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The Antecedents and Consequents of Transaction Efficiency in Electricity Transaction Platforms -A Platform Leadership Perspective

HU Zhouming

Doctor of Management

Supervisors:
PhD Renato Pereira, Assistant Professor with Habilitation,
ISCTE University Institute of Lisbon
PhD TENG Ying, Professor,
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Abstract

Against the backdrop of the deep integration of electricity market-oriented reform and the platform economy in China, this study explores the antecedents of transaction efficiency in electricity transaction platforms and its impact on user enterprise performance from the perspective of platform leadership. Using full-sample data from all 33 provincial-level electricity transaction platforms in China and employing Necessary Condition Analysis (NCA), fuzzy-set Qualitative Comparative Analysis (fsQCA), and multiple regression analysis, this study yields the following key findings: First, transaction efficiency is jointly shaped by platform leadership and electricity market regulation, with no single factor being independently sufficient or decisive. Second, at the platform level, three distinct causal configurations lead to high transaction efficiency: (1) a synergy-driven path between platform leadership and regulation, (2) a regulation-driven path that enhances the quality and efficiency of platform leadership, and (3) a platform leadership incentive-improvement path under moderate regulation. Third, at the user enterprise level, high transaction efficiency significantly improves firm performance, and all four dimensions of platform leadership—guidance power, influence power, coordination power, and control power—play significant moderating roles in this process. The study puts forward the following recommendations: platform leaders should implement precise strategies tailored to their own resource endowments; regulators should transform their roles and adopt precise, collaborative, and dynamic regulatory strategies; and electricity user enterprises should adopt adaptive strategies to convert platform transaction efficiency into internal performance gains. Theoretically, this study transcends the traditional transaction cost economics paradigm by developing a "platform + government" dual-force analytical framework from the platform leadership perspective. It extends the research context to the distinctive electricity platform scenario characterized by "strong physical constraints and real-time balancing," thereby offering novel theoretical insights and practical guidance for enhancing transaction efficiency in electricity markets and improving performance among electricity user enterprises.

Keywords: Electricity transaction; Transaction efficiency; Platform leadership; Influencing factors; Configuration

JEL: M21, M10

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Resumo

Tendo como pano de fundo a profunda integração da reforma do mercado energético e da economia de plataforma na China, esta tese, desenvolvida na perspetiva da liderança de plataforma, explora sistematicamente os antecedentes da eficiência das plataformas de negociação de energia e o seu impacto no desempenho das empresas utilizadoras. Com base nos dados recolhidos em todas as 33 plataformas provinciais de negociação de energia na China, e utilizando NCA, fsQCA e análise de regressão múltipla, esta tese revela as seguintes conclusões principais: Em primeiro lugar, a eficiência da negociação de energia depende da influência combinada da liderança da plataforma e da regulação do setor, sem que nenhum deles individualmente seja determinante. Em segundo lugar, ao nível da plataforma de negociação de energia, existem três configurações antecedentes para alcançar uma elevada eficiência na negociação de energia: (1) condução baseada na sinergia entre a liderança da plataforma e a regulação do setor; (2) condução baseada na regulação que melhora a qualidade e eficiência da liderança da plataforma; e (3) condução baseada numa liderança de plataforma dependente de incentivos e de uma regulação moderada. Finalmente, ao nível da empresa utilizadora de energia, a elevada eficiência negocial pode melhorar significativamente o desempenho da empresa, e quatro tipos de liderança da plataforma — liderança, influência, coordenação e controlo — desempenham papéis moderadores significativos. Esta tese propõe que os líderes das plataformas energéticas implementem políticas precisas com base nos seus próprios recursos. Os reguladores do sector eléctrico devem concentrar-se na transformação dos seus papéis e implementar estratégias regulamentares precisas, colaborativas e dinâmicas; e as empresas utilizadoras de energia devem concentrar-se na adaptação estratégica para transformar a eficiência das negociações em desempenho interno. Este estudo rompe com a perspetiva tradicional da economia dos custos de transação e constrói uma estrutura de análise sistémica das forças duais “plataforma + governo” com base na perspetiva da liderança de plataforma. Estende a investigação ao cenário das plataformas de energia elétrica com “fortes restrições físicas + equilíbrio em tempo real, fornecendo uma nova base teórica e um referencial prático para melhorar a eficiência das negociações de energia e o desempenho dos utilizadores.

Palavras-chave: Comércio de energia elétrica; Eficiência no comércio; Liderança de

plataformas; Fatores de influência; Configurações
JEL: M21, M10

摘　要

围绕电力市场化改革与平台经济深度融合的实践背景，本文立足平台领导视角，系统探究电力交易平台交易效率的前因组态及其对用户企业绩效的作用关系。基于中国 33 家省级电力交易平台的全样本数据，运用 NCA、fsQCA 与多元回归分析等方法，本文揭示了以下核心发现：首先，电力交易效率取决于平台领导力与电力监管的联合影响，不存在单一决定因素；其次，存在三条实现高电力交易效率的前因组态，包括“平台领导与电力监管协同驱动型”、“电力监管驱动平台领导提质增效型”及“适度监管下平台领导激励改善型”；最后，高交易效率能显著提升用户企业绩效，且平台引领力、影响力、协调力、控制力四种平台领导力均在其中发挥显著的调节作用。本文提出，电力平台领导应基于自身禀赋精准施策；电力监管者应注重角色转变，实施精准、协同、动态的监管策略；电力用户企业应聚焦顺势谋略，将交易效率转化为内部绩效。本文研究突破了传统交易成本经济学视野，基于平台领导视角构建“平台+政府”双元力量的系统分析框架，将研究拓展至“强物理约束+实时平衡”的电力能源平台情景，为提升电力交易效率及改善用户绩效提供了全新的理论依据与实践参考。

关键词：电力交易；交易效率；平台领导；影响因素；组态

JEL: M21, M10

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这段旅程的结束，亦是新探索的开始。我将承载着各位师长的教诲与期望，在求知的道路上继续前行。

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Chapter 1: Introduction

1.1 Research background and significance

1.1.1 Research background

China's electricity transaction reform is a process that has gradually deepened alongside the reform of the national economic system. Before the first round of electricity reform in 2002, the government and enterprises were not separated, and the industry operated as a monopoly. In the early stages of reform and opening up, the electricity industry adopted a monopolistic operating model of "integrated government and enterprise, vertical integration of generation, transmission, distribution, and sales," managed by the Ministry of Electric Power Industry, and later by the State Power Corporation (Lin, 2005). Under this system, the industry relied mainly on state investment, resulting in a single source of funding, low efficiency, lack of competition, unclear costs, and a rigid pricing mechanism. Electricity prices were strictly determined by the government, implementing a "one plant, one price; one generator, one price" system, which failed to reflect the true costs and supply and demand relationship. This system could neither effectively incentivize investment nor guide users to use electricity rationally, and the drawbacks of the traditional planned economy became increasingly apparent (Pollitt, 2012). This system could not meet the huge demand for electricity generated by rapid economic development, leading to frequent nationwide electricity shortages (M. Zeng, 2017).

With the establishment of a socialist market economy in China, introducing competition and improving efficiency became a consensus for reform across various industries. As a fundamental sector of the national economy, the planned economy system of electricity was incompatible with the overall market economy environment, making reform imperative. In 2002, the State Council issued the "Electricity System Reform Plan" (State Council Document No. 5 [2002]), initiating the first round of electricity system reform (State Council, 2002). The main aim was to break the monopoly of the State Power Corporation, establishing two major power grid companies (State Grid Corporation of China and China Southern Power Grid Company) and five major electricity generation groups (China Huaneng Group, China Datang Corporation, China Huadian Corporation, China Guodian Corporation, and China Power Investment Corporation, later reorganized into China Energy Investment Corporation, among

others) through "separation of electricity generation and grid, separation of main and auxiliary businesses, separation of transmission and distribution, and competitive bidding for grid access." This attracted social capital investment in electricity generation and addressed the electricity shortage problem (State Council, 2002).Simultaneously, it laid the foundation for the subsequent establishment of a competitive electricity market. The core idea of the reform was "breaking the monopoly and introducing competition," separating the competitive links (electricity generation and sales) from the naturally monopolistic link (electricity grid) (Joskow, 2008). A schematic diagram of the user electricity purchase model after the separation of electricity generation and grid after the first round of reform is shown in Annex A, Figure A1.1.

After more than a decade of development following the first round of electricity sector reform, new problems have emerged, primarily including: First, electricity surplus and structural issues. Electricity supply has shifted from "shortage" to "structural surplus," with a continuous decline in the utilization hours of thermal electricity plants. In 2020, the national average utilization hours of thermal electricity plants dropped to approximately 4,200 hours (National Energy Administration, 2021). Simultaneously, clean energy consumption faces difficulties, with prominent issues of "wind curtailment, solar curtailment, and hydropower curtailment." In 2020, the curtailment rate for wind and solar power was approximately 2%-3%, and the curtailed hydropower exceeded 30 billion kilowatt-hours (National Renewable Energy Center, 2021). Clearly, the original planned electricity allocation model is no longer suitable for the new situation (L. Z. Zhang, 2018). Second, pressure from energy transition. To achieve energy conservation, emission reduction, and the "dual carbon" goals (carbon peaking in 2030 and carbon neutrality in 2060), a new market mechanism must be established, allowing clean energy to win in competition due to its low marginal cost advantage, rather than being squeezed out by planned dispatch (International Energy Agency, 2021). Third, price signals fail to function properly. Under the planned electricity pricing model, prices cannot convey accurate cost and supply-demand signals to investors and users, leading to blind investment and inefficient electricity consumption (Newbery, 2016). Therefore, it is urgent to establish a market-based electricity pricing mechanism that allows prices to rise and fall.

In March 2015, the Central Committee of the Communist Party of China and the State Council issued the "Opinions on Further Deepening the Reform of the Electricity System" (Document No. 9 of 2015), outlining a new round of electricity system reform tasks (Cpc Central Committee and State Council, 2015). One of the key focuses of this new round of electricity system reform is the institutional framework of "controlling the middle and liberalizing both ends" (M. Zeng, 2017). Controlling the middle means strengthening

government supervision of the transmission and distribution network to ensure fair and open electricity grid access and fair market transactions, fully leveraging the scale benefits of the electricity grid and improving management efficiency. Liberalizing both ends means implementing market access on the generation and sales sides, introducing competition, granting users more choices, and allowing prices to be formed by the market (Pollitt et al., 2019). Annex A, Figure A1.2, of the "Opinions on the Organization Model of the Electricity Market in the New Round of Electricity Reform in 2015."

To better facilitate the implementation of the new round of electricity reform and meet the needs of the electricity transaction market and business development, the State Grid Corporation of China, China Southern Power Grid Company, Inner Mongolia Power Company, Beijing Power Exchange Center, Guangzhou Power Exchange Center, and other power grid and transaction institutions have fully utilized digital technologies such as cloud computing, big data, blockchain, and artificial intelligence to build numerous digital platforms to support the operation of electricity businesses (State Grid Corporation of China, 2022). Among these, the electricity transaction platform is the core digital platform in the electricity market, aiming to realize transactions between electricity generation companies and electricity users. This platform provides electricity transaction services for market participants such as electricity generation companies, electricity sales companies, electricity users, energy storage companies, and new energy operators, supporting medium- and long-term transactions, spot transactions, ancillary service transactions, and green electricity and green certificate transactions, realizing large-scale optimized allocation of energy resources and direct transactions by electricity users, and providing a technical support platform for the operation of China's electricity market (Z. T. Liu et al., 2023). See Annex A, Figure A1.3 for a schematic diagram of the interaction between electricity transaction stakeholders through the platform.

Following the full launch of the electricity transaction platform in 2015, the scale of electricity traded in the market remained relatively small until 2020, with approximately 70% of coal-fired power plants and about 50% of industrial and commercial users participating (China Electricity Council, 2021). The electricity market lacked activity, with a small number of participants (approximately 289,000) and limited transaction instruments (mainly medium- and long-term bilateral negotiated transactions) (National Development and Reform Commission, 2021). In 2021, with the National Development and Reform Commission further promoting electricity market reform, documents such as the "Notice on Further Improving the Time-of-Use Pricing Policy" (NDRC Price [2021] No. 1093) abolished the industrial and commercial catalog sales price of electricity, expanded the price fluctuation range, and allowed

coal-fired power prices to fluctuate by 20% above or below the benchmark price, with no 20% restriction on transactions by high-energy-consuming enterprises (National Development and Reform Commission, 2021). The reform also required all industrial and commercial users to enter the market, increasing the number of market participants from 289,000 to 48.194 million. All electricity generated by coal-fired power plants and industrial and commercial users has entered the market. The volume of electricity traded in the coal-fired power market increased by 1 trillion kWh to 3.3 trillion kWh, while the volume of electricity traded on the consumer side increased by 2 trillion kWh to 4 trillion kWh (accounting for approximately 78% of total electricity sales), resulting in a significant increase in the scale of market-based transactions (China Electricity Council, 2022). Since the beginning of the 14th Five-Year Plan period, reforms have been further deepened: In 2023, the National Development and Reform Commission and the National Energy Administration issued the "Guiding Opinions on High-Quality Development of Distribution Networks under the New Situation" (NDRC Energy [2023] No. 1187) and the "Basic Rules for the Electricity Spot Market (Trial)" (NDRC Office Energy [2023] No. 701), promoting the pilot operation of the spot market nationwide (as of October 2025, more than 30 provincial spot markets had entered the trial or formal operation stage), introducing day-ahead, intraday, and real-time transaction mechanisms to achieve "price increases and decreases" and minute-level response (National Development and Reform Commission, 2023; National Energy Administration, 2023). The 2024 "Measures for the Supervision of the Electricity Market" (Order No. 94 of the State Administration for Market Regulation) and the "Guiding Opinions on Accelerating the Construction of a Unified National Electricity Market System" (NDRC [2024] No. 123) further clarified requirements for market access, transaction rules, credit supervision, and anti-monopoly review, emphasizing the construction of cross-provincial and cross-regional transaction, capacity markets, and ancillary service markets, and promoting the formation of a "national unified market" (National Development and Reform Commission, 2024; State Administration for Market Regulation, 2024). Meanwhile, to support the "dual carbon" goals, green electricity transaction and carbon emission rights transaction are deeply integrated with the electricity market. In 2025, the national green electricity transaction volume exceeded 500 billion kWh, and new entities such as distributed photovoltaic, energy storage, and virtual power plants accelerated their entry into the market. The proportion of market-based transaction volume increased to approximately 55% (2024 data), and is expected to reach over 60% by the end of 2025 (China Electricity Council, 2025; National Renewable Energy Center, 2025). The current organizational model of China's electricity transaction market is shown in Figure 1.1.

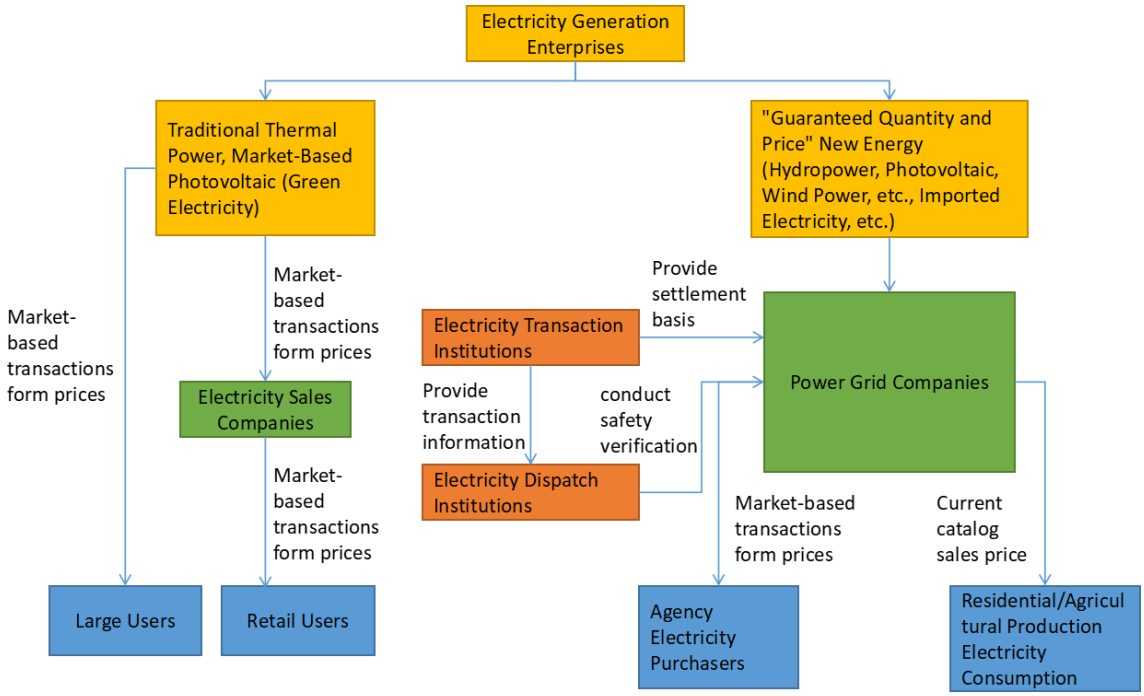


Figure 1.1 China's electricity market organization model

Given the surge in electricity market participants (from millions to tens of millions of users), the significant increase in market-based transaction volume (annual transaction volume exceeding 5 trillion kWh), the increasingly diversified ways the power grid serves users (including demand response, virtual power plants, and microgrid access), the diversification of transaction products (medium- and long-term + spot + derivatives + green certificates), and the provincial differences in regulatory policies (e.g., Guangdong's spot market is more mature than Shanxi's), how can the platform strike a balance of interests among different market participants, such as the government, power grid companies, power generation companies, electricity sales companies, industrial and commercial users, energy storage operators, distributed energy aggregators, third-party agents, and market regulatory agencies, while providing an efficient, fair, transparent, and secure transaction environment to promote transaction activities among market participants? This presents a complex management challenge (Gawer, 2014; Parker et al., 2016). In particular, against the backdrop of peak summer/winter electricity supply, frequent extreme weather events, high-proportion grid connection of renewable energy, and strengthened constraints on the safe and stable operation of the electricity system, electricity transaction platforms must balance economic efficiency with system security, and guard against risks such as abuse of market power, price manipulation, and settlement defaults (Bichpuriya & Soman, 2018). Especially under complex management scenarios and differentiated regulatory policies across provinces (e.g., the Beijing transaction center focuses on inter-regional transaction, while Guangzhou focuses on spot transaction plus

financial derivatives), how electricity transaction platforms can fully leverage their leadership role to actively promote improved transaction efficiency, risk control, and data governance has become a crucial issue in deepening the market-oriented reform of the electricity system (Cusumano et al., 2019).

In transaction practice, electricity transaction platforms differ from ordinary online transaction platforms. For example, electricity products on the platform are characterized by immediate consumption, non-storability (except for pumped storage/energy storage), and physical balance. Transactions between supply and demand are completed instantly, and these transactions must be conducted in accordance with the operating rules of the electricity system (N-1 safety criteria, frequency stability, voltage control), requiring real-time matching of electricity balance and energy balance (Stoft, 2002). Another difference is that some market participants on the electricity transaction platform have dual attributes. Some participants are both demanders and suppliers (such as industrial and commercial users participating in demand response or self-owned electricity plants), while others are both platform companies and agents for demanders (such as electricity sales companies acting as agents for small and medium-sized users) (Rochet & Tirole, 2006). Furthermore, due to its unique industry characteristics (involving national energy security and public utility attributes), electricity transaction receives greater attention and stricter regulation from the government (such as anti-monopoly review by the State Administration for Market Regulation and transaction supervision by the National Energy Administration). How transaction platforms, as platform leaders, can fully leverage their leadership within the permitted institutional framework to coordinate the multilateral stakeholders in electricity transaction (through rule design, data sharing, credit evaluation, and dispute arbitration mechanisms) in order to promote improved efficiency, optimized resource allocation, and green and low-carbon transformation in electricity transaction is particularly worthy of study (Boudreau & Hagiu, 2009). Because electricity transaction platforms differ from traditional e-commerce online transaction platforms (which have no physical constraints and offer instant settlement), It is worthwhile to investigate whether classic governance theories, such as transaction cost theory (Williamson, 1985); principal-agent theory (Jensen & Meckling, 1976), platform theories, such as two-sided market theory (Rysman, 2009); network externalities (Katz & Shapiro, 1994); platform encirclement strategy (Eisenmann et al., 2006), and emerging platform leadership theories (Cusumano et al., 2019) are applicable to electricity transaction platforms, and how these theories function in electricity physical constraints, regulatory compliance, and cross-stakeholder coordination.

Based on this, this research focuses on examining the influencing factors, antecedent

configurations, and effects of transaction efficiency on electricity transaction platforms from a platform leadership perspective, exploring how transaction efficiency is achieved and its effect on user companies. This study contributes to the theoretical insights into the development of digital platforms in the power industry, and also provides a time reference for the transformation of electricity transaction platforms and market-oriented reforms.

1.1.2 Research significance

1.1.2.1 Theoretical significance

This study's contribution to transaction efficiency theory primarily lies in its expanded application scenarios. Traditional research on transaction efficiency often focuses on digital platform scenarios without physical constraints, such as e-commerce or financial markets. However, electricity transaction platforms introduce the immediate consumption, non-storability, and physical balance characteristics of electricity, as well as real-time electricity matching constraints such as the N-1 safety criterion. This study places transaction efficiency within this highly complex physical-economic coupling scenario, expanding its boundary conditions and revealing how platforms can improve transaction efficiency through platform leadership, coordination, and risk prevention mechanisms under constraints such as real-time supply and demand balance, extreme weather, and high-proportion grid connection of renewable energy sources. This provides a new application scenario for transaction efficiency theory. This study also deepens the integration of transaction cost economics and platform leadership theory. Transaction cost economics (Williamson, 1985) emphasizes asset specificity, uncertainty, and opportunistic behavior, while platform leadership theory (Cusumano et al., 2019; Gawer, 2014) focuses on how platform firms dominate multilateral markets through rule design and ecosystem coordination. This study combines these two perspectives to analyze the governance mechanisms of electricity transaction platforms under conditions of high asset specificity (grid infrastructure), high uncertainty (market power abuse, settlement defaults), and stringent regulation (anti-monopoly review, credit regulation). It deepens the understanding of the role of platform leaders in reducing search, matching, and execution costs, particularly in scenarios involving dual-attribute entities (both supply and demand) and differentiated regulatory policies (differences in the maturity of inter-provincial spot markets). The study examines how platform leadership mitigates opportunistic risks through credit evaluation, dispute arbitration, and data governance.

Furthermore, this research contributes to the theoretical development of research on

interactions among electricity transaction platform participants. Existing research on platform interactions is largely based on bilateral market theory (Rochet & Tirole, 2006) and network externalities (Katz & Shapiro, 1994). However, electricity transaction platforms involve complex interactions among multilateral participants (generation companies, electricity retailers, industrial and commercial users, energy storage operators, distributed energy aggregators, third-party agents, and regulatory agencies), and are subject to physical constraints and government intervention. This study develops an inter-agent interaction framework to explore how platform leaders can promote cross-agent coordination (such as demand response and virtual power plant access) under the constraints of balancing interests, green and low-carbon transformation, and system security. It also examines the applicability of principal-agent theory (Jensen & Meckling, 1976) and algorithmic governance (Gillespie, 2018) in the electricity scenario, injecting the dimensions of energy security and regulatory compliance into platform interaction theory.

