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Efficiency Evaluation and Barrier Analysis of Blockchain Technology Application in Cross-Border Trade Finance: A Case Study of Supply Chain Finance in the Guangdong-Hong Kong-Macao Greater Bay Area

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Abstract: Under the special institutional environment of "One country, Two systems, and Three jurisdictions" in the Guangdong-Hong Kong-Macao Greater Bay Area (GBA), cross-border trade finance faces prominent information asymmetry and institutional frictions. Existing studies lack quantitative evaluation of blockchain technology's application efficiency in this context and systematic analysis of barrier mechanisms. This paper constructs an analytical framework of "technological characteristics-financing process-efficiency output", using the DEA-BCC model, Malmquist index, grounded theory, and ISM-ANP model for empirical analysis. The results showed that blockchain significantly empowers cross-border trade finance, with total factor productivity (TFP) increasing by 14% in 2023–2024, mainly driven by technological efficiency improvement. Core enterprises (comprehensive technical efficiency 0.82) outperform SMEs (0.65), showing a "Matthew Effect". Moreover, barriers form a three-level structure of "underlying root-middle-level transmission-surface manifestations", with technical (weight 0.32) and institutional barriers (0.28) as core constraints, especially insufficient cross-border regulatory coordination (0.12) and inconsistent cross-chain standards (0.10). Prioritizing these underlying barriers is key to breaking "digital silos", and the proposed hierarchical governance strategy provides support for GBA financial infrastructure interconnection.

Keywords: Blockchain technology; Cross-border trade finance; DEA-Malmquist; ISM-ANP model; Guangdong-Hong Kong-Macao Greater Bay Area

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1. Introduction

Against the strategic background of the digital economy reshaping global trade and China's "dual circulation" development pattern, cross-border trade finance, as a hub connecting international and domestic markets, directly affects industrial and supply chain resilience. The GBA, with its unique "one country, two systems, three customs territories, three currencies" institutional heterogeneity, has created an active cross-border trade ecosystem but also triggered frictions in capital, logistics, and information flow integration. Long constrained by cross-border information asymmetry and high verification costs, the traditional trade finance model faces a severe "Macmillan Gap", where financial intermediaries adopt credit rationing due to difficulty in penetrating supply chain information fog, leaving numerous foreign trade SMEs in a predicament of difficult and expensive financing. The WTO notes the global trade finance gap remains at the trillion-dollar level, reflecting the efficiency boundary of traditional financial infrastructure in addressing cross-border trust issues.

Blockchain technology, relying on distributed ledgers, asymmetric encryption, and smart contracts, constructs a "trustless trust" mechanism, regarded as the cornerstone of the "value internet". Theoretically, it can transform non-standardized trade information into trusted digital assets, addressing information asymmetry and multi-level credit transmission issues. However, existing research lags behind industry practices. Most focus on technical architecture or single-case descriptions, lacking systematic empirical research combining technological characteristics with the GBA's special institutional environment. Specifically, there is a lack of quantitative analysis on financing efficiency improvement and systematic exploration of barrier mechanisms restricting technology implementation [1].

To fill these gaps, this paper constructs an integrated analytical framework of "technological characteristics-financing process-efficiency output". Taking GBA supply chain finance as the research carrier, it uses the DEA-BCC model and Malmquist index to measure static and dynamic efficiency, and combines grounded theory with the ISM-ANP model to analyze barrier factors' hierarchical structure and core connections. This study aims to reconstruct the theoretical logic of blockchain empowering cross-border trade finance and provide empirical support for the deep integration of fintech in the GBA under institutional heterogeneity.

2. Theoretical basis and literature review

2.1. Core concepts

Blockchain technology, from a technical perspective, is a distributed database based on cryptographic principles, ensuring data timeliness, immutability, and consistency through timestamping, hash algorithms, and consensus mechanisms. In cross-border trade finance, consortium or private blockchains are commonly used to balance decentralization, access control, and performance. Economically, blockchain reduces trust costs, establishing an algorithm-based "code is law" system that transforms non-standardized trade information into tradable digital assets [2].

