gradual upward trend, driven by advancements in scientific research. Secondly, the majority of domestic blockchain listed companies demonstrate average or below-average comprehensive innovation efficiency. This indicates the need for improvement in the technological innovation capabilities and performance levels of these enterprises. Thirdly, a comparison of comprehensive innovation efficiency, pure technical efficiency, and scale efficiency reveals that, except for the initial two years, the average technological innovation efficiency of these companies is lower than the average scale efficiency during the 2011-2020 period. This suggests that the low technological innovation efficiency in current blockchain listed companies primarily stems from their preference for stable scale development and inadequate investment in innovation activities. Lastly, based on the empirical DEA analysis, scale returns, and DEA effectiveness of domestic blockchain listed companies from 2011 to 2020, it is concluded that the equilibrium between innovation and company scale has not reached optimal levels, particularly for companies that are not DEA-effective. These companies often face challenges related to redundant inputs and insufficient outputs, hindering both their scale and innovation activities.

4.2 Theoretical contributions

Firstly, in terms of theoretical significance, the paper starts with the enterprise data of all listed blockchain companies in China in recent years, providing an innovative evaluation index system for the research perspective and path of blockchain listed companies. Secondly, by studying their innovation efficiency, it defines the basic definition of scientific and technological innovation promoting enterprise efficiency improvement and elaborates on a comprehensive evaluation model for scientific and technological innovation and enterprise efficiency improvement. Secondly, in terms of practical significance, based on empirical research on domestic blockchain enterprises in China, it provides recommendations for improving the management of blockchain listed companies, further promoting the high-quality development of enterprises with the assistance of blockchain, and building an ecosystem for blockchain listed companies. Moreover, it is of practical significance for local enterprises to enhance innovation efficiency. The research findings inspire managers to make informed decisions to improve enterprise innovation efficiency.

4.3 Practical implications

The paper provides in-depth empirical analysis results and offers constructive suggestions to enhance the innovation efficiency of Chinese blockchain listed companies. Recommendations are provided for the government, the blockchain industry, and the companies themselves. The government should coordinate market self-regulation and macro-regulation, establish relevant laws, proactive institutional policies, and an efficient regulatory mechanism to ensure healthy development. The blockchain industry should prioritize technology and high-end talents, tapping into technological resources. Companies should optimize resource allocation, recruit managerial talents for strategic direction, and research-oriented talents to stay updated. These efforts are essential to enhance the technological innovation and management capabilities of domestic blockchain listed companies.

4.4 Future research

In future research, the paper aims to provide a deeper and more thorough interpretation of the results obtained during this stage by exploring the important reasons for the generally low innovation efficiency of Chinese blockchain listed companies. It will analyze the factors that determine the innovation efficiency of blockchain enterprises in China from both the broader industry development environment and external factors, as well as the internal factors of the companies. Additionally, the paper acknowledges the limited scope of the selected data and hopes to incorporate more samples and data in future empirical studies to achieve stronger research conclusions.

References

[1] Satoshi Bitcoin, A peer-to-peer electronic cash system[J].*Consulted*, 2008, (2):1-30.

[2] The promise of the blockchain: The trust machine[J].*The Economist*, 2016, (3):1-6.

[3] LiXD, NiuYK, WeiLB, etal. Overview of bitcoin privacy Protection[J].J*ournal of Cryptography*, *6(2)*, 2019, 133- 149.

[4] Rubén Martínez Alonso,María J. Martínez Romero,Alfonso A. Rojo RamírezThe impact of technological innovation efficiency on firm growth: The moderating role of family involvement in management[J]. *European Journal of Innovation Management*, *23(1)*, 2019, 350-355.

[5] Claudio Cruz-Cázares,Cristina Bayona-Sáez,Teresa García-Marco. You can't manage right what you can't measure well: Technological innovation efficiency[J]. *Research Policy*, *42(6-7)*, 2013, 205-217.

[6] Karmaker Shamal Chandra,Hosan Shahadat,Chapman Andrew J.,Saha Bidyut Baran. The role of environmental taxes on technological innovation[J]. *Energy*, 2021, 232:393-401.

[7] GARY D FERRIER,JULIE S TRIVITT. Incorporating quality into the measurement of hospital efficiency: a double DEA approach[J]. J*ournal of Productivity Analysis*, 2013, 40: 337-355.

[8] JUSTIN D, NOIRIN M, MARIE O C. The importance of internal knowledge generation and externalknowledge sourcing forsme innovation and performance: evidence from Ireland[J]. *International Journal of Innovation Management*, 2019, (1):6901-6930.

[9] KANG K N, PARK H. Influence of government R&D support and interfirm collaborations oninnovation in Korean biotechnology SMEs[J].*Technovation*, 2012, (1): 68-78.

[10] TAHIZADEH S K, JAYARAMAN K S, ISMAIL I, et al. Innovation value chain as predictors for innovation strategy in telecommunication industry [J].*Problems and Perspectives in Management*, 2017, (4):533-539.