1.1.2.2 Practical significance

This study provides practical reference for electricity market reform, revealing the role of platforms in balancing the interests of multiple stakeholders. It can guide transaction institutions to optimize rule design, prevent price manipulation and settlement default risks, promote the construction of a "nationwide unified grid and market," and facilitate the transition of the spot market from pilot projects in over 30 provinces to formal operation, enabling electricity prices to "rise and fall" and respond within minutes.

This study has guiding value for the digital platform transformation of electricity management, emphasizing the platform's leadership in data governance, real-time matching, and risk control. It can provide strategies for upgrading the digital platforms already built by institutions such as State Grid and China Southern Power Grid that support medium- and long-term, spot, ancillary services, and green electricity transaction. For example, it can integrate blockchain and AI technologies to improve transparency and security, support the entry of new entities such as distributed photovoltaic, energy storage, and virtual power plants into the market, promote demand-side response and inter-provincial and inter-regional transaction, and contribute to the consumption of clean energy (minimizing wind and solar curtailment rates) and the optimal allocation of energy resources under the "dual carbon" target.

This study provides decision-making basis for government regulation and platform operation. Against the backdrop of peak summer/winter electricity supply, extreme weather, and a high proportion of renewable energy grid connection, platforms need to balance economic

efficiency with system security. They can guide regulatory authorities (such as the National Energy Administration and the State Administration for Market Regulation) to improve credit supervision and anti-monopoly mechanisms, while providing pathways for differentiated operations for platform enterprises such as transaction centers in various regions. For example, Beijing could focus on cross-regional transaction, while Guangzhou could focus on spot transaction plus financial derivatives. This would help resolve structural overcapacity and price signal failure issues, and promote the transformation of the power industry from a planned model to a market-oriented and digitalized one.

1.2 Research questions

As a crucial component of the electricity market, electricity transaction platforms play a key role in its operation and development (Z. T. Liu et al., 2023). One primary goal of platform construction is to support large-scale optimized allocation of energy resources and direct transactions between market participants, enabling multi-variety, multi-cycle transaction operations (State Grid Corporation of China, 2022). A second goal is for the platform to be non-discriminatory and fully open, providing open, transparent, convenient, and efficient electricity transaction services to market participants such as electricity generation companies and electricity users (Cpc Central Committee and State Council, 2015). A third goal is to promote the efficiency of market resource allocation and ensure the healthy development of the market by integrating intelligent application functions such as market analysis and evaluation, monitoring and control, and decision support (Cusumano et al., 2019). However, currently, the platform has not been able to alleviate the contradiction between electricity supply and demand through cross-regional energy coordination and market-based transactions (National Development and Reform Commission, 2024). The overall electricity market is experiencing a tight supply and demand situation, with demand exceeding supply. In the past three years, China's total annual electricity consumption has exceeded total electricity generation (China Electricity Council, 2025). Therefore, the efficiency of electricity transaction platforms has become one of the key factors restricting the development of the electricity market (Newbery, 2016). The efficiency problems of electricity transaction platforms are mainly reflected in the following aspects: First, information asymmetry. electricity transaction platforms suffer from information asymmetry, and in most cases, suppliers are unaware of the latest demand data from demanders (Rochet & Tirole, 2006). This asymmetry stems from delayed demand-side response, lack of real-time sharing of distributed energy data, and insufficient platform data governance

capabilities (Cohen, 2019). Second, transaction rules need improvement. The transaction rules of electricity transaction platforms are formulated by government regulatory agencies, with the participation of platform companies in the process (State Administration for Market Regulation, 2024). Due to the participation of platform companies, uncertainty and unfairness may exist among transaction participants. For example, the platform sets high requirements for registration and access for both supply and demand sides, resulting in a small number of transaction participants and low market activity (China Electricity Council, 2021; Gawer, 2014). Third, the market transmission effect of the price mechanism is weak. Platforms impose certain restrictions on grid connection prices and retail electricity prices (National Development and Reform Commission, 2021). Therefore, when a platform facilitates transactions between parties, the supplier's demands cannot be effectively conveyed to the demand side through pricing, increasing the difficulty of coordination for the platform company and thus affecting transaction efficiency (Bichpuriya & Soman, 2018; Stoft, 2002).

Given these issues, the platform leader (i.e., the owner of the electricity transaction platform), as the core initiator, plays a particularly prominent role in guiding, controlling, and governing this transaction platform ecosystem (Cusumano et al., 2019; Parker et al., 2016). Existing literature lacks clear answers on how platform leaders can implement effective management strategies within the permitted space of government regulation to address these issues and promote improved transaction efficiency (Boudreau & Hagiu, 2009). Overall, the core question of this study is: how can electricity transaction efficiency be achieved from the perspective of platform leaders, and how can it bring an effect on user enterprises? More specifically, the research question can be broken down into two levels: the transaction platform level and the user enterprise level, and then the research can be carried out sequentially. The transaction platform level focuses on the antecedents of electricity transaction efficiency, and the specific issues discussed include: what key factors influence the transaction efficiency of electricity transaction platforms from the perspective of platform leaders? Are there essential factors that determine high transaction efficiency? What combination of strategies (antecedent configurations) is conducive to achieving high transaction efficiency (or avoiding inefficient transaction)? At the user enterprise level, the focus is further on the effect of electricity transaction efficiency. The core question is: what effect does electricity transaction efficiency have on user enterprises, and what role does platform leadership play in this process? These questions remain to be answered (Gillespie, 2018; Rysman, 2009; Williamson, 1985). The existence of these questions necessitates in-depth research into the antecedents and effects of electricity transaction platform efficiency from the perspective of platform leadership, and the

proposal of corresponding countermeasures and suggestions to improve transaction activities among market participants and achieve optimal resource allocation (Joskow, 2008; M. Zeng, 2017).

1.3 Research methods and ideas

This study follows the basic approach of "proposing a problem—analyzing the problem—solving the problem." After reviewing theoretical literature and electricity transaction practices, the research question is proposed, followed by three sub-studies: research on the influencing factors of electricity transaction platform efficiency, research on the antecedent configuration and effects of transaction efficiency in electricity transaction platform. Finally, based on the overall analysis results, research conclusions, theoretical contributions, and management implications are formed, and policy recommendations for deepening China's electricity market reform are proposed.

The overall structure and chapter content of the research are as follows:

Chapter 1: Introduction. Based on the research background, the research question is proposed and broken down into three specific sub-research questions. The research methods and ideas, research technical route, and research innovations are then elaborated upon.

Chapter 2: Literature Review. Based on the CiteSpace bibliometric analysis of transaction efficiency literature, the existing conclusions and theoretical gaps in transaction efficiency research and research on electricity transaction efficiency from the perspective of platform leadership are systematically described. The value and innovation of introducing the platform leadership perspective to analyze electricity transaction efficiency are pointed out, providing overall literature support for the empirical analysis in the following chapters.

Chapter 3: Analysis of Factors Affecting Electricity Transaction Efficiency from the Perspective of Platform Leadership. This chapter primarily analyzes the first sub-research question: "From the perspective of platform leadership, what key factors influence the transaction efficiency of electricity transaction platforms, and are there any essential factors determining high transaction efficiency?" In terms of content arrangement, based on the proposed research question, it specifically conducts a series of tasks including variable selection and measurement, development and determination of measurement scales, characterization of research methods, data collection, data calibration, necessary condition analysis, and robustness testing. The conclusions of Chapter Three are formed through discussion and dialogue.

Chapter 4: Antecedent Configuration Analysis of Electricity Transaction Efficiency from

the Perspective of Platform Leadership. This chapter primarily studies the second sub-research question: “What combination strategies (antecedent configurations) are conducive to achieving high transaction efficiency (or avoiding low transaction efficiency)?” In terms of specific content structure, after proposing the research question through literature discussion and practical dialogue, it clarifies variable selection and measurement, research methods, data collection, data calibration, empirical analysis, among others, and draws the main conclusions of Chapter Four based on robustness testing to ensure the robustness of the research conclusions.

Chapter 5: Analysis of the Effect of Electricity Transaction Efficiency from Platform Leadership Perspective. This chapter revolves around the third sub-research question: “What effects does electricity transaction platforms have on user enterprises, and what role dose platform leadership play in this process?” The content is structured as follows: after posing the research question, a literature review and empirical research model are constructed, and specific research hypotheses are proposed. Then, based on a clear research methodology, data collection, regression analysis, and moderating effect testing are conducted. Finally, the research conclusions of Chapter Five are formed based on robustness tests.

Chapter 6: Conclusion and Discussion. This chapter focuses on the overall research question of the research, “How is electricity transaction efficiency achieved from the perspective of platform leadership, and how does it make an effect on user enterprises?” and summarizes the main research processes and conclusions of the three specific modules of the research, forming the overall conclusion of this research. Subsequently, in conjunction with a discussion of theoretical literature, the overall theoretical contributions and management implications of the research are clarified, and countermeasures and suggestions for optimizing China’s electricity transaction market and electricity transaction platforms to improve electricity transaction efficiency are proposed. Finally, the limitations of this study are systematically discussed, and directions for future research are pointed out.

Furthermore, to ensure the scientific rigor of the research process, the analysis of questionnaire data for variable measurement employed rigorous reliability and validity testing and data calibration. For the questionnaire survey data, exploratory factor analysis (EFA) and confirmatory factor analysis (CFA) were primarily used to examine the rationality of relevant reliability and validity indicators. For the data in the necessary condition analysis and antecedent configuration studies, the currently mainstream quantile method was used for data calibration. Furthermore, at least two robustness testing methods were combined to analyze the robustness of the research conclusions.

The empirical analysis in this study mainly involves the following statistical methods:

descriptive statistics, correlation analysis, exploratory factor analysis (EFA), confirmatory factor analysis (CFA), necessary condition analysis (NCA), fuzzy set qualitative comparison analysis (fsQCA), and regression analysis.

1.4 Research technology roadmap

The technical approach of this study is shown in Figure 1.2 below:

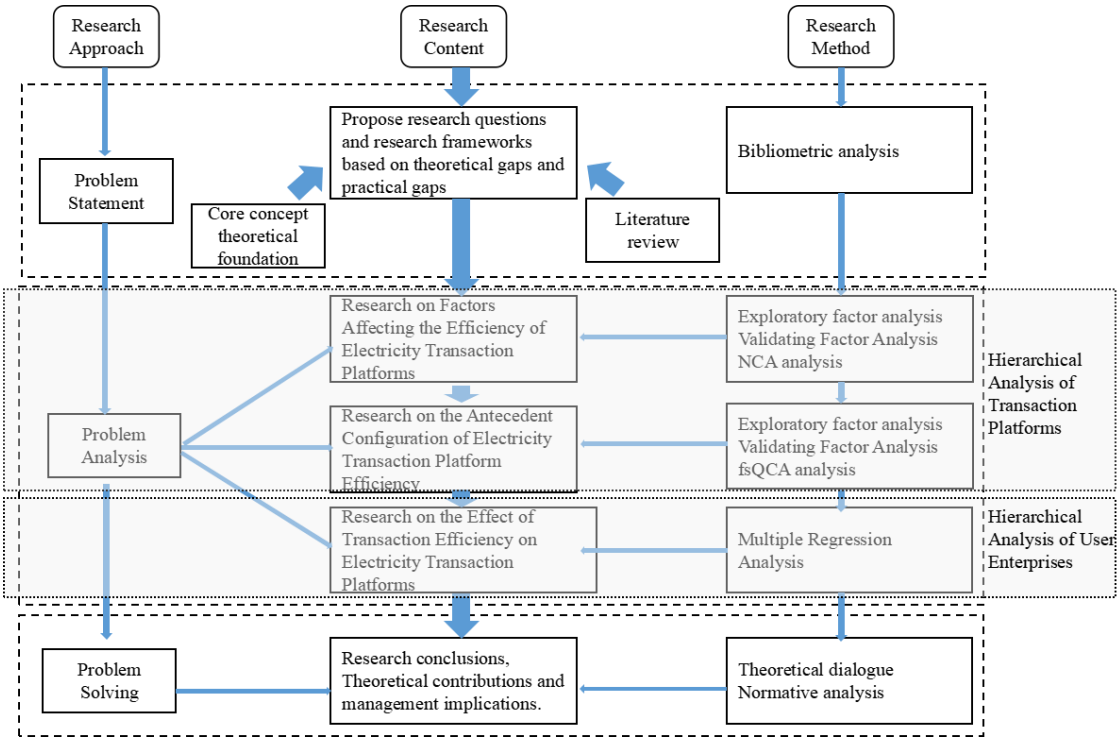


Figure 1.2 Research framework

The core theoretical model of this study is shown in Figures A1.4 of Annex A. The analysis focuses on how platform leadership factors (four types of platform leadership: platform guidance, platform influence, platform coordination, and platform control) and contextual factors (government regulation) affect the transaction efficiency of electricity transaction platforms. In this process, it is necessary not only to analyze the potential necessary conditions affecting high transaction efficiency, but also to examine the antecedent configurations of transaction efficiency outcomes (high and low transaction efficiency), and to deeply reveal the realization mechanism of electricity transaction platform transaction efficiency from the perspective of platform leadership.

1.5 Research innovation points

This study achieves three innovations at the intersection of theoretical deepening and scenario expansion.

The first innovation is in the research perspective. Breaking free from the constraints of traditional transaction cost economics analysis frameworks from the perspective of platform leadership, it expands to the angle of internal and external platform collaboration (the dual power of platform and government), forming a more systematic and suitable analytical framework for industries with public goods attributes, such as the power sector. This systematically addresses the unique governance challenges of electricity transaction platforms as deeply coupled physical-economic-regulatory systems.

1) It expands the theory of transaction efficiency from a "no physical constraint" scenario to a "strong physical constraint + real-time balance" scenario, constructing a boundary analysis framework for electricity transaction efficiency.

Traditional research on transaction efficiency is limited to digital platforms such as e-commerce and finance that allow for storability and delayed settlement (Rysman, 2009), neglecting the immediate consumption, non-storability, and N-1 security criterion constraints of electricity. This study, for the first time, places transaction efficiency within the complex scenario of minute-level power-electricity dual balance, extreme weather, and high-proportion grid connection of new energy sources. It reveals the mechanism by which platforms achieve efficiency leaps through real-time algorithmic matching, second-level data sharing, and proactive risk prevention, breaking through the "frictionless" assumption of classical theory and opening a new branch of transaction efficiency theory under energy physical constraints.

2) It constructs a "dual-drive" integrated model of transaction cost economics and platform leadership theory, elucidating the opportunistic governance path of platform leaders under differentiated regulation.

Existing research either uses transaction cost economics in isolation to analyze asset specificity (Williamson, 1985) or focuses solely on the ecological coordination of platform leadership (Cusumano et al., 2019), rarely intersecting the two. This study innovatively proposes a "regulation-leadership" two-dimensional model, empirically demonstrating how platform leaders can reduce opportunistic costs through different platform leadership strategies under inter-provincial regulatory differences, deepening the applicability of platform leadership theory in regulated public utility markets.

The second aspect is the innovation in research methodology. This study creatively

addresses progressive issues at each stage by employing a combination of analytical methods, thereby achieving a fusion and transformation from theory to empirical evidence, from phenomena to laws, and from knowledge to cognition. The core research question, "How can electricity transaction efficiency be achieved from the perspective of platform leadership and how can it play a role for user enterprises?" is broken down into three progressively deeper sub-research questions, discussing the "influencing factors, implementation paths, and effects" of electricity transaction efficiency. Different methods, such as necessary condition analysis, fuzzy set qualitative comparative analysis, and regression analysis, are used for cross-analysis based on multi-source data to ensure that the research questions at each level are thoroughly explored. This approach effectively overcomes the limitations of previous purely theoretical research or single-factor "net effect" analysis methods such as regression analysis, leading to scientific and systematic research conclusions.

The third aspect is the unique characteristics of the analytical sample. Previous studies, based on the assumption of homogeneity, focused solely on a unified national market, relatively neglecting the differences in provincial-level electricity markets. In the context of electricity market reform and differentiated regulatory implementation, exploring the causes and pathways of electricity transaction efficiency at the provincial level has even more prominent theoretical and practical value. Therefore, this study, for the first time, conducts a comprehensive data survey and in-depth analysis across the entire electricity system in China. It covers the full sample of 33 provincial-level electricity transaction platforms, and also conducts tiered quota sampling surveys of core user groups (electricity generation companies, electricity sales companies, industrial and commercial users, and electricity platform companies) at each platform level. This effectively ensures that the research takes into account both overall patterns and individual differences, contributing to the formation of targeted conclusions based on China's national conditions. The survey and analysis of the full-domain sample effectively characterizes the differences in the electricity market environment and regulatory differences among the 33 electricity transaction platforms in 31 provinces and municipalities across China, providing valuable comparative analysis experience for electricity transaction efficiency analysis at the provincial level.

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Chapter 2: Literature Review

2.1 Bibliometric analysis of transaction efficiency based on CiteSpace

2.1.1 Data sources and literature screening

Bibliometrics, based on literature and citation information, can visually demonstrate the foundation, hot topics, key themes, clustering characteristics, and evolutionary trends of research in a specific field through visualization analysis programs (C. Chen, 2017), thus providing a basis for systematically reviewing research literature and writing reviews. Specifically, this research chooses CiteSpace's bibliometric analysis method to systematically review literature in the field of transaction efficiency research. Its main advantages are:

1) CiteSpace can analyze both Chinese and English literature, providing a good overview of international research progress and the current state of research in China on electricity transaction efficiency;

2) CiteSpace can simultaneously analyze literature and citation information, helping to identify current research hotspots and accurately characterize the research foundation and network population characteristics.

Regarding the research topic of "transaction efficiency" in this thesis, although the discussion of transaction efficiency originated in transaction cost economics, the concept of transaction efficiency was first proposed by Chinese scholar X. K. Yang et al. (1999). Therefore, the bibliometric data mainly involves both Chinese and English literature. For Chinese literature, those meeting both CiteSpace's data analysis requirements and possessing high quality are those included in the Chinese Social Sciences Citation Index (CSSCI). High-quality English literature that meets CiteSpace's data analysis requirements is mostly from the Social Sciences Citation Index (SSCI). Therefore, the bibliometric analysis data for transaction efficiency uses the two standards mentioned above for both Chinese and English literature. The specific data selection process and criteria are shown in Figure 2.1.

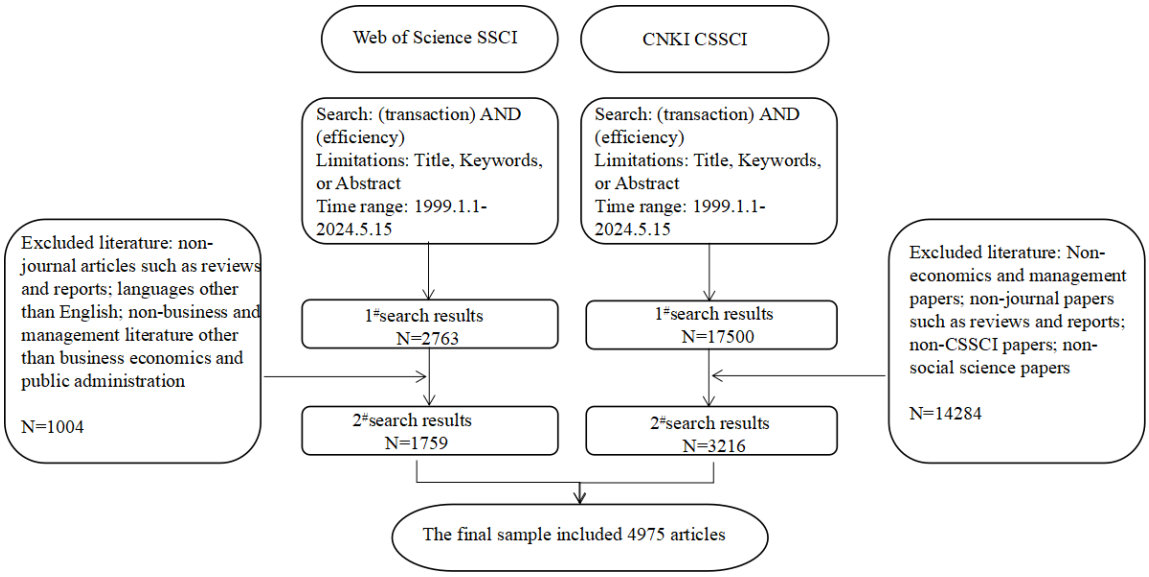


Figure 2.1 Bibliometric data screening process

Referring to Figure 2.1, for English literature, the first step was to select core databases based on the Web of Science database to screen SSCI literature. The search query was defined as including both “transaction” and “efficiency” in the title, keywords, or abstract to ensure coverage of as many important documents related to transaction efficiency as possible. Considering that transaction efficiency was first proposed in 1999, the time range was defined as January 1, 1999–May 15, 2024. The search results showed 2763 SSCI documents potentially related to transaction efficiency. Secondly, literature not relevant to this bibliometric analysis was excluded based on the following criteria:

1) Excluding non-journal studies such as reviews and reports;

2) Excluding studies in languages other than English;

3) Excluding non-business/economics literature other than Business, Economics, and Public Administration.

Following these criteria, 1004 studies were removed, ultimately retaining 1759 SSCI documents related to transaction efficiency. After extracting all relevant titles, keywords, abstracts, and references, the results were saved as a TXT text file for bibliometric analysis.

Similarly, in collecting Chinese literature data, a search was first conducted using the CNKI database, with the search query defined as including both “transaction” and “efficiency” in the title, keywords, or abstract. However, since the Chinese Social Sciences Citation Index (CSSCI) database only allowed searches for literature dated to or earlier than December 31, 2023, on the search date (May 15, 2024), while the CNKI database could update the literature date to May 15, 2024 (synchronizing with the English literature dates) and filter CSSCI literature data by source, the time range of the CNKI data was defined as January 1, 1999 – May 15, 2024. The

search results showed 17,500 studies that might be related to transaction efficiency. Secondly, literature not relevant to this bibliometric analysis was excluded based on the following criteria:

1) Excluding non-journal studies such as reviews and reports;

2) Excluding non-economics and non-management literature;

3) Excluding non-social science literature;

4) Excluding non-CSSCI literature.

Based on the above criteria, 14,284 studies were removed, leaving 3,216 CSSCI studies related to transaction efficiency. After extracting all relevant titles, keywords, abstracts, and references, the data was saved as a TXT text file and converted using CiteSpace software into a text format suitable for bibliometric analysis.

After obtaining the CSSCI Chinese and SSCI English literature data, considering the different language settings and requirements of CiteSpace software, mixed analysis might lead to garbled characters or meaningless analytical conclusions. Therefore, bibliometric analysis was performed separately for each type of data.