Cross-border trade finance refers to funding financing and credit support services for importers and exporters, covering instruments such as letters of credit, collection, and supply chain finance models. Compared with domestic trade finance, it faces more complex challenges in integrating capital, logistics, and information flows, with key pain points including high information verification costs and lengthy, inefficient processes [3].

GBA supply chain finance, shaped by three legal and currency systems, must address both traditional information asymmetry and cross-jurisdictional regulatory compliance and data flow restrictions. Innovative models include cross-border capital pool optimization and "regulatory sandbox" initiatives, such as Hong Kong's eTradeConnect and the mainland's GBA Trade Finance Blockchain Platform, which aim to break institutional barriers through technology [4].

2.2. Theoretical foundations

Information asymmetry theory explains financial market frictions and credit rationing. Blockchain transforms information structure by enabling full-network broadcasting, multi-party verification, and timestamping, reducing adverse selection and moral hazard through algorithmic consensus, shifting from "ex-post supervision" to "ex-ante prevention" and "in-process control" [5].

Transaction cost theory identifies search, bargaining, and execution costs as key inefficiencies in cross-border trade finance. Blockchain reduces these costs through decentralized information sharing, smart contract automation, and standardized interfaces, eliminating manual intervention and opportunistic behaviors [6].

Synergy theory emphasizes non-linear interactions between system subsystems. Blockchain provides a collaborative infrastructure for GBA cross-border trade finance, integrating stakeholders into a trust ecosystem, enabling real-time synchronization and parallel processing, and strengthening core enterprise credit penetration to enhance overall ecosystem financing accessibility [7].

Financial intermediation theory argues that blockchain's application in trade finance is not simple disintermediation but functional reshaping. While blockchain undertakes trust verification and settlement functions, financial institutions retain core roles in risk pricing, liquidity provision, and regulatory compliance, with technology empowering them to focus on high-value-added services [8].

2.3. Literature review and gaps

Existing research on blockchain in cross-border trade finance covers application modes, efficiency evaluation, and barrier factors. Application mode studies summarize core enterprise-led, financial institution-led, and third-party platform-led models, but lack comparative analysis of their adaptability in specific institutional environments like the GBA. Efficiency evaluation studies, mainly using DEA models, focus on single institutions or links, lacking a supply chain-wide perspective and integration of non-financial indicators, with insufficient attention to SMEs. Barrier factor research identifies technical, institutional, and market obstacles but lacks quantitative analysis of hierarchical relationships and action paths.

Three key research gaps exists as follows:

(1) Lack of consideration of the GBA's unique institutional endowment;

(2) Fragmented efficiency evaluation systems;

(3) Superficial analysis of barrier mechanisms.

This paper addresses these gaps through an integrated analytical framework and empirical tests.

3. Practical status of blockchain cross-border trade finance in the GBA

The application of blockchain in GBA cross-border trade finance has evolved into a mature commercial ecosystem with three distinct paradigms.

3.1. Core enterprise-led vertical credit integration model

Represented by Huawei and TCL, this model leverages core enterprises' industrial chain control and credit to build closed financing networks. By integrating IoT devices to upload full-life-cycle cargo data, core enterprises' accounts payable are digitized into liquid, divisible digital payment obligations. SMEs can obtain financing using these credit-backed vouchers, reducing the average financing cycle from 20 days to less than 5 days and lowering costs by over 20%. However, it forms "credit silos" centered on core enterprises, limiting horizontal asset flow across industrial chains.

3.2. Financial institution-led horizontal alliance model

Led by the Hong Kong Monetary Authority's eTradeConnect and its interconnection with the People's Bank of China's Trade Finance Blockchain Platform, this model aims to break inter-bank information barriers. It enables cross-border verification of trade data while respecting jurisdiction-specific data sovereignty, reducing document review error rates from 15% to less than 0.5% and shortening processing time from days to hours. Challenges include complex inter-bank interest coordination and inconsistent data privacy standards.