2.1.2 Bibliometric analysis based on CSSCI literature

2.1.2.1 Distribution of annual research published

From the perspective of annual publication trends, research on transaction efficiency has roughly gone through three stages (Annex A, Figure A2.1). The first stage was from 1999 to 2008, a period of rapid growth. During this period, research on transaction efficiency, after its conception (8 researches in 1999), showed a rapid growth trend, peaking in 2008 (159 researches). The second stage was from 2009 to 2020, a period of stable research. Research on transaction efficiency during this period showed a relatively stable state, with the number of publications mostly fluctuating slightly within the range of 130 to 180 researches, indicating that a relatively stable research paradigm and school of thought may have formed during this period. The third stage was from 2021 to 2024, a period of secondary growth. Research on transaction efficiency during this period originated from new research scenarios such as the platform economy and the digital economy, driving a second rapid growth in transaction efficiency research, with the annual number of publications increasing to over 200. This shows that the characteristics of the new economy and the new era context have promoted a re-understanding of transaction efficiency, while also providing a new research blueprint for the development of transaction cost economics.

2.1.2.2 Distribution of study topics

From the perspective of publication themes, relevant high-frequency keywords focus on "*empirical research"* "*empirical evidence"* and "*economic growth"* (Annex A, Figure A2.2), indicating that current CSSCI literature on transaction efficiency largely focuses on empirical analysis of economic themes. Meanwhile, keywords such as "*digital economy"* "*blockchain"* "*allocation efficiency"* and "*carbon emission transaction"* also appear 23 times or more, indicating that new economic backgrounds and development demands such as the digital economy and green economy have become new trends closely watched in transaction efficiency research in recent years. Taking "*digital economy"* and "*carbon emission transaction"* as examples, although the inclusion of "*digital economy"* and "*carbon emission transaction"* as research themes in transaction efficiency research is relatively recent (2012 and 2019 respectively), both have shown a rapid growth trend since the beginning of research (as shown in Annex A, Figure A2.3).

2.1.2.3 Distribution of published journals

In terms of the journals publishing these studies, the journal with the most publications on transaction efficiency is *Business Research* (40 researches), followed by *Productivity Research* (39 researches), *Science and Technology Management Research* (34 researches), and *The Economist* (24 researches), indicating that the research focus is mainly on economic topics related to productivity development. Meanwhile, journals such as *Modern Management Science*, *Operations Research and Management*, *Shanghai Finance*, and *Price Theory and Practice* also published more than 15 researches each (as shown in Annex A, Figure A2.4), indicating that research based on management science is also relatively abundant, mostly concentrated in management science and engineering, advocating the use of operations research techniques to solve transaction efficiency optimization problems.

2.1.2.4 Distribution of published authors

From the perspective of authors, the most prolific author in domestic research on transaction efficiency is Luo Biliang, a senior professor of humanities at South China Agricultural University, with 19 publications. His research focuses primarily on transaction efficiency issues within the context of agricultural economic system reform. Following him are scholars such as Tang Jijun (9 publications), Lu Shanyong (9 publications), Wang Chengzhang (8 publications), Zhang Xiaodi (7 publications), and Xiang Guocheng (7 publications), each with 7 or more publications (as shown in Annex A, Figure A2.5). Their topics are concentrated on institutional

economics, industrial innovation policies, green economy, and digital transformation. This indicates that research on transaction efficiency has emerged with a group of representative scholars focusing on discussions in different contexts such as agricultural development, innovation policies, green coordination, and transformation and upgrading, thus promoting the deepening of research and the maturation of theory.

Furthermore, combined with CiteSpace emergent analysis, it can be found that important scholars whose influence in the field of transaction efficiency research has significantly increased at different times. Based on the emergent analysis results in Annex A, Figure A2.6, the most influential scholar in the early stages of Chinese research on transaction efficiency was Professor Yang Xiaokai of Monash University, Australia, who pioneered the concept of "transaction efficiency" (X. K. Yang, 2003; X. K. Yang et al., 1999). In the past decade, scholars who have emerged more prominently have focused on areas such as agricultural economic efficiency, financial investment efficiency, and the transformation and upgrading of the manufacturing industry.

2.1.2.5 Distribution of issuing institutions

In terms of publishing institutions, scholars from Renmin University of China published the most research on transaction efficiency, reaching 109. This was followed by Xi'an Jiaotong University (90 researches) and Nankai University (86 researches), with both accumulating over 80 researches. In addition, 14 other universities, including Peking University, Nanjing University, and Shanghai University of Finance and Economics, also published 50 or more researches (Annex A, Figure A2.7), indicating that transaction efficiency research has developed into a number of mature research teams over many years. Taking the top six universities with over 70 publications as examples, and referring to Annex A, Figure A2.8, the research researches published by these six universities in China showing a steady and gradual increase since their first research findings (most of the initial research at these universities was concentrated between 1999 and 2002).

Furthermore, by combining CiteSpace's literature clustering and emergent analysis, we can further discover the central institutions and evolutionary (emergent) trends in transaction efficiency research. Annex A, Figure A2.9, based on CSSCI literature sources, shows the network clustering of research institutions in China's transaction efficiency research. The clustering results show that the Modularity coefficient Q is 0.9653 (close to the critical value of 1), the Sihouette coefficient S is 1, and the Harmonic Mean (Q, S) = 0.9823, all very close to the critical value of 1, indicating good clustering performance. In terms of clustering

characteristics, research institutions such as the School of Economics and Management of Xi'an Jiaotong University, the School of Economics and Management of Northwest University, the Antai College of Economics and Management of Shanghai Jiaotong University, and the School of Economics of Renmin University of China exhibit strong network centrality, indicating that their research findings on transaction efficiency have a relatively higher influence and importance.

Combined with the emergent analysis of publishing institutions, the research institution with the most sustained emergent influence in transaction efficiency research is the School of Management of Sun Yat-sen University, whose research has maintained a high level of interest for 10 years since its research results emerged in 2003 (as shown in Annex A, Figure A2.10). Furthermore, looking at the evolution of research on emergence, the earliest emerging results in transaction efficiency research began in 2002 at the Antai College of Economics and Management, Shanghai Jiao Tong University, while the most recent emerging research results are reflected in two research institutions (the Institute of Industrial Economics, Chinese Academy of Social Sciences, and the School of Business, Hunan University of Science and Technology), with the emergence period being 2022-2024 (a total of 11 and 6 researches published respectively over the three years), focusing on topics such as carbon emissions, digital innovation, platform economy, and data factor markets. This further illustrates that new scenarios and problems derived from digital platforms and digital technologies are emerging hot spots driving current research on transaction efficiency.

2.1.2.6 Keyword analysis of publications

Based on CiteSpace, the keyword network clustering results are shown in Figure 2.2. From the results, the high-frequency keywords in transaction efficiency research include concepts such as "*transaction cost*" "*transaction efficiency*" "*transaction expense*" "*efficiency*" "*blockchain*" "*digital economy*" "*economic growth*" "*property right*" "*pricing efficiency*" "*carbon transaction*" and "*division of labor*". The Modularity coefficient Q is 0.635 (close to the critical value of 1), the Silhouette coefficient S is 0.8901, and the Harmonic Mean (Q, S) is 0.7413, all of which are close to the critical value of 1, indicating a good clustering effect. In terms of clustering characteristics, transaction efficiency research can be clustered into 6 network subgroups. Among them, the most important cluster (i.e., Cluster 0#) centers on the discussion of blockchain, covering related concepts such as "*digital economy*" "*data factors*" "*carbon transaction*" "*platform economy*" "*digital technology*" and "*smart contracts*", focusing on the changes in transaction efficiency brought about by digital technologies like blockchain and their

economic paradigms. Cluster 1# takes efficiency as the core, covering concepts such as "*transaction costs*" "*commercial banks*" "*public goods*" "*property rights system*" "*state-owned enterprises*" and "*e-commerce*", focusing on the analysis of transaction efficiency in business organizations. Cluster 2# centers on transaction costs, including concepts such as "*transaction cost*" "*efficiency*" "*human capital*" "*resource allocation*" "*institutional environment*" and "*corporate governance*", highlighting the analysis of the impact of institutional choices on transaction efficiency. Clusters 3# and 5# have a high degree of overlap. Cluster 3 takes transaction efficiency as the core, and Cluster 5 takes institutions as the core. Both clusters include concepts such as "*institutional efficiency*" "*corporate mergers*" "*theory*" "*innovation*" "*specialization*" "*division of labor*" and "*school of thought*", focusing on the academic analysis of transaction efficiency. Cluster 4# focuses on pricing efficiency, covering concepts such as "*stock index futures*" "*margin transaction and securities lending*" "*information efficiency*" "*liquidity*" "*market quality*" and "*price discovery*", emphasizing the design of price mechanisms in market transactions and the avoidance of opportunistic behaviors to improve transaction efficiency.

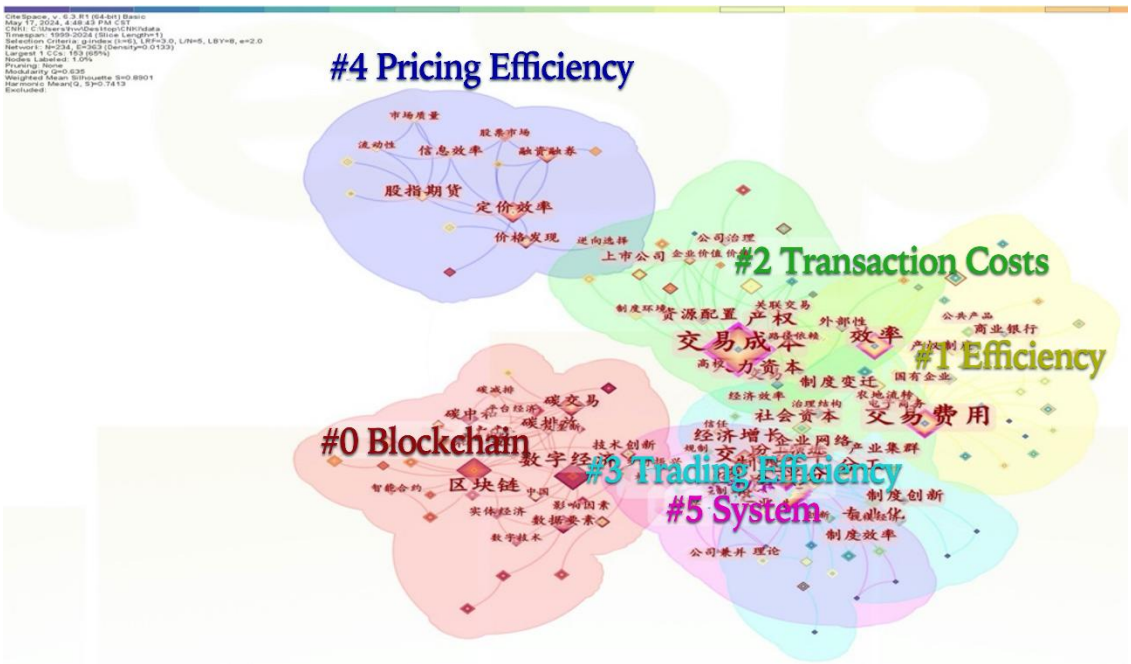


Figure 2.2 Keyword clustering of CSSCI literature

Furthermore, combining timeline clustering and emergent analysis can explain the evolution trend of keywords. As shown in Figure 2.3, although research on institutional choices based on classic transaction cost economics appeared earlier and has had a long-lasting influence, research based on new economic models such as platform economy, digital economy, and green economy has become the most cutting-edge and influential subcategory in recent

years (cluster 0# and cluster 1#). Meanwhile, combining the keyword emergent analysis results in Annex A, Figure A2-11, early (1999-2004) high-influence keywords focused on classic transaction cost economics theories such as "*transaction*" "*transaction costs*" "*property rights*" "*institutions*" "*division of labor*" and "*industrial clusters*". Mid-term (2005-2015) research gradually shifted towards specific market transaction scenarios and transaction design issues such as market information efficiency, market pricing efficiency, and financial transaction efficiency. In contrast, later research (2016-2024) has seen significant changes in transaction efficiency research due to the emergence of new economic scenarios such as the popularization of mobile internet, the application of digital technology, the development of the platform economy, and green economic growth. These changes have led to a reconstruction of transaction efficiency thinking in the platform economy era, driving the continuous deepening and innovation of transaction efficiency research.

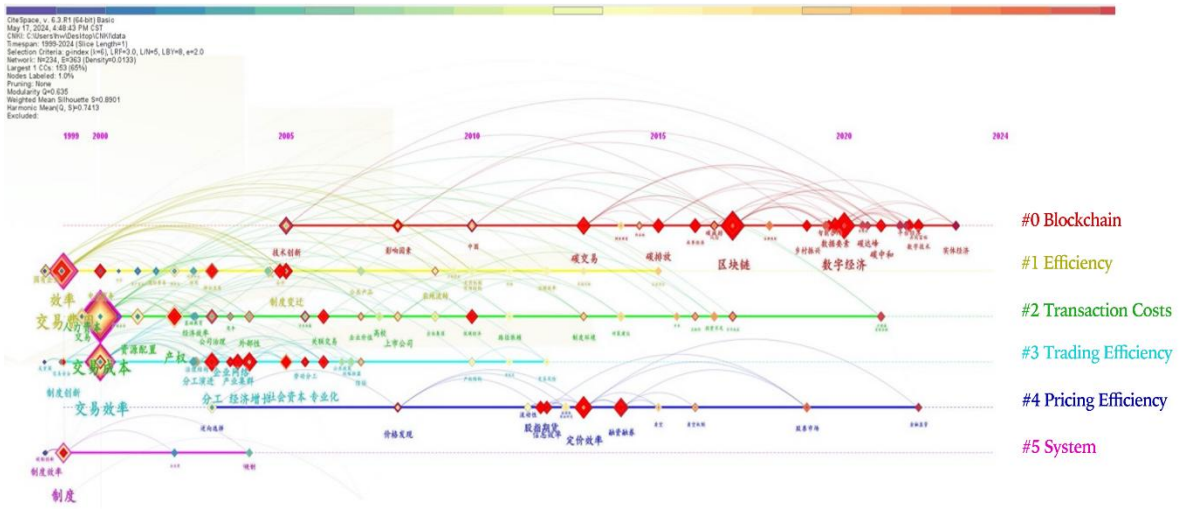


Figure 2.3 Timeline clustering of CSSCI literature keywords

2.1.3 Bibliometric analysis based on SSCI Literature

2.1.3.1 Distribution of annual research published

From the annual SSCI research publication trend, research on transaction efficiency has roughly gone through three stages (Annex A, Figure A2.12). The first stage (1999-2004) was a period of steady development, mainly based on theoretical discussions of the connotation and extension of transaction efficiency, with the annual publication volume remaining within the range of 25-40 researches. The second stage (2005-2013) was a period of rapid growth, during which research on transaction efficiency shifted from conceptual discussions to empirical measurements, and the research context and results expanded rapidly, with the number of publications surging to 85. The third stage (2014-2024) is a period of secondary growth. After

a slight decline, the number of publications showed a faster growth trend, mainly due to the rapid prosperity of new business entities (platform enterprises) and emerging economic scenarios (digital economy, sharing economy, green economy, among others), which promoted the continuous revision and improvement of existing theoretical insights in transaction efficiency research. Meanwhile, considering the overall citation data of the research literature, the 1758 SSCI researches were cited a total of 54082 times, with an average of 30.76 citations per research and an H-index of 103. This indicates that research on transaction efficiency has generally received high attention and popularity, becoming an important supporting body for research in other related fields.

2.1.3.2 Distribution of studies by field

In terms of research fields, economics (36%) had the highest proportion of publications on transaction efficiency, followed by business finance (17%), management (15%), and business studies (10%), all of which accounted for 10% or more of the total (as shown in Annex A, Figure A2-13). In contrast, environmental studies (6%), public administration (4%), operations research and management science (4%), agricultural economic policy (3%), environmental science (3%), and regional urban planning (2%) all had publications below 10%. This indicates that research on transaction efficiency is relatively concentrated, with core research areas still heavily focused on disciplines related to market economics, business operations, and business finance.

2.1.3.3 Author distribution

From the perspective of authors, the most prolific author in international research on transaction efficiency is Bel G, with 7 publications. This is followed by Andrews R, Chan E H W, Deininger K, Lee J, Loch A, Qian Q K, Shynkevicch A, Wang H, and Wang J, each with 5 publications (see Annex A, Figure A2.14). The top 10 authors account for only 2.96% of the total publications on transaction efficiency, roughly the same as the top ten most prolific authors in China (83/3216 = 2.58%). This indicates that, whether in Chinese CSSCI research or international SSCI research, the proportion of publications by highly prolific authors is relatively low, and the research paradigms, research contexts, and resulting research schools of thought are relatively dispersed, providing favorable conditions for expanding the breadth of research on transaction efficiency.

2.1.3.4 Distribution of publishing institutions

From the perspective of publishing institutions, the University of California System published

the most research on transaction efficiency, reaching 51, accounting for 18% of the total publications of the top ten institutions. Following closely are the University of London (42 researches) and the State University System of Florida (31 researches), both with more than 30 publications in total. In addition, seven other institutions, including the National Institute of Economic Research, the University of California Berkeley, and Cornell University, also published more than 20 researches each (Annex A, Figure A2.15), indicating that relatively mature research teams are gradually forming in international transaction efficiency research.

Meanwhile, based on the emergence analysis of publishing institutions using CiteSpace analysis software (as shown in Annex A, Figure A2.16), it can be seen that early high-influence institutions in transaction efficiency research were mainly well-known universities in the United States, such as Cornell University, Harvard University, and the University of California, Berkeley. Later, as the research context expanded and the research conclusions deepened, research hotspots gradually spread to universities and research institutions in Asian countries. Among them, China, benefiting from the rapid development of the digital economy and emerging markets, has promoted the maturity and improvement of transaction platforms, and in recent years has rapidly formed a unique transaction efficiency research system, featuring emerging high-influence research institutions represented by universities such as City University of Hong Kong (2016-2020) and Zhongnan University of Economics and Law (2023-2024). Furthermore, combined with the country-of-publication network clustering in Annex A, Figure A2.17, it can be seen that research institutions represented by the United States and China have formed a very strong network center position in the field of transaction efficiency research, and play a key role in leading and driving other important research institutions in the United Kingdom, Germany, Australia, and other countries to form high-quality collaborative research results.

2.1.3.5 Keyword analysis of publications

Based on 1758 SSCI researches on transaction efficiency research, the CiteSpace keyword network clustering results are shown in Figure 2.4. The results show that the high-frequency keywords in transaction efficiency research are "*efficiency"* (339 times), "*transaction costs"* (246 times), "*performance"* (191 times), "*information"* (129 times), "*market"* (119 times), and "*market efficiency"* (109 times), all appearing more than 100 times. From the clustering characteristics, transaction efficiency research can be clustered into three network subgroups, with high correlation and overlap among them. The most important cluster (cluster 0#) focuses on discussing transaction costs, encompassing related concepts such as "*efficiency"* "*economics"*

"*costs*" "*markets*" "*technology*" and "*management*", concentrating on the conceptual connotation and theoretical mechanism of transaction efficiency derived from transaction cost economics theory. Cluster 1# focuses on market efficiency, encompassing concepts such as "*transaction costs*" "*performance*" "*policy*" "*integration*" "*returns*" "*behavior*" and "*investment*" emphasizing the analysis of institutional choices that achieve transaction efficiency. Cluster 2# focuses on prices, encompassing concepts such as "*risk*" "*information*" "*liquidity*" "*governance*" and "*model*", highlighting how the design of price mechanisms and the improvement of governance rules in market transactions can enhance transaction efficiency.

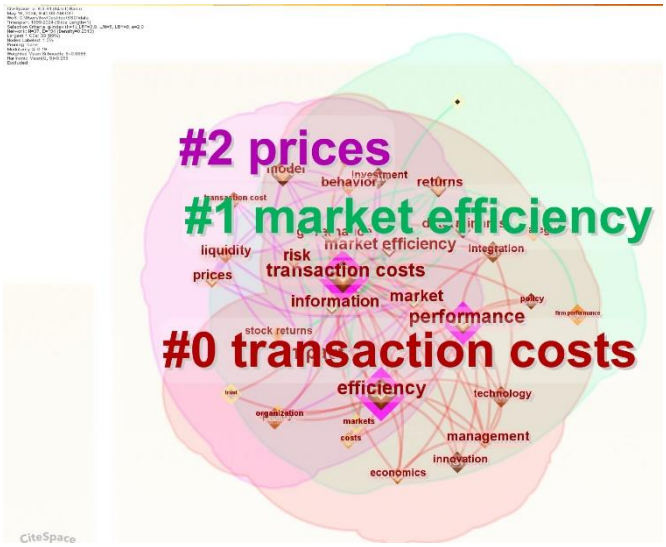


Figure 2.4 SSCI literature keyword network clustering

Furthermore, combining timeline cluster analysis reveals the temporal evolution trends of each subgroup. As shown in Figure 2.5, research on transaction costs in subgroup 0# emerged earlier and maintained greater duration and intensity, with the core keywords shifting from "*economics*" and "*efficiency*" in the early stages to "*technology*" "*policy*" and "*integration*" in the later stages. Research on market efficiency in subgroup 1# maintained high intensity for a relatively shorter period, with the core keywords shifting from "*information*" and "*market efficiency*" in the early stages to terms such as "*risk*" "*returns*" and "*determinants*" in the later stages. Research on prices in subgroup 2#, during its evolution, saw the emergence of many core terms related to transaction design and governance, such as "*model*" "*behavior*" "*impact*" and "*quality*", indicating a later focus on the management and guidance of the entire transaction process to promote an efficient and orderly transaction market. The keyword emergence analysis in Annex A, Figure A2.18, also reveals that international research on transaction efficiency has gradually shifted from early discussions on related concepts to the rational design and effective governance of market transaction processes. By exploring the influencing factors of transaction efficiency in different scenarios, it promotes the continuous improvement of

transaction design and management.

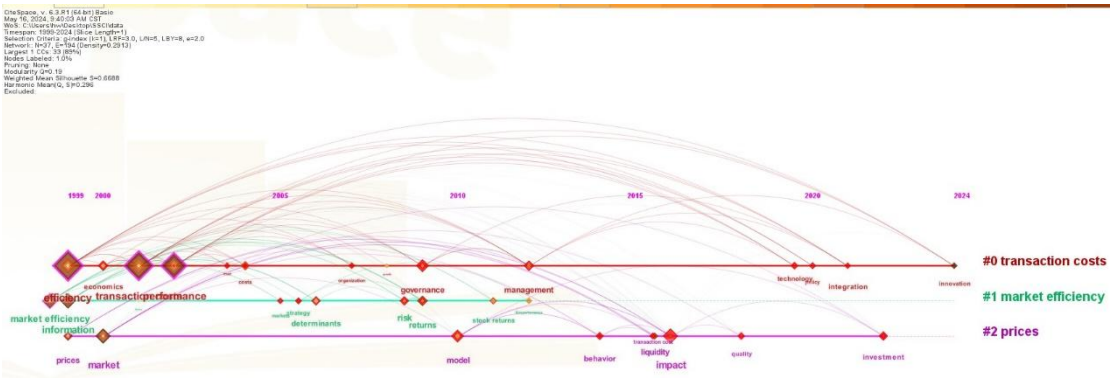


Figure 2.5 Timeline clustering of SSCI literature keywords

2.1.3.6 Citation analysis

Based on CiteSpace citation analysis, the literature foundation and theoretical basis of transaction efficiency research can be intuitively translated. First, a cluster analysis of highly cited authors, as shown in Annex A, Figure A2.19, reveals a high degree of overlap and relevance among the three network subgroups. The research of Williamson O E and Fama E Y occupies a central position in the network, representing key foundational figures in this field. In addition, scholars such as Coase R H, Grossman S J, Jensen MC, Hasbrouck J, North DC, and Shleifer A also hold representative positions in their respective subgroups.

Second, a cluster analysis of highly cited journals, as shown in Annex A, Figure A2.20, shows that the highly cited journals differ among the three network subgroups formed by the cited literature. Cluster 0# discusses transaction costs, primarily citing well-known economics journals such as *Economitrica, J ECON PERSPECT, REV ECON STUD*, and *REV ECON STAT*. Cluster 1# discusses equity market issues, heavily citing well-known finance journals such as *J BANK FINANC*, *J FINANC QUANT ANAL*, and *J CORP FINANC*. Cluster 2# discusses business model design issues, heavily citing well-known management journals such as *STRATEGIC MANAGE J*, *ACAD NANGE REV, ACAD MANAGE J*, *J MANAGE STUD*, *MANAGE SCI*, and *J MARKETING*. Therefore, research on transaction efficiency is likely mainly distributed across three major research areas: economics, management, and finance, each with its own research characteristics.

Finally, a surge analysis of cited literature on transaction efficiency is conducted, as shown in Annex A, Figure A2.21. The results show that early high-impact cited literature is mainly concentrated in the field of economics, with typical cited works including Keim (1997), Fama (1998), Gompers (2001), and Lesmod (2004). As research deepens and contexts diversify, high-value research results are constantly being enriched, and cited literature is gradually shifting

towards many fields such as public administration, business management, financial markets, energy economics, and land policy. Typical cited literature includes research such as Hyland (2013), Brounen (2011), Voorn (2019), Wang (2019), Harvey (2016), and Aldag (2020).

2.2 Literature review on transaction efficiency

2.2.1 Definition of transaction efficiency

The discussion of transaction efficiency originated from the study of transaction cost economics. In classical transaction cost economics, transaction costs are considered as the costs of using the price system, including price discovery, negotiation, and contract signing (R. H. Coase, 1937). Due to the imperfections of market mechanisms, based on the assumptions of bounded rationality and opportunism of the actors in the transaction process, the transaction process generates higher transaction costs under conditions of information asymmetry (Williamson, 1975). For example, in order to promote compliance with transaction rules among all parties in market transactions, people need to negotiate and draft contracts, and implement supervision to ensure that the contract terms are fulfilled (G. H. Coase, 2013). In subsequent studies, scholars have not equated the content covered by transaction costs. For example, Williamson (1985) believes that transaction costs include the costs of drafting, negotiating, and preparing contracts beforehand, as well as the costs of possible disputes, maintenance, and ensuring contract performance afterward. Barzel (1997) argues that transaction costs are the costs of transferring, acquiring, and protecting rights. Furthermore, because transaction costs often interact with production costs (Benham & Benham, 2004), measuring transaction costs in isolation is relatively difficult.

Therefore, some scholars have begun to think in reverse about transaction costs, proposing and analyzing the concept of "transaction efficiency" to measure them. X. K. Yang et al. (1999) pioneered the concept of "transaction efficiency," which is the maximum market transaction volume achievable per unit cost. For example, in a market transaction, for every 1 unit of product purchased, the buyer actually only receives k units of goods, of which 1-k units are consumed during the transaction process, mainly including transportation costs, transaction execution costs, and storage costs; k can then be called transaction efficiency. In a macro sense, the connection between transaction efficiency and transaction costs is mainly reflected in four aspects: the focus of evaluation, the difficulties in evaluation, the scope involved, and the relationship with economic development (as shown in Annex A, Table A2.1). The concept of

transaction efficiency solves the problem of directly measuring transaction costs, facilitating the modeling and quantification of transaction costs, and thus incorporating transaction costs into the analytical framework of general equilibrium. As an input-output relationship, transaction efficiency reflects the volume or frequency of transactions achievable with a given set of input factors. Higher transaction efficiency indicates that the market can achieve a larger volume of transactions at a lower cost.

When defining the dimensions of transaction efficiency, researchers often differentiate them based on the volume (or frequency) of transactions achieved by the input factors. For example, regional transaction efficiency is reflected through indicators such as infrastructure, transportation, and communication levels (e.g., the number of mobile phone owners, internet access, year-end urban road area, and total freight volume of highways, waterways, and air transport) (Fan et al., 2022; Yao et al., 2015; S. H. Zeng & Liu, 2020). Other studies, based on the fundamental needs upon which market economic transactions depend, decompose transaction efficiency into four dimensions: economic and financial level, public governance level, transportation and communication level, and education and teaching level (Gong et al., 2023). Overall, the breakdown of transaction efficiency is related to the various infrastructure, technical services, and institutional conditions that support the completion of transactions.

2.2.2 Measurement of transaction efficiency

Early ideas for measuring transaction efficiency came from X. K. Yang et al. (1999), who proposed the concept of transaction efficiency. He believed that transaction efficiency could be represented by the ratio of the difference between transaction value and transaction costs to the transaction value (X. K. Yang, 2003). Subsequent research emphasized decomposing transaction efficiency into different efficiency indicators to comprehensively reflect it. F. Gao (2007) advocated reflecting transaction efficiency by comparing the input and output of the transaction activities of both parties. In terms of specific measurement, by distinguishing between technical transaction costs and institutional transaction costs, a comprehensive transaction efficiency indicator system including market transaction efficiency, transportation transaction efficiency, and other indicators was constructed. X. F. Shi et al. (2023) combined institutional efficiency and technical efficiency to comprehensively measure transaction efficiency. Considering that institutional efficiency is relatively stable due to industry development and the rise of large e-commerce platforms, the variation in measurement mainly comes from technical transaction efficiency. Therefore, X. F. Shi et al. (2023) combined the

perspectives of transaction stock and transaction flow, and used principal component analysis to synthesize technical transaction efficiency using six indicators such as the number of express deliveries at the end of the year, and used it as a proxy variable for transaction efficiency. M. L. Zhang (2023), in her research on how technological innovation in universities promotes high-quality regional economic development, primarily used transportation and communication infrastructure as the basis for measuring transaction efficiency. In her research on China's land market, H. B. Chen (2022) constructed an evaluation index system encompassing four aspects: land price, land demand, land supply, and land management, and used the entropy method with time variables to measure transaction efficiency.

Compared to measuring transaction efficiency in regional market development, some researchers focus more on analyzing transaction efficiency from a micro-enterprise perspective. Xiong and Lou (2022), based on data analysis of listed manufacturing companies, used the inverse relationship between transaction costs and transaction efficiency to calculate enterprise transaction efficiency using the ratio of operating revenue to the sum of sales and administrative expenses. Yuan et al. (2022), in their research on third-party collaborative healthcare platforms, measured transaction efficiency by combining the quantity and quality of medical service resources provided by the platform, including specific indicators such as the scope and level of experts available on the platform (the accuracy, real-time nature, and comprehensiveness of expert information) and the efficiency of the platform's communication mechanisms for all partners.

In addition, some studies have attempted to comprehensively measure transaction efficiency from both macro and micro perspectives. C. Y. Liu et al. (2020) measured transaction efficiency from a comprehensive perspective combining macro and micro transaction costs. The calculation of macro transaction costs mainly followed the measurement approach of Wallis and North (1986), while micro transaction costs were calculated using the ratio of transaction costs to operating revenue. J. Zhu et al. (2020) used the entropy weight method to measure the carbon market transaction efficiency of China's power industry, finding that Beijing's carbon market had the highest transaction efficiency, followed by Guangdong Province and Shenzhen. In terms of specific measurement methods, two primary indicators were set: quota allocation efficiency and market transaction efficiency, which were further decomposed into four secondary indicators: carbon price efficiency (number of carbon emission control enterprises), carbon price stability (carbon price index), market liquidity (total carbon market transaction volume, total carbon market turnover rate, and transaction activities), and regulatory mechanism (number of third-party verification agencies).

More specifically, the measurement of electricity market transaction efficiency is mostly based on the conversion and calculation of objective data. First, in terms of measurement indicators, existing research focuses on environmental efficiency and utilization rates. F. Wang and Wu (2016) used a nonparametric network data envelopment analysis (DEA) model, considering the impact of electricity production and inter-provincial transactions, to calculate the energy and environmental efficiency of Chinese provinces from 2000 to 2012. They found that the traditional DEA method overestimates the energy and environmental efficiency of electricity-importing provinces and underestimates that of electricity-exporting provinces. Furthermore, Z. Chen (2020) discussed the social welfare adjustment mechanism for inter-provincial electricity transactions, proposing that government-authorized contracts for difference (CIFs) have a relative advantage and can address the issue of compensation for consumer welfare losses in electricity sales areas. Montoya et al. (2020) proposed two new metrics for international electricity transaction efficiency—an unweighted and a price-weighted inefficient interconnection line utilization index—which are more accurate under different market conditions. S. H. Shi et al. (2018) constructed a comprehensive evaluation model for the efficiency of the direct transaction market based on extension cloud theory and evaluated the efficiency of the direct electricity transaction market through numerical examples. These studies provide multiple methods and perspectives for measuring electricity transaction efficiency, contributing to a more accurate assessment of the operational efficiency of the electricity market.

In the aspects of calculation methods, the calculation of electricity transaction efficiency is mostly represented by weighted methods or DEA efficiency calculations. Wei and Zhang (2016) studied the impact of initial license allocation on the carbon transaction efficiency of the power industry through experiments, and found that the two-way auction system can effectively suppress market power and improve transaction efficiency. J. Zhu et al. (2020) used the entropy-weighted TOPSIS method to analyze the transaction efficiency of China's power industry carbon market. The results showed that the Beijing carbon market had the highest transaction efficiency, while the carbon markets in Shanghai, Tianjin and Chongqing had lower transaction efficiency. F. Wang and Wu (2016) used a nonparametric network data envelopment analysis model, considering the impact of electricity production and inter-provincial transaction, to calculate the energy and environmental efficiency of Chinese provinces from 2000 to 2012. The results showed that the traditional DEA method overestimates the energy and environmental efficiency of electricity-importing provinces and underestimates the energy and environmental efficiency of electricity-exporting provinces. Based on this, J. Wen and Qin

(2021) used the DEA model combined with the difference-in-differences method to empirically test the impact of carbon pilot policies on the operating efficiency of listed power companies in China, and found that carbon pilot policies significantly promoted the operating efficiency level of listed power companies. In addition, Zhong (2024), based on relevant data of Shanghai Electric Power from 2009 to 2022, used the DEA model to evaluate the operating efficiency of listed companies in my country's power industry, and found that the overall operating efficiency of Shanghai Electric Power under the background of carbon emission transaction has improved. S. H. Shi et al. (2018), based on extension cloud theory, proposed a comprehensive evaluation model for the efficiency of the direct electricity transaction market. This model combines the uncertainty analysis method of the cloud model with the qualitative and quantitative analysis methods of the matter-element theory in extension theory. Through numerical examples, the efficiency of the direct electricity transaction market was evaluated, and relevant optimization suggestions were proposed accordingly. In addition, X. Wang and Li (2023) studied the benefit evaluation of green electricity transaction in new energy electricity plants and proposed a comprehensive evaluation framework. This framework integrates fuzzy comprehensive evaluation and the improved AHP-entropy weight method, and enhances the robustness of the model through Monte Carlo simulation and expert weight sensitivity analysis. It should be noted that although current calculations of transaction efficiency can reflect the overall market efficiency level well through the conversion of objective indicators, in the case of the electricity transaction market led by digital platforms, user companies' perception of electricity transaction efficiency may differ due to platform differences and regional market differences. This is precisely an important measurement approach that is missing in the current evaluation model.

2.2.3 Factors affecting transaction efficiency

Williamson (1975), in his monograph discussing markets and bureaucracy, proposed that transaction costs depend on three factors: asset specificity, transaction frequency, and uncertainty. Asset specificity includes site specificity (e.g., a supplier establishing a factory near a customer), physical asset specificity (e.g., specialized equipment purchased to provide services to a specific customer), human asset specificity (e.g., proprietary knowledge and know-how), and dedicated assets (e.g., customizing body molds for an automaker). Higher asset specificity leads to higher transaction costs. Higher transaction frequency also increases transaction costs. Uncertainty includes environmental and behavioral uncertainty; the higher

the degree of uncertainty, the weaker the binding force of transaction contracts on potential opportunistic behavior.

As research on transaction costs has shifted its focus to transaction efficiency, the factors influencing transaction efficiency have begun to be studied in richer contexts. Zantout (1995), based on a sample analysis of 48 companies that announced collaborative R&D between 1983 and 1990, found that inter-company collaborative R&D helps improve transaction efficiency. Q. G. Tang (2009), based on the perspective of social division of labor, proposed that the improvement of transaction efficiency depends on the material conditions, transaction technology, and transaction system required for transactions. Material conditions include natural resources, geographical location, infrastructure, and tradable goods or services. Transaction technology refers to the operational methods and skills developed by people based on transaction practice experience and principles. Examples include logistics technology (represented by packaging, warehousing, transportation, and logistics management), information technology (represented by the collection, analysis, dissemination, and communication of transaction-related information), and financial technology (represented by providing exchange, settlement, trust, leasing, consulting, and wealth management services for transactions). Transaction systems can be used to define the behavioral norms of transactions, including formal or informal systems such as property rights systems, price systems, credit systems, and monetary systems. Tu et al. (2014), in their research on electronic markets, found that the online dynamic transaction environment helps improve transaction efficiency, average product quality, market size, and overall social welfare. C. Y. Liu et al. (2020), based on data analysis of micro-industrial enterprises in China, found that the completeness of market institutional infrastructure (such as investment in hardware infrastructure and optimization of the business environment) helps reduce micro-transaction costs for industrial enterprises, thereby improving transaction efficiency. S. H. Zeng and Liu (2020) found that the application of Internet technology can effectively improve transaction efficiency, increase service consumption demand, and thus promote the development of the service industry. Yuan et al. (2022)found that sharing of diagnostic and treatment data and medical research data based on big data resources in medical collaboration networks helps improve the transaction efficiency of medical services. Masroor et al. (2023) argued that transaction governance structure is a key factor determining the transaction costs and efficiency of SMEs, while the existence of institutional loopholes increases the uncertainty and complexity of transactions. Based on a sample analysis of SMEs in Bangladesh, Masroor et al. (2023) found that transaction governance structure plays a positive role in reducing transaction costs and improving

transaction efficiency, while institutional loopholes play a moderating role in this process.

2.2.4 The role of transaction efficiency in relation to other factors

In research exploring transaction efficiency, many studies focus on the role of transaction efficiency in relation to other factors and its effect on socioeconomic entities. L. Xu et al. (2018), through an analysis of e-commerce transaction scenarios, proposed that transaction technology and structure are crucial factors driving the improvement of transaction efficiency on B2B e-commerce platforms. This is because e-commerce itself, as a transaction technology, can save transaction time, reduce transaction friction, and decrease information asymmetry, thus significantly reducing transaction costs and improving efficiency. Furthermore, the transaction structure based on a two-sided market not only enhances trust between the transacting parties but also fully leverages the brand advantages, value-added services, and dynamic capabilities of e-commerce platforms to improve various aspects of the transaction process (such as product development, supply chain, logistics, and customer relationship management) (H. Xu et al., 2011), thereby promoting transaction efficiency.

From a macro-market perspective, research on transaction efficiency focuses on its role in regional economic development and improving social welfare. Zhao and Yin (2006) argued that improving overall market transaction efficiency is an important way to promote the elimination of the urban-rural gap in China. Martínez and Goetz (2007), in their analysis of the water market, pointed out that balancing supply and demand is a way to improve transaction efficiency, but technical or political barriers can increase transaction costs and thus reduce the benefits of the water market. Yu et al. (2010), based on vertical transaction theory, argued that the vertical transaction efficiency and boundary organization costs of China's coal-fired power industry are key factors in determining the choice of transaction form (vertical specialization or vertical integration). X. F. Shi et al. (2023) examined the relationship between the digital economy, transaction efficiency, and the upgrading of residents' consumption structure. Based on provincial panel data analysis, they found that transaction efficiency plays a partial mediating role in the process of the digital economy driving the upgrading of residents' consumption structure. M. L. Zhang (2023) found that transaction efficiency can strengthen the positive impact of university technological innovation on the high-quality development of regional economy, and that the conditional role of information transmission efficiency is greater than that of transportation efficiency.

From the perspective of micro-enterprises, research on transaction efficiency focuses on its

role in promoting enterprise operation and development. Lam and Liu (2004) empirically tested the relationship between transaction efficiency and enterprise production scale, finding that if the transaction efficiency of labor is higher than that of intermediate goods, firm-like institutions will emerge. With the emergence of firms, if the efficiency of intermediate goods transactions exceeds the efficiency of labor transactions, then the size of firms (measured by the number of employees) will decrease. Saygili (2009) used a stochastic production frontier approach to jointly estimate the relationship between transaction costs and production efficiency, finding that transaction costs lead to a decrease in firm production efficiency. Similarly, Xiong and Lou (2022) found that improved firm transaction efficiency can promote increased production efficiency, thereby driving firms to enhance their self-sustaining capabilities. Ketokivi and Mahoney (2020), after analyzing the basic logic and assumptions of transaction costs, proposed that transaction cost economics can serve as an effective means of transaction governance to promote the improvement of firm supply chain efficiency.

2.2.5 Changes in transaction efficiency in the context of platform enterprises

In classic institutional economics, firms are viewed as institutional arrangements that save on transaction costs (R. H. Coase, 1960), thus defining the boundaries of internalized transaction costs. However, in the digital economy era, heterogeneous consumer demand has led to a rapid increase in transaction costs, while open digital technologies, as general-purpose technologies, are continuously reducing market transaction costs (X. Xiao & Qi, 2021). Therefore, platform companies, acting as intermediaries in digital technologies and bilateral markets, have become the most efficient organizational form in terms of transaction efficiency, currently active between the market and bureaucracy (Eisenmann et al., 2011; F. L. Liu et al., 2023). Furthermore, because platform companies, as creators of the platform ecosystem, guide the innovation-driven development and scale expansion of the platform ecosystem through leadership, demonstration, and management, they are also figuratively called “platform leaders” (Gawer & Cusumano, 2002; M. Luo & Du, 2018). With the rapid development of technology and the widespread adoption of the internet, platform leaders have gradually emerged as a significant force driving modern socio-economic development. Based on the application of digital technologies, platform leaders achieve the efficient flow and allocation of goods, services, funds, and information by building two-sided market transaction platforms. Specifically, compared to traditional enterprises, the improved transaction efficiency of platform enterprises (platform leaders) is prominently reflected in the following aspects:

First, platform leaders improve transaction efficiency by eliminating information asymmetry. In traditional transaction models, buyers and sellers often struggle to obtain comprehensive and accurate product information, leading to low transaction efficiency (Chowdhury & Martin, 2017; Rochet & Tirole, 2003, 2006). Platform leaders, based on two-sided markets, promote direct and indirect interaction between buyers and sellers. Through e-commerce technologies such as centralized display of product information, provision of user reviews, and introduction of third-party certification, they effectively reduce the degree of information asymmetry (Hagiu, 2009). Buyers can access more product information through the platform, and sellers can more accurately target their customers, thereby improving transaction efficiency and success rates (J. Chen et al., 2009). For example, the application of distributed network payment channels can improve the efficiency and security of payments during transactions (J. Zhang et al., 2023).

Secondly, platform leaders improve transaction efficiency by reducing transaction costs. In traditional transaction models, buyers and sellers need to spend a lot of time and energy finding suitable transaction partners and negotiating and fulfilling transactions (M. Luo & Du, 2018; J. Xu & Zhang, 2006). Platform leaders, through centralized transactions, standardized processes, and intelligent matching, significantly reduce transaction costs (W. R. Chen & Yu, 2013; Miremadi et al., 2023; Parker et al., 2017). Due to the deeper market depth, buyers and sellers on the platform have the freedom to choose and compare transaction partners (Ton & Agarwal, 2023). By leveraging the platform's search and recommendation system, users can quickly find suitable transaction partners and conduct transaction negotiations and fulfillments through standardized processes, thereby significantly improving transaction efficiency (Engert et al., 2022).

Furthermore, platform leaders have enhanced transaction efficiency by innovating transaction models, improving the flexibility of the transaction process and meeting diverse transaction needs. With the continuous development and application of technology, platform leaders are constantly innovating transaction models, such as the sharing economy, pre-sale models, and auction models (Aulkemeier et al., 2016). These innovative transaction models not only meet the diverse needs of consumers but also improve transaction flexibility by simplifying the transaction process (Y. X. Wang et al., 2022). For example, the sharing economy model effectively improves resource utilization efficiency and reduces transaction costs by reusing idle resources (Celata et al., 2017); the pre-sale model reduces inventory pressure and the risk of unsold inventory by locking in consumer demand in advance (T. Zhu et al., 2023); and the auction model achieves optimal allocation and efficient utilization of

resources through competitive pricing mechanisms (Liaquat et al., 2023).

However, while improving transaction efficiency, platform leaders also face challenges and problems in transaction efficiency governance. First, platform companies need to strengthen the supervision and control of information quality to avoid the negative impact of false information and fraudulent activities on transaction efficiency (Mukhopadhyay et al., 2016). Second, platform leaders need to balance user experience (public interest) and commercial interests, avoiding excessive pursuit of commercialization at the expense of user experience and needs (H. J. Xiao, 2020; H. J. Xiao et al., 2023; Z. Yang et al., 2021). Furthermore, platform leaders need to strengthen their focus on user data security and privacy protection to ensure that user privacy rights are not violated (Yin & Cui, 2023).

In summary, changes in transaction efficiency under platform leadership are a complex and important issue. Platform leaders improve transaction efficiency and promote economic development by eliminating information asymmetry, reducing transaction costs, and innovating transaction models. However, it is also necessary to strengthen the management and supervision of information quality, user experience, commercial interests, and data security to ensure the healthy and sustainable development of platform transactions. Therefore, this research will systematically review research on platform leadership in order to provide insights for improving platform transaction efficiency.