3.3. Third-party platform ecological model

Technology giants like Tencent and OneConnect build open "blockchain + AI" platforms, integrating multi-dimensional data (customs, taxation, logistics, ERP) for dynamic enterprise profiling and real-time risk control. JD Technology's practice shows a "de-coreization" trend, allowing SMEs to accumulate "data credit" and reduce reliance on core enterprises. These platforms have increased GBA SMEs' cross-border trade finance coverage from 32% to 48%, enhancing financial inclusiveness and promoting cross-chain standard unification.

4. Efficiency evaluation

4.1. Evaluation index system

Input indicators include financing cost (ten thousand yuan per ten million yuan), process time (days), technology investment (ten thousand yuan), and labor cost (ten thousand yuan). Output indicators include financing scale (ten million yuan), financing success rate (%), risk control effect (reciprocal of non-performing rate), and business expansion capacity (ten million yuan).

4.2. Sample selection and data sources

100 GBA enterprises (20 core enterprises, 80 SMEs) from electronic information, textile and clothing, mechanical equipment, and chemical industries are selected. Data sources include enterprise surveys, platform operation data (GBA Chain, Yuexinrong), financial institution data (China Merchants Bank, HSBC), and public statistics. The data period is January 2023 to December 2024, with missing data supplemented by interpolation (**Table 1**).

Table 1. Descriptive statistics of input and output indicators for blockchain cross-border trade finance efficiency evaluation (2023–2024)

Indicator type	Variable name	Unit	Mean	Standard deviation (S.D.)	Minimum (Min)	Maximum (Max)
Input indicators	Financing cost	Ten thousand yuan per ten million yuan	12.45	3.20	8.50	22.00
	Process time	Days	7.25	4.12	2.00	18.00
	Technology investment	Ten thousand yuan	58.60	24.35	15.00	120.00
	Labor cost	Ten thousand yuan	18.30	5.60	8.00	35.00
Output indicators	Financing scale	Ten million yuan	4.50	3.85	0.50	25.00
	Financing success rate	%	48.50	18.20	15.00	95.00
	Risk control effect	% (Non-performing rate)	0.85	0.35	0.10	2.50
	Business expansion capacity	Ten million yuan	2.10	1.50	0.00	8.00

4.3. Evaluation models

The input-oriented DEA-BCC model (variable returns to scale) measures static comprehensive technical efficiency (TE), decomposed into pure technical efficiency (PTE) and scale efficiency (SE, TE = PTE × SE). The Malmquist index quantifies dynamic total factor productivity (TFP) changes, decomposed into technological efficiency change (EC) and technological progress (TC).

4.4. Static efficiency results

The overall average comprehensive technical efficiency is 0.68, with only 20% of enterprises reaching the efficiency frontier. Core enterprises (0.82) outperform SMEs (0.65) due to stronger technology investment and resource integration capabilities. Core enterprises' efficiency bottleneck lies in scale inefficiency, while SMEs face insufficient technical application capacity (**Table 2**).

Table 2. Static efficiency evaluation results of blockchain technology application

Enterprise type	Core enterprises	Small and medium-sized micro-enterprises	Total
Sample size	20	80	100
Average comprehensive technical efficiency	0.82	0.65	0.68
Average pure technical efficiency	0.91	0.78	0.80
Average scale efficiency	0.90	0.83	0.85
Number of efficient enterprises (TE=1)	8	12	20
Efficiency rate (%)	40.0	15.0	20.0

4.5. Dynamic efficiency results

TFP increased by 14% from 2023 to 2024, driven by both technological progress (1.04) and technological efficiency improvement (1.10). Core enterprises (18% growth) outperform SMEs (12%), but SMEs show significant growth potential with continued technical capacity improvement (**Table 3**).