2.3 Literature review on electricity transaction efficiency from the perspective of platform leadership

2.3.1 The theoretical connotation of platform leadership

The concept of platform leadership first appeared in Gawer's (2000) doctoral dissertation, "*Platform-Led Organizations: An Empirical Study of Intel's Management Processes to Promote Complementary Innovation by Third Parties"* In this thesis, Gawer (2000) defined platform leadership as driving third-party complementarists to develop and innovate complementary products by examining how Intel incentivized them to innovate around Intel's platform architecture and foundational services. Subsequently, in their book *Platform Leadership*, Gawer and Cusumano (2002) further argued that platform leadership is a process of innovation centered around a core platform, enabling complementary products that lack inherent value to leverage platform services and generate value far exceeding the value of the complementary products themselves. They believe that in the world of platform economies,

success is not determined by the best product, but by relying on the best platform. For example, according to a survey by Cusumano et al. (2019), among the 43 publicly listed platform companies in the Forbes Global 2000, the annual revenue of the platform business was the same as that of the non-platform business (approximately US$4.5 billion), but the number of employees was only half that of the non-platform business, the operating profit was twice that of the non-platform business, and the market capitalization and growth rate were also much higher. Gawer and Cusumano (2008) proposed that platform leaders are considered to possess leadership capabilities because platform companies can take the lead and set an example, such as solving platform technical and business challenges, thereby creating conditions for reasonably incentivizing complementary partners and providing efficient platform infrastructure services. Lee et al. (2010) defined platform leadership as the ability to shape a competitive advantage by leveraging the core architecture and business of their platform to generate significant financial benefits for the company.

Effective platform leadership is not merely about companies independently selling products, but rather about driving the improvement of complementary products and services based on fully open underlying technologies, achieving a positive feedback loop between the platform and its complements (Cusumano, 2011). It can guide companies from a traditional supply chain-driven logic to a platform-based logic under different organizational principles (Gawer & Phillips, 2013). Compared to traditional hierarchical leadership, platform leaders can mobilize and deploy boundary resources, effectively balancing organizational control with the contributions of third-party complementarities, optimizing resource allocation across the platform ecosystem while protecting their own interests (Ghazawneh & Henfridsson, 2013). Platform companies with platform leadership can provide foundational products, services, or technologies, and drive external innovators to organize as members of an innovative business ecosystem to develop complementary products, technologies, or services for the platform (Gawer & Cusumano, 2014). Meanwhile, as key participants in the co-creation of platform ecosystem value, complementarists typically provide complementary goods free of charge. Driven by heterogeneous motivations outside the price system, guiding healthy competition and value co-creation among these free complementarists and appropriately constraining their behavior becomes a crucial aspect of platform leadership (Boudreau & Jeppesen, 2015). In terms of capabilities, platform leadership is considered to possess dynamic capabilities related to innovation processes and environmental responses, such as environmental scanning and sensing capabilities, innovation capabilities, and integration capabilities (Y. X. Wang et al., 2022). Due to network effects and cold start, platforms face a “seesaw effect” (i.e., reducing

merchant-side multi-attribution leads to an increase in consumer-side multi-attribution). To effectively balance the user base and prevent user abandonment, platforms must leverage multilateral user attribution strategies to maintain leadership (H. Li & Zhu, 2022). In other words, platform leadership in the platform context is also understood as a form of control that prevents user churn and seizes key user resources from competitors.

In general, while international research differs in its conceptual definitions, it largely agrees that platform leadership is the ability of platform enterprises to drive innovation among complementors or users around platform products or services, based on the characteristics of a two-sided market. The first explicit definition of platform leadership in the field of digital platforms in China comes from the research of M. Luo and Du (2018), who view it as the ability of platform enterprises to embed and exercise substantial choices within the platform ecosystem using multiple complementary roles, thereby constructing strategic resilience and helping platform enterprises create asymmetric benefits. Subsequent studies have also expanded upon this research, such as Y. Zhang et al. (2020) and X. W. Luo et al. (2021).

Overall, although domestic and international research, based on different theoretical perspectives and research scenarios, depict the characteristics of platform leadership differently, their theoretical connotations all point to the coordination and value guidance of the interactive relationships between platform enterprises (platform leaders) and different participating entities within a two-sided market platform ecosystem. In particular, for the electricity transaction platform discussed in this research, transaction completion and innovation-driven development are not only essential basic goals of the platform but also fundamental prerequisites for ecosystem development and prosperity. Therefore, based on the common characteristics of platform leadership definitions at home and abroad, this research defines platform leadership as the influence of platform enterprises (platform leaders) on other participants in the platform ecosystem. This influence is mainly manifested in coordinating the interests of ecosystem entities (supply and demand sides, users, enterprises, complementarities, among others), promoting innovative output, and achieving bilateral (multilateral) user transactions.

2.3.2 The measurement basis of platform leadership

Currently, the measurement of platform leadership is mainly conducted through questionnaires, and scale development relies primarily on case interviews, coding analysis, reliability and validity testing, and scale purification techniques. The earliest measurement of platform leadership appeared in a study by B. Hao et al. (2013) from the School of Business, East China

University of Science and Technology. They defined platform leadership as "the influence of a core enterprise on other member enterprises of the platform formed by constructing a technology production platform and effectively integrating inter-enterprise network knowledge and resources," and measured platform leadership as a dimension of inter-enterprise leadership (B. Hao et al., 2013). Similar approaches can be seen in the studies of Zheng et al. (2016) and Bian et al. (2018), but these studies primarily focus on inter-enterprise relationships rather than the relationships among platform ecosystem participants, and their measurement dimensions are somewhat limited. Subsequently, Y. Zhang (2019) developed a measurement scale for platform leadership based on grounded analysis from the perspective of business ecosystems. The scale includes 12 measurement items in four dimensions: platform influence, platform guidance, platform coordination, and platform control. (EFA showed that Cronbach's α value was 0.839, KMO value was 0.861, and the significance P value was 0; the best model of EFA, Model 3, showed that GFI=0.983, AGFI=0.915, RMSEA=0.022, CMIN=10.422, df=2, X2/df=5.211). Platform influence is comprised of three sub-dimensions related to the platform enterprise (platform leader)'s status and prestige, leading example, and goal achievement; platform guidance is comprised of three sub-dimensions related to the platform enterprise (platform leader)'s strategic control, adaptability, and member followership; platform coordination is comprised of three sub-dimensions related to the platform enterprise (platform leader)'s task coordination, relationship coordination, and goal promotion; and platform control is comprised of three sub-dimensions related to the platform enterprise (platform leader)'s behavioral control, business control, and methodological control (Y. Zhang, 2019). This measurement basis has been continuously adopted by subsequent studies (Y. Zhang & Liu, 2019, 2020), or based on the idea of measuring platform leadership through the multiple roles of leaders (X. W. Luo et al., 2021). Furthermore, research on platform leadership from a human resources perspective has led to the development of a measurement scale for platform leadership (X. G. Hao et al., 2021). This scale comprises 25 items across six dimensions: inclusion, personal charisma, change planning, platform building, platform optimization, and shared growth (EFA analysis: Cronbach's $\alpha = 0.937$; CFA analysis: $X^2/df = 1.400 < 2$; RMSEA $= 0.036 < 0.05$; CFI and NNFI > 0.90; PNFI $= 0.848 > 0.50$). This scale has also been consistently adopted in organizational behavior research (L. Li et al., 2022; X. Xiao, 2021).

Similar to the definition of platform leadership, research on its measurement is mainly divided into two perspectives: inter-organizational relationships (platform ecosystem relationships, such as Y. Zhang (2019); Y. Zhang et al. (2020) and human resources (internal leadership member relationships, such as X. G. Hao et al. (2021); Xin et al. (2020). Relatively

speaking, Y. Zhang's (2019)Platform Leadership Strength Scale more accurately covers the consensus characteristics of platform leadership both domestically and internationally (such as demonstration and leadership, relationship coordination, among others), and aligns with the ideas of mainstream platform leadership researchers such as Gawer and Cusumano (2002), as well as the definition of e-commerce platform leadership in this research. In the specific analysis process, distinguishing different types of platform leadership to accurately depict the different roles and functions of platform leaders helps to grasp the micro-process of platform leadership empowerment more meticulously. Therefore, this research also mainly adopts Y. Zhang's (2019) questionnaire for measuring platform leadership, and decomposes platform leadership into platform guidance, platform influence, platform coordination, and platform control for independent analysis, in order to clarify the differences in the roles of different leadership types.

2.3.3 The effect of platform leadership on electricity transaction efficiency

Platform leadership's effect on transaction efficiency is often achieved through reducing transaction costs, improving transaction fairness, and creating and maintaining a healthy ecosystem. Regarding cost reduction, Y. Zhang et al. (2019) analyzed the evolution and mechanism of platform leadership based on the platform lifecycle, finding that platform leaders reduce transaction costs in the initial, development, and mature stages through capture-and-hunt mechanisms, connection and integration mechanisms, and empowerment and co-creation mechanisms, respectively. Furthermore, Y. Zhang et al. (2020), using grounded theory, found that the influencing factors of platform leadership mainly include four aspects: architectural foundation, connection and coordination, innovation leadership, and integration and expansion. They also found that platform leaders can effectively reduce transaction costs by optimizing platform architecture and technical standards. J. M. Liu (2020) starting from the role and behavioral strategies of platform leaders, emphasized the role of platform leaders in platform governance, pointing out that platform leaders should adopt proactive regulatory behaviors to ensure the fairness and efficiency of platform transactions. Z. Chen (2020) explored the social welfare adjustment mechanism for inter-provincial electricity transactions, achieving a balance between electricity transaction efficiency and fairness through platform market regulation means such as government-authorized contracts for difference.

In terms of fairness, platform leaders possess both commercial and public responsibilities, and prioritizing the overall interests of the platform ecosystem is the fundamental guarantee for

their legitimate leadership position (H. J. Xiao, 2020). Through rule-based guidance and institutional guarantees, platform leaders can more easily build core competitive advantages in their unique platform markets (Du et al., 2023; J. X. Wang et al., 2021), thereby creating an open-driven innovation system (Jin & Pan, 2014). Regarding the creation and maintenance of a healthy ecosystem, a governance system involving platform leaders and multiple stakeholders such as the government is a crucial means to effectively leverage platform leadership and form an effective platform market. M. Luo and Du (2018) explored the substantive choice of platform leaders, arguing that the key to effective platform leadership lies in flexibly responding to environmental uncertainties, building strategic resilience, and obtaining asymmetric benefits, which is also crucial for the vitality of platform leaders. Z. Chen (2020) studied the social welfare adjustment mechanism of inter-provincial electricity transaction and proposed that government-authorized contracts for difference (CIFs) as a means of regulating the electricity transaction market can achieve Pareto improvement, that is, improve overall social welfare without harming the interests of market participants on the electricity transaction platform. S. H. Shi et al. (2018) analyzed the efficiency of the direct electricity transaction market based on extension cloud theory and proposed the G-SCP paradigm to evaluate market efficiency, emphasizing the impact of government intervention, market structure, and market behavior on market efficiency. J. Wen and Qin (2021) empirically studied the impact of the carbon emission transaction system on the operating efficiency of Chinese power companies through a difference-in-differences model, and found that the carbon pilot policy significantly promoted the operating efficiency of power companies, and that financing constraints played a partial mediating role in this process. The above studies indicate that in the context of electricity transaction led by digital platforms, research on transaction efficiency needs to consider the dual forces of "platform leadership-government regulation" simultaneously, and the synergistic configuration of the two forces may play a decisive role in the overall improvement of transaction efficiency and the performance optimization of user companies.

2.4 Research review

2.4.1 The research value of electricity transaction platform transaction efficiency from the perspective of platform leadership

As a crucial component of the modern energy market, the unique characteristics of electricity transaction platforms and their research value are increasingly prominent. Therefore, from the

theoretical perspective of platform leadership, this research explores the issue from three aspects: the characteristics of electricity transaction platforms, the influencing factors of transaction efficiency, and their research value.

First, regarding the characteristics of electricity transaction platforms, China's electricity transaction platforms possess distinct industry uniqueness. Their transaction process involves multiple stages, including electricity generation, transmission, distribution, and sales (T. H. Gao et al., 2024). These stages are interconnected, and failure in any one stage can lead to the failure of the entire transaction process. Furthermore, the transaction object of electricity transaction platforms is electrical energy, a special commodity whose production and consumption must maintain a real-time balance (S. Q. Xu & Xu, 2024). Therefore, the leadership of electricity transaction platforms must possess high flexibility and real-time capabilities to ensure efficient transaction. Third, compared to traditional commodities and services, electricity resources not only require effective supply and demand regulation but also necessitate different pricing and user demand strategies for different regions (provinces) (J. W. Zhang, 2023). The electricity market's high dependence on government electricity policy control also means that electricity transaction prioritizes pure public interest over commercial interests (An et al., 2024). This necessitates that electricity transaction platform leaders provide a platform architecture that meets the differentiated electricity demand, electricity supply capacity, and electricity policy control requirements of different regions (provinces). Therefore, the transaction management and efficiency improvement scenarios for electricity transaction platforms are more complex than those for general e-commerce platforms or transaction platforms.

Secondly, regarding the factors influencing electricity transaction efficiency, the transaction efficiency of electricity transaction platforms is comprehensively affected by many factors, including technology, systems, policies, and market structure. First, technology and infrastructure factors are key. The transaction platform's technical architecture, data processing capabilities, and cybersecurity directly affect transaction efficiency. Infrastructure related to electricity supply and demand, such as electricity generation, transmission, distribution, and sales, determines the grid's transaction capacity (Mi et al., 2023). A stable and efficient technology platform and sound infrastructure are fundamental to ensuring the smooth operation of electricity transaction. Secondly, market structure is also an important factor affecting transaction efficiency. The degree of competition in the electricity market, the diversity of market participants, and the sophistication of market regulation all affect transaction efficiency (Zhou et al., 2023). Finally, the policy environment is also a crucial factor. Government policy support for the electricity market and the sophistication of laws and regulations all influence

the transaction efficiency of electricity transaction platforms (Y. Wang et al., 2023). Similarly, the completeness of the transaction rules and systems established by platform leaders plays a key role in the efficient and orderly transaction of electricity transaction platforms (Y. Zhang & Song, 2008). The clearer the definition of interface rules and transaction systems, the more clearly the responsibilities of the parties involved in the transaction can be clarified through formal or informal contracts, and the more likely it is to facilitate the balancing of cross-regional and cross-market electricity transaction.

Finally, from a research value perspective, studying the transaction efficiency of electricity transaction platforms from the perspective of platform leaders has significant theoretical and practical value. First, in-depth research into the influencing factors and implementation paths of electricity transaction efficiency through the platform leadership process can help us better understand the platform operation mechanism of the electricity market and provide theoretical support for the healthy development of the electricity market. Secondly, studying the process by which platform leadership plays a role in electricity transaction efficiency helps identify bottlenecks in China's electricity market reform and platform-based transformation, providing policymakers with decision-making support and promoting the reform and progress of the electricity market. Finally, studying electricity transaction efficiency from the perspective of platform leadership can drive technological innovation, market innovation, and optimized design of platform transaction architecture, thereby improving the operational level and market competitiveness of electricity transaction platforms.

2.4.2 Areas where existing research urgently needs to be deepened

Existing research shows that research on transaction efficiency, originating from the economics of transaction costs, has been continuously refined in both connotation and extension since its concept was proposed. Researchers have discussed the theoretical foundation, conceptual connotation, involved dimensions, and measurement criteria of transaction efficiency, and analyzed its role and influencing mechanisms from the perspectives of macroeconomic development and micro-enterprise growth. Meanwhile, in the context of digital economic transformation, with the growth of platform enterprises, bilateral (multilateral) market transaction scenarios represented by e-commerce platforms have provided new models and carriers for improving transaction efficiency, greatly enriching theoretical insights into transaction efficiency.

However, compared to research focusing on the more commercially oriented e-commerce

platform scenario, research on public transaction platforms for special commodities such as electricity remains scarce. Regarding research objects, as bearers of public value interests, electricity transaction platforms not only need to consider the management complexities arising from the supply and demand balance of electricity commodities, but also how to promote the overall improvement of intra-regional and cross-regional transaction efficiency under different regulatory policy backgrounds in different regions (provinces). In particular, factors such as infrastructure, digital technology conditions, the specific market structure formed by electricity transaction entities, platform management and maintenance rules, and government regulatory policies can all intertwine, leading to increased complexity in electricity transaction market management. In complex management contexts, how to design, manage, and optimize electricity transaction platforms to improve transaction efficiency has become a key issue in promoting the reform and development of China's electricity market. Therefore, exploring the process of improving transaction efficiency from the perspective of platform leadership is of great significance for deepening the market-oriented reform and platform-based transformation of China's electricity transaction market. However, current research on platform leadership mainly focuses on the theoretical connotation, measurement basis, and functional relationships of platform leadership, with an emphasis on general e-commerce platforms or transaction platforms in terms of analytical context. Research on public transaction platforms, especially electricity transaction platforms, is scarce, and there is a lack of in-depth examination of the differences in the effects and combinations of leadership across different types of platforms. From the perspective of responsibility systems, platform leaders naturally possess both commercial and public responsibilities for platform development, which is particularly prominent for state-owned electricity transaction platforms (H. J. Xiao, 2020; H. J. Xiao et al., 2023).

In terms of research context, existing research tends to use the entire country or a single province as the analytical unit to examine the process of improving electricity transaction efficiency (Guo, 2023; S. H. Shi et al., 2018; Zhong, 2024). This homogenized approach ignores the regional differences in electricity market development across different provinces. Furthermore, when measuring transaction efficiency, it often relies on electricity input-output indicators or objective transaction cost indicators to calculate overall efficiency (F. Wang & Wu, 2016; X. Wang & Li, 2023; J. Wen & Qin, 2021), neglecting the micro-level differences in the perception of transaction efficiency among different user enterprises (electricity generation companies, electricity sales companies, and industrial and commercial users) under the leadership of digital platforms. Based on this, the proposed optimization suggestions for

electricity platforms often fail to adapt to regional characteristics and differences between different transaction platforms, resulting in weak applicability and universality of policy recommendations.

Therefore, this study, based on transaction cost economics and complexity theory, comprehensively investigates 33 provincial-level electricity transaction platforms in China, and systematically examines the influencing factors of electricity transaction platform transaction efficiency from the perspective of platform leadership, aiming to reveal the necessary conditions, antecedent configurations, and implementation paths for achieving high/low transaction efficiency in electricity transaction platforms. Simultaneously, this study aims to explore, through multiple regression analysis, how platform-leading enterprises in the electricity transaction market can improve electricity transaction efficiency and successfully translate this efficiency into user enterprise performance by leveraging platform leadership empowerment actions (platform leadership leverage). This research not only contributes to deepening the understanding of transaction cost economics and platform leadership theory but also expands the research context for electricity transaction efficiency, providing theoretical reference for operational optimization and competitiveness enhancement in China’s electricity transaction market.

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Chapter 3: Analysis of Factors Affecting Electricity Transaction Efficiency from the Perspective of Platform Leadership

3.1 Research question statement

As the hub of the electricity transaction system, China's electricity transaction platforms play crucial public roles in balancing electricity supply and demand, promoting efficient energy utilization, and ensuring robust electricity services. The realization of these public functions often relies on the electricity transaction platform providing a comprehensive and efficient service system. From a transaction cost economics perspective, transaction efficiency largely depends on the completeness of market coordination. When the free market struggles to accurately coordinate supply and demand to achieve market clearing at reasonable prices, transaction platforms, like those of enterprises, become substitutes for market price mechanisms, internalizing external market activities to achieve cost savings and efficiency improvements. Furthermore, considering the two-sided market theory, two-sided (multi-sided) markets face two or more transaction or interactive groups (i.e., market "sides"). Their pricing rules cannot simply replicate the cost-based pricing rules of unilateral markets; instead, they are complex pricing rules based on multilateral game theory. Therefore, how the transaction platform, as the leader, coordinates transactions among multiple stakeholders such as suppliers, demanders, and complementary parties becomes the core issue of transaction management in a platform-led scenario.

More importantly, the electricity market exhibits significant and unique differences compared to ordinary consumer goods markets. First, electricity in China is a public good, subject to national policy guidance and local government regulation. Furthermore, regulatory policies vary across provinces due to differences in electricity supply and demand. This means that the management of China's electricity transaction market cannot rely solely on a single national platform; instead, it is managed by 33 provincial-level electricity transaction platforms (i.e., power exchange centers) based on provincial characteristics. These regional differences in electricity transaction and regulation increase the complexity of market management, necessitating a focused attention on both common and dissimilar factors in promoting transaction on these platforms. Second, electricity is a commodity with immediate consumption

characteristics; transactions between supply and demand are completed instantly, and transactions on the platform must adhere to the operating rules of the electricity system. In contrast, ordinary consumer goods can be produced in advance and stored to meet consumption demands. Therefore, the immediate consumption and reasonable pricing of electricity both affect the efficiency of the electricity transaction market. Third, unlike traditional e-commerce platforms that emphasize commercial interests, electricity transaction platforms prioritize public interests. Due to its unique industry characteristics, electricity transaction receives greater government attention and stricter regulation. How transaction platforms, as leaders, can fully leverage their leadership within the permitted institutional framework to coordinate the interests of multiple stakeholders in electricity transaction and promote efficiency improvement has become one of the most pressing research topics in the current electricity market reform process. To analyze this topic, it is first necessary to systematically examine which factors influence electricity transaction efficiency and which conditions are necessary for improving efficiency in the context of China's electricity transaction platforms.

Existing research suggests that transaction cost economics, in conjunction with the design, formation, and management of transaction markets, identifies numerous influencing factors, primarily focusing on transaction context, transaction system, transaction structure, transaction model, and transaction implementation. Williamson (1975), in his monograph discussing markets and bureaucracy, proposed that transaction costs (an inverse variable of transaction efficiency) depend on three factors: asset specificity, transaction frequency, and uncertainty. Q. G. Tang (2009), based on the perspective of social division of labor, argues that improving transaction efficiency depends on the material conditions, transaction technology, and transaction system required for transaction. Tu et al. (2014) found in their research on electronic markets that online dynamic transaction environments help improve transaction efficiency, average product quality, market size, and overall social welfare. C. Y. Liu et al. (2020), based on data analysis of micro-industrial enterprises in China, found that the completeness of market institutional infrastructure (such as investment in hardware infrastructure and optimization of the business environment) helps reduce micro-transaction costs for industrial enterprises, thereby improving transaction efficiency. S. H. Zeng and Liu (2020) found that the application of internet technology can effectively improve transaction efficiency, increase demand for services, and thus promote the development of the service industry. Yuan et al. (2022) found that sharing of diagnostic and treatment data and medical research data based on big data resources in medical collaboration networks helps improve the transaction efficiency of medical services. Masroor et al. (2023) argued that transaction governance structure is a key factor

determining transaction costs and efficiency for SMEs, while the existence of institutional loopholes increases the uncertainty and complexity of transactions. A sample analysis of SMEs in Bangladesh, Masroor et al. (2023) found that transaction governance structures play a positive role in reducing transaction costs and improving transaction efficiency, while institutional loopholes play a moderating role in this process.