Table 3. Dynamic efficiency evaluation results of blockchain technology application (2023–2024)

Enterprise type	Core enterprises	Small and medium-sized micro-enterprises	Total
Total factor productivity (TFP)	1.18	1.12	1.14
Technological progress index	1.05	1.03	1.04
Technological efficiency change index	1.12	1.09	1.10
Pure technical efficiency change index	1.08	1.06	1.07
Scale efficiency change index	1.04	1.03	1.03

5. Barrier factor analysis

5.1. Identification based on grounded theory

Through open, axial, and selective coding of 20 interviews (150,000 words), 4 main categories, 12 sub-categories, and 35 initial concepts are identified as outlined:

(1) Technical barriers: Inconsistent cross-chain standards, high security risks, insufficient adaptability, data

sharing difficulties;

(2) Institutional barriers: Imperfect cross-border regulatory coordination, lagging laws, unclear policies;

(3) Market barriers: Fragmented credit consensus, low enterprise awareness, imperfect third-party services;

(4) Subject barriers: Insufficient core enterprise participation motivation, weak SME technical capacity, limited financial institution innovation willingness.

5.2. Hierarchical structure based on ISM model

The ISM model classifies 12 sub-category barriers into three levels (**Table 4**). The barriers are as listed:

(1) Underlying roots (S1-S6): Core drivers affecting the entire barrier system, including regulatory coordination, technical standards, laws, policies, security risks, and credit consensus;

(2) Middle-level transmission (S7-S10): Connect underlying and surface barriers, including data sharing difficulties, insufficient adaptability, core enterprise motivation, and financial institution innovation restrictions;

(3) Surface manifestations (S11-S13): Direct application difficulties, including low awareness, weak SME capacity, and imperfect third-party services.

Table 4. Heatmap of ISM reachability matrix of barrier factors

No.	Barrier factors	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	Level
S1	Lack of cross-border regulatory coordination	1	0	0	0	0	0	1	1	1	1	1	1	1	Underlying
S2	Inconsistent cross-chain standards	0	1	0	0	0	0	1	1	0	0	1	1	1	Underlying
S3	Lagging laws and regulations	0	0	1	0	0	0	0	0	1	1	1	0	1	Underlying
S4	Unclear regulatory policies	0	0	0	1	0	0	0	0	0	1	1	0	0	Underlying
S5	High technical security risks	0	0	0	0	1	0	0	0	1	0	1	0	0	Underlying
S6	Fragmented credit consensus	0	0	0	0	0	1	0	0	1	1	1	0	0	Underlying
S7	Difficulty in data sharing	0	0	0	0	0	0	1	0	0	0	1	1	1	Middle-level
S8	Insufficient technical adaptability	0	0	0	0	0	0	0	1	0	0	0	1	0	Middle-level
S9	Insufficient motivation of core enterprises	0	0	0	0	0	0	0	0	1	0	0	0	1	Middle-level
S10	Restricted financial institution innovation	0	0	0	0	0	0	0	0	0	1	1	0	1	Middle-level
S11	Low enterprise awareness	0	0	0	0	0	0	0	0	0	0	1	0	0	Surface
S12	Weak technical capacity of SMEs	0	0	0	0	0	0	0	0	0	0	0	1	0	Surface
S13	Imperfect third-party services	0	0	0	0	0	0	0	0	0	0	0	0	1	Surface

5.3. Weight determination based on ANP model

The ANP model shows technical barriers (0.32) and institutional barriers (0.28) are core constraints. Top five barrier factors by weight: lack of cross-border regulatory coordination (0.12), inconsistent cross-chain standards (0.10), fragmented credit consensus (0.09), lagging laws (0.08), high technical security risks (0.07) (total weight 46%).

5.4. Core connections

Core barriers form a "vicious circle", where insufficient regulatory coordination restricts financial institution innovation, highlighting low enterprise awareness. Inconsistent cross-chain standards cause data sharing and adaptability issues, limiting SME application. Fragmented credit consensus and lagging laws reduce core enterprise participation, hindering platform ecological construction.