In summary, existing research on the factors influencing transaction efficiency, while differing in emphasis, mainly focuses on two aspects related to transactions. First, it focuses on the design of the transaction market itself, such as the design of the market, the transaction structure, the price mechanism, and the guidance of transacting parties' behavior. Second, it focuses on the specific context of transactions, such as transaction uncertainty and the location characteristics of the transaction market, emphasizing the discussion of external favorable or constraining conditions. In the context of electricity transaction platforms, because provincial electricity transaction platforms partially replace intangible market forces through their physical identities, becoming key entities representing the government in designing, managing, and coordinating electricity transactions, the effectiveness of the transaction market design itself largely depends on how the electricity transaction platform, as the platform leader, constructs and exerts its platform leadership. This shifts the research focus of transaction efficiency in the electricity transaction platform context to the study of electricity transaction platform leadership. On the other hand, government regulation of the electricity transaction market is a core intervention condition. Government incentive and constraint policies not only affect the vitality of transaction but also significantly impact the optimal allocation of transaction resources and the reduction of cross-regional transaction costs, thereby promoting overall market efficiency improvement. However, existing research has not identified the influencing factors of electricity transaction platform efficiency under digital platform management scenarios, nor has it combined a holistic analysis of provincial-level electricity markets across China to clarify the necessary conditions for transaction efficiency.

Therefore, this study specifically analyzes the research question, "What key factors influence electricity transaction efficiency from the perspective of platform leadership?" A questionnaire survey was conducted among different market participants in 33 provincial-level electricity transaction platforms across China. Based on necessary condition analysis, the study delves into the influencing factors, necessary conditions, and their impact levels of electricity transaction efficiency, aiming to provide a reference for deepening research on transaction efficiency in the power industry context and promoting electricity market reform and platform-based management.

3.2 Variable selection and measurement

In the context of platform-based management of electricity transaction, transaction efficiency primarily depends on platform leadership and market environment variables. Platform leadership refers to the electricity transaction platform leader's guidance, influence, coordination, and control over other market participants, while the most significant absolute factor in the market environment variables is the government's regulatory policies on electricity transaction. Platform leadership refers to the influence of the core enterprise (platform leader) on other platform members through the construction of a technological platform and the effective integration of network knowledge and resources among participants (B. Hao et al., 2013). Platform guidance is reflected in the platform leader's strategic control, adaptability, and member loyalty; strong platform leadership helps market participants collaborate efficiently under the unified coordination of the electricity transaction platform. Platform influence consists of the platform leader's status, prestige, exemplary leadership, and goal achievement. Electricity transaction platforms with strong influence are often better able to design matching transaction structures and systems based on national electricity policy requirements in uncertain market environments, thus promoting market clearing. Platform coordination capabilities comprise the platform leader's task coordination, relationship coordination, and goal-driven efforts. Strong coordination helps the electricity transaction platform guide rules and manage processes in areas such as electricity policy interpretation, electricity supply and demand allocation, electricity consumption, and electricity market opening, thereby mitigating electricity supply and demand imbalances and price distortions. Platform control capabilities consist of the platform leader's behavioral control, business control, and methodological control. By controlling the behavior, business, and methods of electricity market participants, the electricity transaction platform can promptly understand the complex and evolving demands of different participants and comprehensively allocate resources based on these interests to achieve Pareto improvement in the overall market. Simultaneously, strong platform control can prevent opportunistic behavior through platform rules, protecting the effective order of the electricity market. On the other hand, government regulation of the electricity market covers many aspects, including monopoly constraints, incentives for diverse participants, market-based allocation, energy consumption and transformation, standardized transaction behavior, risk control, and optimization of price signals and investment guidance. Through effective and appropriate regulatory actions, the electricity transaction platform can adopt suitable incentive and constraint strategies based on the actual conditions of each region, stimulating market

vitality while maintaining electricity market order and continuously improving the efficiency of provincial and inter-provincial electricity transaction.

Therefore, this study mainly selected platform leadership and government regulation as core variables in terms of antecedent conditions (influencing factors). Platform leadership specifically includes four variables: platform influence, platform guidance, platform coordination, and platform control. The measurement comes from the platform leadership measurement scale developed by Y. Zhang (2019) based on grounded analysis from the perspective of business ecosystems. It includes a total of 12 measurement items in four dimensions: platform influence, platform guidance, platform coordination, and platform control (EFA shows that Cronbach's α value is 0.839, KMO value is 0.861 and the significance P value is 0; the best model of EFA—Model 3—shows that GFI=0.983, AGFI=0.915, RMSEA=0.022, CMIN=10.422, df=2, X2/df=5.211). Platform influence is comprised of three sub-dimensions related to the platform enterprise (platform leader): status and prestige, leadership and demonstration, and goal achievement. Platform guidance is comprised of three sub-dimensions related to the platform enterprise (platform leader): strategic control, adaptability, and member followership. Platform coordination is comprised of three sub-dimensions related to the platform enterprise (platform leader): task coordination, relationship coordination, and goal promotion. Platform control is comprised of three sub-dimensions related to the platform enterprise (platform leader): behavioral control, business control, and methodological control (Y. Zhang, 2019). This measurement basis has been continuously adopted by subsequent studies (Y. Zhang & Liu, 2019, 2020), or based on the idea of measuring platform leadership through the multiple roles of leaders (X. W. Luo et al., 2021).

The measurement of government regulation integrates existing research on the intensity of regulation in pricing, access, transaction, and safe operation to form a measurement scale. Specifically, referencing studies by S. Zhang (2007), F. L. Chen and Xu (2009), and Han (2023), this study primarily examines the government's regulatory strength over the power industry in areas such as pricing, market access, transaction, safety, and the operating environment, comprising five items. Pricing regulation examines whether government departments strictly regulate the electricity pricing and regulation systems; market access regulation examines whether the number of government-issued licenses is sufficient to foster competition; market transaction and competition regulation examines the strength of government rules binding electricity transaction and competition; electricity safety regulation examines whether any major electricity safety accidents have occurred in the past five years; and electricity operating environment regulation examines the degree of energy conservation and emission reduction by

power companies, mainly reflected through clean power production (the proportion of clean or green electricity) and the intensity of desulfurization and denitrification upgrades in thermal power plants.

The outcome condition in this study is electricity transaction efficiency. Empirical measurements primarily employ two methods: objective indicator measurement and subjective questionnaire measurement. Objective indicators are primarily measured through the inverse indicator approach of transaction costs, calculated by calculating transaction expenses, as seen in studies such as X. K. Yang et al. (1999), C. Y. Liu et al. (2020), and Xiong and Lou (2022). Subjective questionnaires, on the other hand, focus more on market participants' genuine perceptions of transaction efficiency, reflecting not only their own experience of convenient and efficient transactions but also their perceived transaction costs related to asset specificity, transaction frequency, and uncertainty. For example, studies by Williamson (1979), Long et al. (2012), and Duan and Wang (2018) all reflect these issues from the perspectives of asset specificity, transaction frequency, and uncertainty, transforming them into positive indicators through dimensionless processing. In contrast, given the significant differences in provincial regional characteristics and actual transaction situations, subjective questionnaires are better able to refine the micro-level differences in transaction efficiency among different participants, effectively compensating for the limitations of fixed conclusions drawn from total or ratio indicators such as transaction volume and transaction input-output ratio. Therefore, this study, drawing on the research of Long et al. (2012) and Duan and Wang (2018), measured 15 items related to the intuitive perception of asset specificity, transaction frequency, uncertainty, and transaction efficiency.

Furthermore, considering that all scales used in this study have been modified for the electricity transaction platform scenario, to ensure a more scientific use of appropriate measurement criteria, this study first revised and confirmed the core variable scales based on the initial questionnaire. Subsequently, based on the validated questionnaire with good reliability and validity suitable for the electricity transaction platform research scenario, a formal large-sample data collection was conducted. After data calibration, necessary condition analysis was used to explore influencing factors, necessary conditions, and their levels of necessity.

3.3 Core variable scale revision and confirmation

3.3.1 Data collection (preliminary survey)

Based on the core variable measurement questionnaire, this study first used data from the first round of questionnaire surveys to revise the scales. A total of 310 questionnaires were collected from user companies (including electricity generation companies, electricity sales companies, and industrial and commercial users) of electricity transaction platforms in various provinces of China. The collected data was primarily used to conduct preliminary reliability and validity tests and scale revisions for three revised scales: platform leadership, government regulation, and transaction efficiency, thereby improving the measurement scales.

The collection of the 310 questionnaires took place in December 2024, covering all 33 electricity transaction platforms in China (each platform included questionnaire data from at least two user companies). The questionnaire survey was mainly conducted through the electricity transaction network system where the authors worked. Each provincial electricity transaction platform sent questionnaire invitations to user companies, who completed the electronic questionnaires via a link after receiving approval. The demographic distribution of the survey sample is shown in Annex A, Table A3.1.

3.3.2 Original entry purification

3.3.2.1 Original scale item T-test

1) Normality test for original scale items

The normality test for the original scale can effectively ensure the robustness of the data sample analysis. According to the analysis criteria, if the absolute value of the sample kurtosis is less than 8 and the absolute value of the skewness is less than 2, it indicates that the sample conforms well to the normality assumption (Byrne & Van De Vijver, 2010). Based on the analysis results in Table A3.2 of Annex A, the absolute values of kurtosis and skewness for all items are below the standard values, indicating that the research sample exhibits a normal distribution, suitable for conducting an independent samples t-test. Based on this, the independent samples t-test helps to further determine whether there are significant differences between different samples (Xue, 2012). In practice, we used the top 27% and bottom 27% of the total scores for each item (platform leadership, government regulation, and transaction efficiency) as the criteria for dividing the high and low groups, and compared the high and low groups (Wu, 2010). Finally, we compared the difference between the high and low groups

(Critical Ratio, CR), and deleted the corresponding items if the critical ratio was not significant. According to the analysis results, all items in the independent samples t-test of this study passed the test.

2) Independent samples T-test

To confirm whether an item should be deleted due to its inability to explain variation, this study divided the sample into high and low 27% quantiles and performed a t-test between the high and low samples. The corresponding values for the high 27% (73rd percentile) and low 27% (27th percentile) after sample division are shown in Table A3.3 of Annex A.

3) T-test of original scale items

The t-test of each item in the original scale can further verify whether there is significant variation in each item. According to the results in Table A3.4 of Annex A, there were significant differences between the samples in the upper 27% (i.e., 73rd percentile) and the lower 27% (i.e., 27th percentile) after all items were segmented, and all passed the test, so the original items can be retained.

3.3.2.2 Original scale item correlation coefficient test

The homogeneity test examines the correlation between individual items of the original scales, such as platform leadership, government regulation, and transaction efficiency, and the total score of the original scales. If the correlation coefficient is lower than 0.4, the item is considered unsuitable and should be deleted. Based on the results in Annex A, Tables A3.5, A3.6, and A3.7, the correlation coefficients between all items in the original scales and the total score are higher than the standard; therefore, all items are retained.

3.3.2.3 Original scale item reliability test

Reliability reflects the credibility of a scale's measurement and is used to describe the reliability of the analytical conclusions (Golafshani, 2003; Koo & Li, 2016). According to the judgment criteria (Z. L. Wen & Ye, 2011), a Cronbach's α coefficient greater than 0.7 indicates good reliability of the measurement scale. Combined with the analysis result in Table A3.8 of Annex A, the Cronbach's α values of the original scales for platform leadership, government regulation, and transaction efficiency, without deleted items, were 0.984, 0.982, and 0.974, respectively (with the Cronbach's α values for the four types of platform guidance, platform influence, platform coordination, and platform control being 0.942, 0.951, 0.955, and 0.932, respectively). This indicates that the original scales for platform leadership, government regulation, and transaction efficiency have good reliability. Meanwhile, the corrected item-total correlation

(CITC) between independent entries and the population were all significantly greater than the 0.5 standard (Churchill, 1979). Therefore, all entries related to platform leadership, government regulation, and transaction efficiency were retained.

3.3.2.4 Original scale item validity test

Validity focuses on whether a measurement scale accurately reflects the effectiveness of the measurement (Golafshani, 2003), primarily reflected in construct validity and content validity (Wu, 2010). Construct validity is generally reflected in statistical methods using factor loadings. Considering that factor loadings are often specifically presented in exploratory factor analysis, construct validity analysis based on factor loadings will be discussed in the exploratory factor analysis section. Regarding content validity, this study conducted theoretical review, thematic discussions, and interviews during the determination of the original scale to ensure that the original scale fits the electricity trading scenario, thereby guaranteeing good content validity.

3.3.3 Measurement scale formation and verification

3.3.3.1 Exploratory factor analysis

Exploratory factor analysis (EFA) can effectively assess the construct validity of measurement scales (Worthington and Whittaker, 2006). Before conducting EFA analysis, it is necessary to combine Bartlett's test of sphericity and the Kaiser-Meyer-Olkin (KMO) value to comprehensively judge the association between variables (Ford et al., 1986; X. G. Hao et al., 2021). Based on the scale analysis results of this study, the KMO value is 0.971, and Bartlett's test of sphericity is significant at the 0.1% level, indicating that the study is suitable for conducting exploratory factor analysis (Dziuban & Shirkey, 1974). In practice, referring to existing mature practices (Bryman & Cramer, 1997; Hou et al., 2014), this study extracts factors with eigenvalues greater than 1 based on the maximum variance rotation method and principal component analysis method, and removes entries with factor loadings less than 0.45, or entries with cross factor loadings greater than 0.4 and factor loading differences less than 0.35.

1) Exploratory factor analysis of platform leadership

The factor analysis results for platform leadership are shown in Table A3.9 of Annex A. The results show that KMO = 0.967, $p < 0.001$, and platform leadership cumulatively explained 80.445% of the variance extracted into four common factors.

The factor loadings for platform leadership are shown in Table A3.10 of Annex A. Each entry can be well classified into the four categories of platform leadership common factors (all factor loadings are greater than 0.8), indicating that the measured items are highly consistent

with the expected direction of the factors (platform guidance, platform influence, platform coordination, and platform control).

2) Exploratory factor analysis of government regulation

The factor analysis results for government regulation are shown in Table A3.11 of Annex A. The results show that KMO = 0.965, $p < 0.001$, and government regulation explains 69.727% of the cumulative variance extracted from four common factors.

The factor loadings for government regulation are shown in Table A3.12 of Annex A. Each item can be well classified into the four categories of common factors for government regulation (all factor loadings are greater than 0.7), indicating that the measured items are highly consistent with the expected direction of the factors (regulation of electricity pricing, access, transaction, and operation).

3) Exploratory factor analysis of transaction efficiency

The factor analysis results for transaction efficiency are shown in Table A3.13 of Annex A. The results show that KMO = 0.965, $p < 0.001$, and transaction efficiency explains 74.881% of the cumulative variance extracted from three common factors.

The factor loadings for transaction efficiency are shown in Table A3.14 of Annex A. Each item can be well classified into the three common factors of transaction efficiency (all factor loadings are greater than 0.8), indicating that the item measurement is very consistent with the expected direction of the factors (asset specificity, uncertainty, and transaction frequency).

3.3.3.2 Confirmatory factor analysis

1) Research sample and analysis procedure

To meet research needs, researchers conducted a second round of data collection in February 2025 to validate and confirm the final version of the measurement scale. The second round of questionnaires was conducted using the Wenjuanxing platform, distributing a total of 450 questionnaires. Invalid questionnaires were subsequently deleted for the following reasons: ① incorrect answers to questions related to attention checks; ② excessively short response times (less than 40 seconds); ③ other instances of poor questionnaire quality or inconsistent responses. Ultimately, 18 invalid questionnaires were removed, and 432 valid electronic questionnaires were actually returned, representing a valid response rate of 96%. The questionnaires covered all 33 electricity transaction platforms nationwide, with at least two user companies on each platform. The demographic distribution of the survey sample is shown in Table A3.15 of Annex A.

Subsequently, confirmatory factor analysis was conducted using SPSS online software to

further examine construct validity. Following the practices of mainstream journal articles (C. Y. Tang et al., 2021; G. Tang et al., 2018), this study prioritized merging factors with more similar concepts. When assessing the goodness of fit and construct validity of the model, a comprehensive judgment was made by comparing the fit indices of the original model with those of the alternative model. In the comparison, CR and AVE values were mainly used to determine convergent validity, while CFI, TLI, SRMR, and RMSEA were comprehensively used to measure the overall goodness of fit of the model (H. Wen & Liang, 2015; Z. L. Wen et al., 2004). The goodness of fit criteria were: CFI > 0.9, TLI > 0.9, SRMR < 0.05, and RMSEA < 0.1. Simultaneously, a model with a CR value greater than 0.7 and an AVE value greater than 0.5 was considered to have good convergent validity. Meanwhile, when the original model's fit was better than all alternative models, the model's construct validity was good, and it could be used to scientifically measure the connotations of variables. The specific confirmatory factor analysis results for each variable are shown below.

2) Confirmatory factor analysis of platform leadership

The AVE and CR results of the four-factor model of platform leadership (platform guidance, platform influence, platform coordination, and platform control) are shown in the table. As can be seen from Table A3.16 in Annex A, the AVE values for all four factors are greater than 0.5, and the CR values are all higher than 0.7, indicating that the data in this analysis has good convergent validity.

As shown in Table 3.1, the four-factor model ($\chi2$=253.701, df=48, p<0.001, TLI=0.966, CFI=0.975, SRMR=0.012, RMSEA=0.098) all met the threshold criteria, and their goodness of fit was superior to other alternative models. Therefore, this study concludes that the four-factor model of platform leadership has good structural validity.

Table 3.1 Comparison of platform leadership factor model indicators

Models	$\chi2$	df	$\Delta\chi2$	CFI	TLI	RMSEA	SRMR
Four-Factor Model	253.701	48	—	0.975	0.966	0.098	0.012
Three-Factor Alternative Model 1	262.259	51	8.558	0.975	0.966	0.100	0.013
Three-Factor Alternative Model 2	275.629	51	21.928	0.973	0.965	0.101	0.013
Two-Factor Alternative Model	278.589	53	24.888	0.973	0.966	0.099	0.013
Single-Factor Alternative Model	471.427	54	217.726	0.950	0.938	0.134	0.020

Note: N=432. Four-factor model (platform guidance, platform influence, platform coordination, platform control); Three-factor alternative model 1 (platform guidance, platform influence, platform coordination + platform control); Three-factor alternative model 2 (platform guidance + platform influence, platform coordination, platform control); Two-factor alternative model (platform guidance + platform influence, platform coordination + platform control); Single-factor alternative model (platform guidance + platform influence + platform coordination + platform control).

3) Confirmatory factor analysis of government regulation

The AVE and CR indices of the four-factor (pricing regulation, transaction regulation, operational regulation, and efficiency regulation) model of government regulation are shown in the table. As shown in Table A3.17 of Annex A, the AVE values for all four factors are greater than 0.5, and the CR values are all greater than 0.7, indicating that the data analyzed have good convergent validity.

As shown in Table 3.2, the four-factor model ($\chi2$=153.004, df=29, p<0.001, TLI=0.973, CFI=0.983, SRMR=0.011, RMSEA=0.090) all met the threshold criteria, and their goodness of fit was superior to other alternative models. Therefore, this study concludes that the four-factor model for government regulation has good structural validity.

Table 3.2 Comparison of indicators in government regulatory factor model

Models	$\chi2$	df	$\Delta\chi2$	CFI	TLI	RMSEA	SRMR
Four-Factor Model	153.004	29	—	0.983	0.973	0.090	0.011
Three-Factor Alternative Model 1	178.313	32	25.309	0.980	0.972	0.103	0.011
Three-Factor Alternative Model 2	184.470	32	31.466	0.979	0.970	0.105	0.012
Two-Factor Alternative Model	209.915	34	56.911	0.976	0.968	0.110	0.012
Single-Factor Alternative Model	210.174	35	57.170	0.976	0.969	0.108	0.012

Note: N=432. Four-factor model (pricing regulation, transaction regulation, operational regulation, efficiency regulation); Three-factor alternative model 1 (pricing regulation + transaction regulation, operational regulation, efficiency regulation); Three-factor alternative model 2 (pricing regulation, transaction regulation, operational regulation + efficiency regulation); Two-factor alternative model (pricing regulation + transaction regulation, operational regulation + efficiency regulation); Single-factor alternative model (pricing regulation + transaction regulation + operational regulation + efficiency regulation).

4) Confirmatory factor analysis of transaction efficiency

The AVE and CR indices of the three-factor (asset specificity, uncertainty, transaction frequency) model for transaction efficiency are shown in the table. As shown in Table A3.18 of Annex A, the AVE values for all four factors are greater than 0.5, and the CR values are all greater than 0.7, indicating that the data analyzed have good convergent validity.

As shown in Table 3.3, the three-factor model ($\chi2$=427.769, df=84, p<0.001, TLI=0.960, CFI=0.968, SRMR=0.019, RMSEA=0.097) all met the threshold criteria, and their goodness of fit was superior to other alternative models. Therefore, this study concludes that the three-factor model for transaction efficiency has good structural validity.

Table 3.3 Comparison of indicators in the transaction efficiency factor model

Models	$\chi 2$	df	$\Delta\chi 2$	CFI	TLI	RMSEA	SRMR
Three-Factor Model	427.769	84	—	0.968	0.960	0.097	0.019
Two-Factor Alternative Model 1	749.938	89	322.169	0.939	0.928	0.131	0.023
Two-Factor Alternative Model 2	749.938	89	322.169	0.939	0.928	0.131	0.023
Two-Factor Alternative Model 3	1516.234	89	1088.465	0.868	0.844	0.193	0.047
Single-Factor Alternative Model	1645.096	90	1217.327	0.856	0.832	0.200	0.051

Note: N=432. Three-factor model (asset specificity, uncertainty, transaction frequency); Two-factor alternative model 1 (asset specificity + uncertainty, transaction frequency); Two-factor alternative model 2 (asset specificity, uncertainty + transaction frequency); Two-factor alternative model 3 (asset specificity + transaction frequency, uncertainty); Single-factor alternative model (asset specificity + uncertainty + transaction frequency)

5) Common method variance test

In this study, the high correlation coefficients among variables may stem from the approximate expression of different types of platform leadership during measurement. To mitigate the common method variance (CMV) issue, this study employs two strategies: first, data is collected across multiple time points and rounds, the research objectives are clearly stated, and timely and comprehensive guidance is provided to users during the questionnaire completion process to reduce misunderstandings during questionnaire completion; secondly, Harman's single-factor test was conducted, drawing on existing research practices. Harman's one-way factor test indicates a serious common method bias if only one factor can be extracted from the unrotated principal component factor analysis, or if the variance explained by the first factor is not less than 40% (Podsakoff et al., 2003). As shown in the previous exploratory factor analysis, the variance explained by the first common factor for all variables did not exceed 40%. Furthermore, this research analyzed all variables in a single-way model and found that the model parameters were significantly worse than the goodness of fit of the original models ($\chi 2$=5255.862, df=629, p<0.001, TLI=0.833, CFI=0.842, SRMR=0.038, RMSEA=0.131), as shown in Table A3.19 of Annex A.