6. Countermeasure suggestions

6.1. Technical level

At the technical level, efforts should be focused on three aspects: standard unification, security assurance, and adaptability improvement. A "Blockchain Technology Standards Committee" should be established to formulate unified standards for interfaces, data formats, and smart contracts, supplemented by certification and policy support. Meanwhile, increase investment in the research and development of encryption technologies, identity authentication, and privacy protection technologies, and establish emergency response mechanisms and third-party security assessment systems. In addition, it is necessary to develop lightweight and low-cost application modules, provide targeted technical training and subsidies for SMEs, and enhance technical adaptability.

6.2. Institutional level

Optimization at the institutional level should focus on cross-border regulatory coordination, improvement of the legal system, and optimization of policy support. A regular communication mechanism should be established between regulatory authorities in the Chinese mainland, Hong Kong, and Macao, a regulatory information sharing platform should be built, and a "regulatory sandbox" model should be explored in pilot areas. At the same time, revise relevant laws and regulations such as the Negotiable Instruments Law and the Civil Code to clarify the legal status of electronic documents and smart contracts, and formulate targeted management measures for blockchain cross-border trade finance in the Guangdong-Hong Kong-Macao Greater Bay Area (GBA). Additionally, introduce policies such as financing interest subsidies and technical investment grants, encourage financial institutions to innovate through measures such as preferential risk reserve policies, and establish a dynamic evaluation mechanism for policy effects.

6.3. Market level

At the market level, efforts should be made to build a unified credit consensus, enhance enterprise awareness, and improve the third-party service system. It is necessary to integrate multi-dimensional credit data such as customs, taxation, and logistics, establish a distributed credit ledger, and promote cross-border credit rating cooperation to form a unified credit consensus. For instance, popularize the advantages of blockchain technology through industry forums and case demonstrations, and drive the participation enthusiasm of the entire industrial chain through leading enterprises. Meanwhile, cultivate professional third-party service institutions to provide services

such as technology development, security assessment, and legal consulting, and establish a diversified dispute resolution mechanism to improve the market service ecosystem.

6.4. Subject level

At the subject level, it is necessary to strengthen the coordination capacity of all participants, and enhance the participation motivation of core enterprises, the technical capacity of SMEs, and the innovation vitality of financial institutions. Tax incentives and credit incentives can be used to enhance the participation enthusiasm of core enterprises and establish an industrial chain benefit-sharing mechanism. For SMEs, simplify the financing process, provide personalized solutions, and encourage core enterprises to provide credit support through long-term cooperation agreements. Financial institutions need to set up specialized innovation departments, and the government can jointly establish a risk compensation fund with enterprises and institutions to reduce innovation risks and stimulate innovation willingness.

7. Research conclusions and prospects

7.1. Conclusions

The research conclusions show that blockchain technology can significantly improve the efficiency of cross-border trade finance in the GBA. The average overall comprehensive technical efficiency is 0.68, among which core enterprises (0.82) outperform SMEs (0.65). The TFP increased by 14% from 2023 to 2024, mainly driven by the dual wheels of technological progress and efficiency improvement. Concurrently, the obstacles to blockchain application present a four-dimensional structure of "technology-institution-market-subject" and a three-level hierarchical characteristic of "underlying roots-middle-level transmission-surface manifestations". Insufficient cross-border regulatory coordination, inconsistent cross-chain standards, and fragmented credit consensus are the core restrictive factors, with a total weight of 31%. Based on this, improving application efficiency requires building a "four-in-one" governance system of "technological innovation-institutional guarantee-market cultivation-subject coordination", and breaking through development bottlenecks through measures such as standard unification, regulatory coordination, and credit integration.

7.2. Limitations and prospects

Limitations include a limited sample scope, incomplete efficiency evaluation indicators, and insufficient consideration of external environmental impacts. Future research should expand samples for cross-regional comparisons, improve indicator systems with long-term benefit metrics, analyze external environment impacts (e.g., RCEP, Belt and Road), and explore integrated blockchain-AI-big data application efficiency.

Disclosure statement

The authors declare no conflict of interest.

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