3.4 Research method

For the research question in this chapter, "What key factors influence the transaction efficiency of electricity transaction platforms from the perspective of platform leadership?", Necessary Condition Analysis (NCA) is suitable for analysis, for the following reasons. First, NCA is best suited for in-depth analysis of factors influencing electricity transaction because its core logic is to identify the bottleneck levels of antecedent conditions, thereby discovering the "threshold

effect" and determining the priority of condition settings (Dul, 2024). Traditional causal analysis (such as regression) focuses on finding independent relationships between factors and outcomes but cannot identify the priority order among factors. However, NCA specifically seeks necessary but not sufficient conditions leading to outcomes and uses statistical parameters to precisely quantify bottleneck levels, thereby determining the necessity level and priority order of influencing factors. In this chapter's research on electricity transaction efficiency, this method helps to clearly reveal which influencing factors are indispensable (must-invest) essential elements for electricity transaction efficiency, thus clarifying the priority action strategies for improving transaction efficiency.

Furthermore, NCA does not rely on complex statistical assumptions (such as normal distribution), but instead intuitively quantifies the "minimum necessary level" of influencing factors through "blank areas" and "ceiling lines" (Ding, 2022). It answers the question, "What level of input must be made from antecedent factors to achieve high electricity transaction efficiency?" This methodology is well-suited for studying complex electricity transaction systems because it not only reveals key necessary conditions but also provides clear threshold references for resource allocation and strategy formulation.

3.5 Data collection and analysis procedures

After finalizing the formal questionnaire, this study conducted a third round of data collection in March-April, 2025 for the formal analysis of influencing factors and necessary conditions. The third round of questionnaire surveys still relied on the Wenjuanxing platform for data collection, with a total of 750 questionnaires distributed. The following invalid questionnaires were then deleted: ① questions related to attention checks were answered incorrectly without following the prompts; ② questionnaire response time was too short (less than 40 seconds); ③ other instances of questionnaire completion quality not meeting requirements or not following a consistent pattern. Ultimately, 13 invalid questionnaires were removed, and 737 valid questionnaires were returned, resulting in a valid response rate of 98.27%. The questionnaire covered all 33 electricity transaction platforms nationwide. To ensure that different user companies could objectively evaluate the 33 electricity transaction platforms, this study adopted a quota sampling method, ensuring that each electricity transaction platform had at least 5 electricity generation companies, 5 electricity sales companies, and 5 industrial and commercial user companies participating in the evaluation. In the specific implementation of the survey, the author's electricity network system was used to send survey requests to each

electricity transaction platform. Each electricity transaction platform invited participating electricity generation companies, electricity sales companies, and industrial and commercial user companies to complete the questionnaire. The authenticity of the sample was verified by the IP addresses and company names entered in the questionnaires to avoid duplicate submissions. The distribution of the 737 questionnaires across various electricity transaction platforms is shown in Table A3.20 of Annex A.

The distribution of variables is shown in Table A3.21 of Annex A. The results show that the sample is relatively evenly distributed among electricity generation companies, electricity sales companies, and industrial and commercial users; over 67% of users choose a single platform when participating in electricity transaction; management personnel account for 68.66% of the total sample, facilitating an understanding of electricity transaction behavior from a corporate strategic perspective; user companies are covered across different size levels, making it easier to control for differences caused by employee size; stable companies with more than 5 years of operation account for 87.11%, facilitating accurate characterization of long-term experience differences and overall feelings in electricity transaction according to continuous policies.

Since the exploratory and confirmatory factor analyzes above have confirmed that each questionnaire item can effectively measure the main variables, this research derives the scores for each variable by averaging the measurement items for the same variable. Meanwhile, the evaluations from all user enterprises (electricity generation companies, electricity sales companies, and industrial and commercial users) of each electricity transaction platform were averaged to obtain the breakdown of the 33 electricity transaction platforms. Since this research focuses on the role of leadership in different types of platforms, four types of platform leadership were retained as four independent variables. Table 3.4 shows the descriptive statistics of the main variables based on 737 questionnaires.

Table 3.4 Descriptive statistics of variables

Conditions	Minimum	Maximum	Mean	Standard Deviation	Skewness		Kurtosis	
					Statistics	Standard Error	Statistics	Standard Error
PLG	3.686	4.917	4.409	0.320	-0.412	0.409	-0.113	0.798
PLI	3.510	4.926	4.399	0.337	-0.765	0.409	0.658	0.798
PLC	3.588	4.889	4.412	0.299	-0.838	0.409	0.792	0.798
PLT	3.745	4.870	4.411	0.282	-0.616	0.409	0.127	0.798
GR	3.571	4.872	4.434	0.305	-0.884	0.409	1.037	0.798
TE	3.451	4.848	4.352	0.306	-0.785	0.409	1.299	0.798

3.6 Data calibration

Before conducting the necessary condition analysis, the data first needs to be calibrated. Lacking sufficient theoretical experience, this study calibrated the data using the mainstream quantile method, employing the 75th, 50th, and 25th percentiles as calibration reference values for complete membership, cross-ambiguity points, and complete non-membership, respectively. The calibration reference values for the variables corresponding to the necessary conditions are shown in Table 3.5.

Table 3.5 Reference values for variable calibration

Conditions	Fully subordinate	Intersecting fuzzy points	Not subordinate at all
Platform Guidance	4.611111110	4.411764706	4.264705882
Platform Influence	4.686274510	4.424242424	4.253968254
Platform Coordination	4.628930818	4.454545455	4.298245614
Platform Control	4.592592590	4.400000000	4.300000000
Government Regulation	4.636842105	4.448484848	4.294736842
Transaction Efficiency	4.564705882	4.330158730	4.225157233

Note: Since the differences between all variable data are small after mean normalization, in order to accurately distinguish and capture the micro differences between variables, this research retains the numerical results to 9 decimal places during calibration.

3.7 Single necessary condition analysis

Single necessary condition analysis and bottleneck level analysis were performed using R software, and the results are shown in Table 3.6.

Table 3.6 Single necessary condition analysis

Conditions	Estimation Method	Accuracy	Upper limit region	Range	Effect Size	p-value
PLG	CR	90.9%	0.291	1.000	0.291	0.000
	CE	100%	0.114	1.000	0.114	0.000
PLI	CR	93.2%	0.356	1.000	0.356	0.000
	CE	100%	0.193	1.000	0.193	0.000
PLC	CR	93.9%	0.319	1.000	0.319	0.000
	CE	100%	0.091	1.000	0.091	0.000
PLT	CR	87.9%	0.342	1.000	0.342	0.000
	CE	100%	0.097	1.000	0.097	0.000
GR	CR	93.9%	0.360	1.000	0.360	0.000
	CE	100%	0.178	1.000	0.178	0.000

To compare the robustness of the analysis results, regression upper limit (CR) and envelope upper limit (CE) techniques were used to calculate the estimation precision, upper limit region, range, effect size, and p-value. Following the suggestion of Dul (2024), the proposer of the

NCA method, three criteria must be met simultaneously to determine if a single condition is necessary:

1) The effect size of the single condition is greater than or equal to 0.1;

2) The p-value of the permutation test based on 10,000 permutations reaches the significance standard;

3) The estimation precision reaches 95% or higher. From the results in the table, although the effect sizes of each condition are greater than 0.1 and the p-values are significant, the estimation precision based on the regression upper limit technique does not reach 95%, therefore, no condition constitutes a single necessary condition for the outcome.

3.8 Bottleneck level analysis

Further bottleneck level analysis can reveal the necessity level of conditions for specific outcomes. Since all variables are continuous, the more suitable CR-FDH technique is used for bottleneck level analysis. Table 3.7 shows that platform coordination and government regulation were the earliest bottleneck factors affecting electricity transaction efficiency. As electricity transaction efficiency increases, the bottleneck effects of each factor gradually increase. When reaching a 20% electricity transaction efficiency level, 99.3% platform influence and 99.2% government regulation are required. When reaching a 40% electricity transaction efficiency level, all factors exert a combined influence, requiring 89.6% platform guidance, 77.4% platform influence, 88.4% platform coordination, 82% platform control, and 77.1% government regulation. This indicates that the transaction efficiency of an electricity transaction platform is jointly constrained by multiple conditions related to platform coordination and government regulation, with platform coordination and government regulation being the most significant influencing factors on electricity transaction efficiency.

Table 3.7 Bottleneck level analysis

TE	PLG	PLI	PLC	PLT	GR
0	NN	NN	NN	NN	NN
10	NN	NN	NN	NN	NN
20	NN	NN	99.3	NN	99.2
30	NN	88.4	NN	94.3	88.2
40	89.6	77.4	88.4	82.0	77.1
50	77.2	66.4	74.8	69.7	66.0
60	64.7	55.5	61.3	57.5	55.0
70	52.3	44.5	47.7	45.2	43.9
80	39.8	33.5	34.2	32.9	32.9
90	27.4	22.5	20.6	20.7	21.8

3.9 Robustness test

To test the robustness of the research conclusions, this research made the following attempts:

1) Simultaneously calculating various values based on the regression upper limit technique (CR) and the envelope upper limit technique (CE), and comprehensively judging the necessity analysis conclusions (see Table 3.6);

2) Conducting single necessary condition analysis and bottleneck level analysis based on uncalibrated raw data, the results of which are shown in Annex A, Tables A3.22 and A3.23.

The results show that, apart from minor changes in the indicator parameters, there is still no single necessary condition affecting the results. Meanwhile, platform coordination and government regulation remain the earliest factors affecting electricity transaction efficiency. Therefore, the research conclusions are deemed robust.

3.10 Chapter conclusion

3.10.1 Research conclusions

Based on the systematic revision and confirmation of the measurement scale for the core variables of this study, this chapter systematically examines the influencing factors and necessary conditions for the transaction efficiency of electricity transaction platforms. Using descriptive statistics, factor analysis, and necessary condition analysis, this chapter, combined with three rounds of data surveys and empirical analysis of all 33 provincial-level electricity transaction platforms in China, reveals the following main conclusions:

1) The transaction efficiency of electricity transaction platforms depends on the influence of platform leadership (internal factor) and government regulation (external factor), and there is no single factor determining the efficiency of electricity transaction. In the scenario of unified coordination and management of provincial-level electricity transaction implemented through digital platforms, the efficiency of provincial-level electricity transaction depends on the platform's guidance, influence, coordination, and control, and is also affected by the government regulation of each province. Specifically, the necessity analysis results show that both platform leadership and government regulation have good explanatory power for electricity transaction efficiency, but neither of these conditions constitutes a necessary condition, indicating that the realization of electricity transaction efficiency may rely more on the combined effect of internal and external factors (government+platform dual management).

2) Among all influencing factors, platform coordination and government regulation were the earliest bottleneck factors affecting the efficiency of electricity transaction. Meanwhile, as the efficiency of electricity transaction increases, the bottleneck effects of various factors gradually increase. The bottleneck level analysis in this chapter reveals that achieving a 20% electricity transaction efficiency level requires 99.3% platform influence and 99.2% government regulation. At a 40% efficiency level, all factors work together, requiring 89.6% platform guidance, 77.4% platform influence, 88.4% platform coordination, 82% platform control, and 77.1% government regulation. This indicates that electricity transaction efficiency is constrained by multiple factors, among which platform coordination and government regulation are the most critical to consider.

3.10.2 Research contributions

Based on existing research, the contributions of this chapter's analysis are mainly reflected in two aspects: First, it expands the research on factors influencing electricity transaction efficiency under the context of digital platform management, providing theoretical reference for improving the transaction of special product categories. Research has found that electricity commodities have a more prominent public attribute, and their consumption exhibits significant immediate consumption characteristics. In the process of improving transaction efficiency, particular attention needs to be paid to the dual forces of platform leadership and government regulation, and neither single force is sufficient to fully explain transaction efficiency. This is significantly different from previous research scenarios in the e-commerce context of traditional consumer goods markets (Du et al., 2023; X. F. Shi et al., 2023). Therefore, this chapter's analysis can provide a new contextual analysis framework for the construction of transaction for public goods.

Second, by combining necessary condition analysis methods, it deepens the research on the conditions for prioritizing the construction of electricity transaction efficiency. Previous studies, based on regression analysis methods to explore the "net effect" of a single factor and its outcome (X. F. Shi et al., 2023), often only draw relatively superficial conclusions based on the significance level of regression analysis when explaining the differences in the effects of different factors, and cannot deeply reveal whether or which necessary conditions exist that determine transaction efficiency. Therefore, this chapter, based on the necessary condition analysis method, systematically examines the necessary conditions and their bottleneck levels, revealing the primary impact of platform coordination and government regulation on improving

electricity transaction efficiency, and providing direct reference for deepening the construction of conditions prioritizing electricity transaction efficiency.

3.10.3 Research implications

Based on the findings of this chapter, the following key insights are drawn: First, the efficiency of electricity transaction platforms depends on the combined efforts of platform leadership and government regulation; neither single force can fully determine the level of efficiency. In practice, electricity transaction platforms can develop guidance, influence, coordination, and control strategies tailored to the specific supply and demand characteristics of each province within the framework of government regulatory policies, thus promoting the concerted efforts of both forces. For example, electricity transaction platforms can leverage big data analysis of user electricity consumption behavior and electricity structure (influence) to provide the government with information on load peak-valley characteristics and renewable energy output fluctuations; the government can then dynamically adjust peak-valley electricity pricing policies based on this data (pricing regulation) and push this information to market participants through the platform to guide off-peak allocation and reduce the peak-valley electricity gap. Alternatively, electricity transaction platforms can establish inter-provincial transaction zones (coordination), automatically matching the electricity surplus and shortage between supply and demand provinces; government regulatory departments can break down inter-provincial barriers (transaction regulation), eliminating inter-provincial transaction approval levels and enabling online transaction registration through the platform, thereby improving the overall utilization rate of transmission channels.

Second, platform coordination and government regulation are key areas that need to be prioritized and actively developed in the construction of the electricity transaction market. electricity transaction platforms, leveraging their significant influence, can reduce transaction costs and invigorate market participants through technological empowerment (data, systems, innovative models). Conversely, the government, through rule-making and enforcement, can effectively ensure fair order and clarify the direction of electricity market development. Prioritizing the development of both platforms fosters a value loop of “market innovation - policy support - efficiency improvement.” In practice, electricity transaction platforms can reduce structural complexity by building data hubs to enhance collaboration, simplifying platform processes to shorten market entry cycles, introducing “peak-valley price difference visualization tools” to aid in electricity supply and demand allocation, and deploying AI

algorithms to identify abnormal transactions. This allows them to gain significant influence through a user-friendly platform system. Correspondingly, the government can effectively play its dual role of supervision and incentive by setting bottom lines, establishing pricing fluctuation ranges, implementing dynamic evaluation, promoting data standards, and appropriately relaxing entry requirements. This will help electricity transaction stimulate market vitality and achieve overall efficiency improvement within a well-ordered environment.

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Chapter 4: Antecedent Configuration Analysis of Electricity Transaction Efficiency from the Perspective of Platform Leadership

4.1 Research question statement and configuration study framework

Electricity transaction efficiency is a core indicator for measuring the optimization of electricity market resource allocation, and its influencing factors encompass multiple dimensions, including technological innovation, policy regulation, and market structure. With the global energy transition and the penetration of digital technologies, electricity transaction models are evolving from traditional centralized to distributed and market-oriented models, making the mechanisms influencing transaction efficiency more complex. In particular, in the new era of digital transformation and platform-based management of China's electricity transaction, how the dual forces of platform leadership and government regulation interact and collaborate to improve transaction efficiency is of particular concern.

Following the previous analysis, the research in the previous chapter systematically examined the influencing factors and necessary conditions for the transaction efficiency of China's electricity transaction platforms, finding that platform leadership and government regulation are crucial factors determining the efficiency of electricity transaction at the provincial level. However, several issues still warrant further discussion.

First, the electricity transaction market, as a holistic system involving multiple participants, requires analysis based on its overall characteristics to arrive at conclusions more suitable for the Chinese electricity transaction platform scenario. In this sense, marginal or net effect analyzes based on single factors remain at a relatively simplified "decompositional" level, failing to characterize the true scenario of achieving electricity transaction efficiency based on a holistic "reductionist" approach. For example, most studies based on simulation (S. Q. Huang, 2022; Q. S. Shi et al., 2022; Tai et al., 2017), DEA data envelopment analysis (Zhong, 2024), regression analysis (Guo, 2023), social welfare analysis using economic modeling (Z. Chen, 2020), or evaluation models (R. H. Huang et al., 2010; S. H. Shi et al., 2018) can only simulate the design or implementation process of electricity transaction contracts based on simplified model parameters. They cannot systematically analyze the process of achieving transaction

efficiency from the perspective of market management (leadership). Therefore, research conclusions tend to remain at the institutional design level, neglecting the impact of interactions between different stakeholders on transaction efficiency.

Secondly, when discussing the realization of transaction efficiency, existing research is mostly based on narrow theoretical frameworks, focusing on the influence of a few core variables on transaction efficiency, ignoring the heterogeneous combinations resulting from the interplay of multiple factors, and failing to deeply reveal the regional and structural differences in electricity transaction efficiency at the provincial level. Existing research has considered the impact of technological, environmental, and structural conditions on transaction efficiency, including blockchain technology architecture (S. Q. Huang, 2022), digital economy conditions (Guo, 2023), policy coordination (Zhong, 2024), government regulation (S. H. Shi et al., 2018), and market structure (R. H. Huang et al., 2010; F. Wang & Wu, 2016; Yu et al., 2010). While this provides valuable insights for analyzing the transaction efficiency of general commodities, it is not entirely applicable to the analysis of the electricity transaction market. This is because electricity consumption is immediate, and electricity transaction is subject to relatively strict institutional control. Furthermore, the basic conditions, supply and demand realities, user groups, and guiding policies of the electricity market may exhibit regional differences across different provinces. Ignoring provincial differences and treating China's provincial electricity markets as homogenous not only hinders the analysis of regional differences in electricity transaction efficiency but may also lead to theoretical guidance lagging behind practical electricity market development due to inadequate market construction, thus weakening the theoretical reference value.

Finally, in analyzing the principles behind electricity transaction efficiency, the analysis often relies on the assumption of symmetrical causal relationships, neglecting the inherent complexity that contributes to the success or failure of transaction efficiency. In reality, the combinations (configurations) of factors determining the success or failure of electricity transaction efficiency may not be identical, and the same factors may play completely different roles in different regions (provincial transaction markets). Therefore, methods based on mean-law analysis such as regression analysis (Guo, 2023; Zhong, 2024) cannot effectively reveal potential asymmetric causal relationships.

In light of this, this chapter focuses on the research question "How can electricity transaction platforms achieve high/non-high electricity transaction efficiency?" From the theoretical perspective of platform leadership, it discusses how the dual forces of platform leadership and government regulation can collaboratively achieve differentiated effects on

electricity transaction efficiency at the provincial level.

Specifically, platform leadership determines the effectiveness of the electricity transaction platform leader's (platform enterprise) design, management, and coordination of the transaction platform. It plays a crucial role in incentivizing platform users (electricity generation companies, electricity retailers, and industrial and commercial users) to actively participate in electricity transaction, exerting a vital influence, guiding, coordinating, and controlling effect. Regarding platform influence, electricity transaction platforms attract diverse stakeholders (electricity generation companies, electricity retailers, and industrial and commercial users) to join by expanding market coverage and integrating cross-regional resources, forming a large-scale transaction network. Simultaneously, they establish a credit evaluation system based on data accumulation, and guide users to regulate their behavior and prioritize participation in green electricity transaction through information openness and the design of green transaction zones, strengthening market ecosystem stickiness and resource allocation guidance. In terms of platform guidance, the electricity transaction platform is driven by technological innovation, improving transaction efficiency by overcoming key technologies such as minute-level transaction clearing and high-concurrency systems. It also pioneered composite transaction models and electricity financial derivatives, defining market rules, promoting renewable energy consumption and user risk hedging, and leading the electricity market towards intelligent and diversified evolution. Regarding platform coordination, the electricity transaction platform addresses the problem of fragmented resource allocation through cross-regional market linkages (inter-provincial and intra-provincial connections) and joint clearing of ancillary services and the electricity market. It designs differentiated mechanisms for different stakeholders (such as aggregator representation of small and medium-sized users and fair competition parameter settings) to balance the interests of the generation and user sides, achieving dynamic coordination of diverse demands. In terms of platform control, the electricity transaction platform constructs a full-chain risk prevention and control system, identifying abnormal transactions through intelligent monitoring systems and ensuring performance through margin and credit mechanisms. It adopts a dual-active disaster recovery architecture to ensure system security and maintains market order through market assessment and intervention, solidifying compliance and safety bottom lines.

Furthermore, the government, as the core regulatory force influencing the electricity market, also plays a crucial role in the efficiency of electricity transaction through its rule constraints and policy incentives. government regulation provides institutional guarantees and guidance for improving electricity transaction efficiency through a dual policy tool of "incentives and

guidance + constraints and regulations." On the incentive side, regulatory policies lower market entry barriers through market-oriented reforms (such as loosening electricity pricing mechanisms and prioritizing cross-provincial and cross-regional transaction channels), encouraging diverse participants such as electricity retailers and energy storage companies, and promoting the expansion of transaction products from single-energy electricity to composite types such as ancillary services and green electricity transaction, thereby stimulating market vitality. Simultaneously, policies such as green electricity subsidies and renewable energy consumption weighting assessments guide resources towards low-carbon sectors, optimizing the energy structure. On the constraint side, government regulation focuses on market fairness and system security, preventing market power abuse and vicious competition and protecting the rights and interests of small and medium-sized users through anti-monopoly reviews (such as restricting the market share of electricity generation companies and cracking down on bid-rigging), transaction compliance supervision (such as real-time monitoring of abnormal transaction behavior), and cross-regional interest coordination mechanisms. Furthermore, by formulating unified transaction technical standards (such as data interface specifications and settlement rules) and contingency plans, transaction costs and system risks are reduced. Therefore, regulatory policies, by balancing efficiency and fairness, innovation and safety, promote the transformation of electricity transaction from "administrative command-driven" to "market allocation-driven," achieving a comprehensive effect of simplified transaction processes, optimized resource allocation, and improved social welfare.

In reality, neither platform leadership (internal) nor government regulation (external) alone can fully explain the process of achieving electricity transaction efficiency. The complexity of the electricity market requires a dual-drive approach of "technology empowerment and institutional norms"—government regulation defines the operational boundaries of the platform, while the platform implements regulatory objectives through technological innovation. A lack of coordination or improper combination of these two approaches may lead to "excessive regulation suppressing platform innovation" or "disorderly platform expansion exceeding regulatory limits." For example, emphasizing only platform technology leadership without regulatory constraints on market power may result in monopolistic pricing; rigid regulatory policies (such as fixed electricity price mechanisms) will hinder the effectiveness of innovative tools such as green electricity transaction. Therefore, this chapter proposes a configuration analysis framework as shown in Figure 4.1, aiming to reveal the antecedent configurations that generate high/low electricity transaction efficiency based on configuration effect analysis, thereby providing detailed references for the classification management and market-oriented

reform of China's electricity transaction.

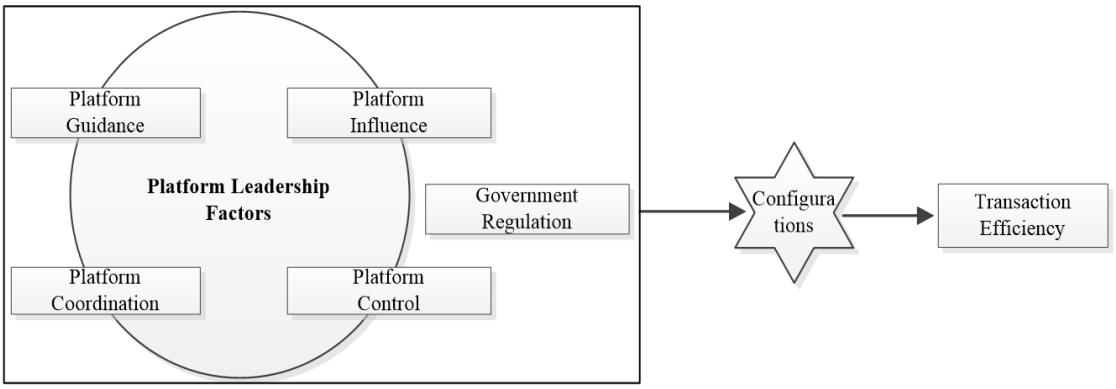


Figure 4.1 Framework for studying electricity transaction efficiency configuration

4.2 Variable selection and measurement

Since the core variables studied in this chapter are relatively consistent with those in the previous sections, the measurement methods described above are also used. The outcome variable, transaction efficiency, is measured using a scale tested through exploratory and confirmatory factor analyzes. This scale includes 15 items covering three main dimensions: transaction frequency, asset specificity, and uncertainty, such as "Our company provides dedicated production or service facilities for the electricity transaction platform" and "Our company integrates its advanced management processes and digital technologies into the electricity transaction platform." The measurement was originally developed based on relevant research in transaction cost economics (Masroor et al., 2023; Q. G. Tang, 2009; Williamson, 1975), and appropriately revised within the context of the electricity trading platform with reference to the questionnaires adopted by Long et al. (2012) and Duan and Wang (2018).

The measurement of the antecedent variable, platform leadership, is subdivided into four sub-variables: platform influence, platform guidance, platform coordination, and platform control. Each sub-variable is measured using a scale with three questions, totaling 12 measurement questions, such as "the electricity transaction platform has a certain reputation, popularity, or word-of-mouth among users (including registered electricity generation companies, electricity sales companies, industrial and commercial users, among others)" and "some aspects of the electricity transaction platform (such as certain platform technical architecture, transaction rules, transaction support capabilities, among others) are leading or have a leading and exemplary role domestically or internationally" (Y. Zhang, 2019; Y. Zhang & Liu, 2020). The measurement of government regulation integrates existing research on

electricity pricing, transaction, access, and safe operation (F. L. Chen & Xu, 2009; Han, 2023; S. Zhang, 2007) to form a preliminary questionnaire. Based on the scale development and validation procedures, the scale with 10 items was confirmed, including "the province or city fully solicited the opinions of all users on the power exchange center and platform before the policy on electricity pricing and regulation was released" and "the province or city has relatively relaxed market access conditions for registered users participating in the electricity market, which can attract a sufficient number of electricity transaction users to participate in the electricity market and form competitive vitality."

4.3 Research method

The core research method discussed in this chapter is fuzzy set Qualitative Comparative Analysis (fsQCA). Based on set theory and Boolean algebra, fsQCA integrates the advantages of qualitative and quantitative research. By leveraging fuzzy set theory, it overcomes the dichotomous limitations of traditional clear set (csQCA), allowing variables to be represented by continuous membership values between 0 and 1, thus better reflecting the characteristics of gradual social phenomena in reality (Ragin, 2008). Its core logic lies in treating cases as configurational combinations of conditional variables. Through a "calibration" step, the original data is transformed into set membership degrees (e.g., setting three anchor points: complete membership, intersection, and no membership). This allows for necessity and configurational analysis to identify sufficient combinations of conditions leading to specific outcomes.

This method is particularly suitable for solving three core types of problems in academic research. First, it addresses multi-conditional concurrent causal relationships, where multiple factors act on the outcome through different combinations, rather than the independent influence of a single variable. For example, multiple factors may produce the same efficiency improvement. Second, it analyzes complex mechanisms in small to medium-sized samples, suitable for research scenarios with 10-50 cases, compensating for the limitations of large-sample statistical methods in terms of case depth, especially suitable for fields like the electricity market where data acquisition is limited. Third, it addresses asymmetric causal relationships between variables, focusing not only on the combinations of conditions leading to the outcome but also revealing the configurations that hinder the outcome, thus helping to uncover potential asymmetric causal relationships.

In the analysis of transaction efficiency on electricity transaction platforms, fsQCA's

applicability is reflected in three levels: First, for multi-dimensional measurement of transaction efficiency (asset specificity, transaction frequency, uncertainty), fuzzy set calibration can transform questionnaire data into unified membership values, resolving measurement differences between indicators. Second, it can integrate platform leadership (influence, guidance, coordination, control) and government regulation as conditional variables to identify the impact of different configuration paths on efficiency. Finally, it clarifies key preconditions through necessity analysis and identifies differentiated paths through configuration comparison. This method not only overcomes the dependence of single regression analysis on linear relationships, but also provides provincial-level "locally tailored" configuration optimization suggestions for electricity market policymaking, thus demonstrating its unique advantage in revealing complex causal relationships.

4.4 Data collection

After identifying the core variables involved in the research and revising and confirming the variable measurements using preliminary survey data, this chapter of the study initiated formal data collection. The core data collection period was from March to May, 2025, using electronic questionnaires distributed and collected via Wenjuanxing (a survey platform). To ensure the robustness and reliability of the research conclusions, this chapter conducted questionnaire surveys at both the platform and user levels. User-level evaluation data (electricity generation companies, electricity sales companies, and industrial and commercial users) served as the primary basis for analysis, while platform-level evaluation data (electricity transaction platform companies) was used as a robustness check to avoid interpretation bias caused by a single data sample source. More specifically, user-level data covered all 33 provincial-level electricity transaction platforms in China. Quota sampling was implemented for each platform to avoid user group evaluation bias, ensuring that each electricity transaction platform had at least 5 electricity generation companies, 5 electricity sales companies, and 5 industrial and commercial user companies providing evaluations. For the platform-level survey, frontline employees or managers familiar with the operation and management of each electricity transaction platform company were invited to complete the questionnaires, with at least 3 questionnaires completed for each platform.

Meanwhile, during the questionnaire data acquisition process, to ensure the validity of the analysis, invalid questionnaires were eliminated based on the following principles: questionnaires with a response time of less than 40 seconds; questionnaires with errors in

attention check questions; questionnaires with substandard quality or inconsistent answers; and questionnaires with completely duplicate IP addresses. Ultimately, 750 questionnaires were distributed and collected from users, with 737 valid questionnaires, resulting in a valid response rate of 98.27%; 222 questionnaires were distributed and collected from the platform, resulting in a valid response rate of 100%.

4.5 Data calibration

QCA data calibration is a core step connecting raw data with set theory analysis. Its core function is to transform diverse raw information (such as quantitative data and qualitative judgments) into unified set membership values (between 0 and 1), allowing for precise measurement of a case's "degree of belonging" within a specific set. By setting theoretical or empirical anchor points (complete membership, intersection, and no membership), calibration overcomes the limitations of traditional dichotomy, preserving the continuous characteristics of data while transforming abstract concepts into operational quantitative standards, thus solving the problem of integrating qualitative and quantitative data. Simultaneously, calibration ensures comparability across cases and variables, laying the foundation for subsequent necessity analysis and configuration comparison. Furthermore, the calibration process must be combined with the theoretical logic of the research problem, avoiding reliance solely on statistical thresholds, making data processing more aligned with the essential characteristics of the research context, ultimately ensuring the accuracy and scientific rigor of QCA in analyzing complex causal relationships.

In the context of this chapter's research, because the platform user-level variable data involved in this analysis exhibit significant differences at the provincial level and lack mature theoretical reference experience, the mainstream numerical method is adopted for calibration. Specifically, the 75th, 50th, and 25th percentiles are used as calibration reference values for complete membership, cross-ambiguity points, and complete non-membership, respectively. Details of the data calibration are shown in Table A4.1 of Annex A.

4.6 Empirical analysis

4.6.1 Necessity analysis

Before conducting configuration analysis, it is necessary to examine whether there are

necessary conditions affecting specific outcomes (high electricity transaction efficiency versus low electricity transaction efficiency). Based on the data calibrated above, and with cases of membership score of 0.5 in the fsQCA analysis automatically deleted, and referring to existing research (Ragin, 2006), 0.501 was used to replace cases with a calibrated membership score of 0.5. The necessity analysis results for outcomes of high electricity transaction efficiency (TE) and low electricity transaction efficiency (~TE) using R software are shown in the table below. From Annex A, Table A4.2, it can be seen that for the outcome of high electricity transaction efficiency (TE), the consistency of the three conditions—high platform coordination (PLC), high platform control (PLT), and high government regulation (GR)—is greater than 0.9 and the coverage is greater than 0.5, indicating that these three conditions may constitute necessary conditions for high electricity transaction efficiency. For the outcome of non-high electricity transaction efficiency (~TE), the consistency of the three conditions—low platform influence (~PLI), low platform coordination (~PLC), and low government regulation (~GR)—is greater than 0.9 and the coverage is greater than 0.5, indicating that these three conditions may constitute necessary conditions for non-high electricity transaction efficiency.

Since the previous single necessary condition analysis (NCA) did not find any necessary conditions affecting electricity transaction efficiency, further testing of potential necessary conditions is needed by plotting scatter plots. Referring to the criteria for necessity judgment in previous studies (Schneider & Wagemann, 2012), if more than 1/3 of the points in the scatter plot of the cause and effect conditions are distributed above the diagonal or most of the points are distributed to the right of the Y-axis, then the condition is considered not to constitute a necessary condition for the outcome. Scatter plots for the six possible necessary conditions are shown below. From the results in Figure 4.2, the criteria for non-necessary conditions are met for the high electricity transaction efficiency outcome; therefore, there are no necessary conditions leading to high electricity transaction efficiency. Regarding the results for low electricity transaction efficiency, most points indicating low platform influence (~PLI) and low platform coordination (~PLC) are not located above the diagonal or to the right of the Y-axis, thus constituting a necessary condition for low electricity transaction efficiency. However, over one-third of the points indicating low government regulation and low electricity transaction efficiency are located above the diagonal, therefore not constituting a necessary condition for low electricity transaction efficiency.

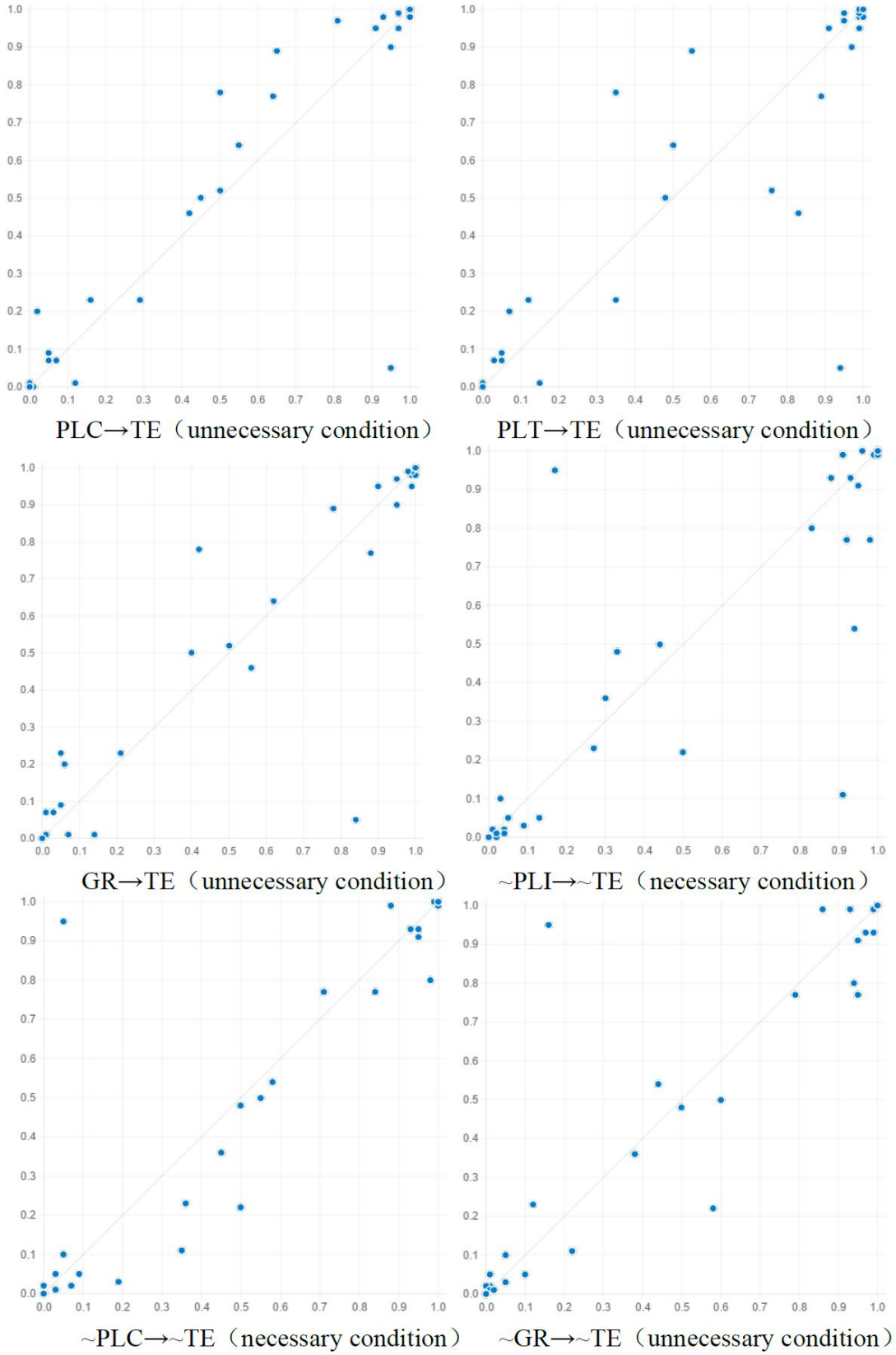


Figure 4.2 Further testing of the single necessary condition

4.6.2 Sufficiency analysis

Sufficiency analysis can reveal the configurational effects of antecedents on outcomes, thus revealing equivalent causal relationships of "multiple concurrencies." Following established practices in previous research (Ding, 2022), this study sets the sample frequency to 1, the raw consistency threshold to 0.8, and the proportional reduction in inconsistency (PRI) threshold to 0.7. Since no necessary conditions were found for the outcome of high electricity transaction efficiency (TE), no expected direction was set for high electricity transaction efficiency. For the outcome of non-high electricity transaction efficiency (~TE), two necessary conditions were found: low platform influence (~PLI) and low platform coordination (~PLC). These two conditions were thus set as the "absent" state in the configuration analysis of non-high electricity transaction efficiency (~TE), and no expected direction was set for the other conditions.

Subsequently, the configuration analysis results were plotted and compiled based on intermediate and simplified solutions, as shown in Table 4.1. Conditions appearing in both intermediate and simplified solutions are designated as core conditions, while conditions appearing only in intermediate solutions are designated as marginal conditions. The configurations are then graphically represented.

Table 4.1 Sufficiency analysis

Conditions	High TE			Non-high TE
	H1a	H1b	H2	L1
Platform Guidance		⊗	•	⊗
Platform Influence	•		•	⊗
Platform Coordination	●	●	●	⊗
Platform Control	•	•	⊗	⊗
Government Regulation	•	•	⊗	⊗
Consistency	0.936	0.974	0.970	0.975
PRI	0.922	0.882	0.854	0.969
Coverage	0.809	0.204	0.120	0.829
Unique coverage	0.639	0.040	0.012	0.829
Typical Platform	Shandong (1,1), Hunan (1,1), Northern Hebei (0.99,0.98), Hubei (0.98,1), Hebei (0.96,0.99), Shanxi (0.95,0.95), Qinghai (0.95,0.9), Ningxia (0.95,0.99), Tibet (0.93,0.98), Shanghai (0.87,0.95), Sichuan (0.83,0.05), Henan	Tianjin (0.55, 0.89), Jiangxi (0.501, 0.64)	Hainan (0.501, 0.78)	Xinjiang (1,1), Kunming (1,1), Guizhou (1,1), Zhejiang (0.99,0.99), Anhui (0.99,0.99), Fujian (0.93,0.93), Gansu (0.91,1), Chongqing (0.9,0.91), Guangdong (0.88,0.93), Guangxi

	(0.81,0.97), Jilin (0.64,0.77), Eastern Inner Mongolia (0.501,0.52)	(0.86,0.99), Shaanxi (0.85,0.99), Jiangsu (0.84,0.77), Heilongjiang (0.65,0.77)
Solution consistency	0.939	0.975
Solution coverage	0.861	0.829

Note: ●indicates the presence of a core condition, ⊗ indicates the absence of a core condition, ●indicates the presence of a marginal condition, ⊗ indicates the absence of a marginal condition, and a blank column indicates that the presence or absence of a condition has no impact on the result.

4.6.2.1 High power transaction efficiency configuration

The sufficiency results of the configurations are shown in Table 4.1. The results show that the overall consistency of the configuration solution achieving high electricity transaction efficiency reaches 0.939 (greater than the threshold of 0.8), and the coverage reaches 0.861. The consistency coefficients of the three configurations are all above 0.9, and the PRI values are all above 0.75, indicating that the configuration results can well explain high electricity transaction efficiency. More specifically, considering the composition of the three high-efficiency configurations, they correspond to three different types of high-efficiency realization.

Platform leadership and government regulation collaborative driving configuration. In configuration H1a, platform leadership (platform influence, platform coordination, platform control) and government regulation both play a promoting role as "existing" conditions for high electricity transaction efficiency. Simultaneously, the coverage (0.809) and unique coverage (0.639) of this configuration are the highest among all configurations, making configuration H1a the most representative in the Chinese provincial electricity transaction market. Taking the Shandong Power Exchange Center (platform) as an example, the Shandong Power Exchange Center has built a highly efficient operating system integrating "technology empowerment, institutional norms, and risk prevention" through deep collaboration between its platform influence, coordination, control, and government regulation. In terms of platform influence, relying on its status as one of the first pilot electricity spot markets in the country, the center has created a demonstration effect through a four-market collaborative operation mechanism of "medium- and long-term + spot + retail + ancillary services" (with a transaction volume of 371.4 billion kWh in 2022, a 488% increase compared to 2016). Government regulation, through policies such as green electricity transaction subsidies and new energy consumption weight assessment, has guided the platform to transform innovative practices such as green electricity transaction and virtual power plant registration into market consensus. In 2022, it completed 940 million kWh of green electricity transaction and 8,732 unsubsidized green certificate transactions, achieving a two-way activation of policy objectives and market vitality.

At the platform coordination level, the center focuses on the "1+N" supply guarantee mechanism and cross-regional transaction strategy. Through a "five AC, three DC, one ring network" power grid architecture, it achieves interconnection with power grids in North China and Northwest China. In 2022, the peak external electricity input to Shandong reached 29.38 million kilowatts (accounting for 31% of the load). Government supervision provides institutional guarantees for the platform to coordinate resources both inside and outside the province through priority allocation of cross-provincial transaction channels and inter-provincial interest coordination mechanisms, ensuring the efficiency of emergency purchase and dispatch response under extreme weather conditions (such as the summer load exceeding 100 million kilowatts in 2022). At the platform control level, the center has established a "credit profile + mandatory delisting" risk control system. In 2024, 340 non-compliant electricity sales companies were shut down. Market entity constraints are improved through mechanisms such as performance bonds and insurance management. Government supervision is supplemented by anti-monopoly reviews (restricting the market share of electricity generation companies) and real-time monitoring of transaction compliance, forming a dual defense line of "platform self-governance + administrative supervision." With the synergy of these three elements, the platform's third-party service satisfaction has ranked first in the State Grid operating area for three consecutive years. This success stems from both technological innovation (such as a fully online retail platform) to reduce transaction costs and regulatory rules to prevent the abuse of market power. Ultimately, it achieves a dynamic balance between expanding transaction scale, renewable energy consumption, and system security, providing a "Shandong model" for improving the efficiency of provincial electricity markets.

Government regulation drives platform leadership to improve quality and efficiency. In configuration H1b, government regulation and some platform leadership (platform coordination and control) act as "existing" conditions that promote high electricity transaction efficiency, while some platform leadership (platform guidance) acts as a "missing" condition. Furthermore, the coverage of this configuration is significantly lower than that of configuration H1a. This indicates that configuration H1b is a new configuration type distinct from most provincial characteristics. In this type of configuration, electricity transaction platform leadership and government regulation do not function in complete parallel; electricity transaction platform enterprises lack strong platform guidance. In this case, greater reliance is placed on government regulation rules and guidance to provide institutional guarantees for the platform-based management of electricity transaction. The Tianjin Power Exchange Center, as a typical H1b configuration case, highlights a complementary model of "regulatory leadership

and platform collaboration" in achieving electricity transaction efficiency. Given the relatively limited platform guidance, regulatory departments such as the Tianjin Development and Reform Commission and the Energy Bureau have constructed an institutional framework through "rules first + process control." For example, they took the lead in issuing the "Tianjin Municipal Power Ancillary Services Market Management Measures," clarifying the access standards and revenue mechanisms for new entities such as energy storage and virtual power plants, providing clear policy guidance for platform transactions. Simultaneously, considering the local market's predominantly small and medium-sized users, regulatory departments promoted the establishment of a hybrid transaction model of "government-guided electricity prices + platform competitive bidding," ensuring stable electricity prices for residential use while leveraging the platform's coordination capabilities to organize "point-to-point" direct transactions between distributed photovoltaic projects and industrial park users. The platform's control focuses on the compliance of the entire transaction process. Relying on the "negative list of transaction behaviors" system authorized by regulatory departments, it implements real-time monitoring of market power abuse and abnormal data reporting, intercepting abnormal transactions through the platform's risk control system to ensure the effective implementation of regulatory policies. This collaborative mechanism of "regulators setting rules, platforms enforcing them" provides institutional guarantees for transaction efficiency through government regulation when platform guidance is insufficient. Platforms, leveraging their localized coordination capabilities and rigid control (such as performance bond management and credit rating systems), translate regulatory requirements into market practices, ultimately improving transaction settlement accuracy, shortening average transaction cycles, and continuously enhancing transaction efficiency.

A moderately regulated platform leadership incentive-based improvement model. In configuration H2, most platform leadership (platform influence, platform coordination, platform guidance) contributes to high electricity transaction efficiency as "existing" conditions, while government regulation and a small portion of platform leadership (platform control) play a role as "missing" conditions. This configuration has the lowest coverage (0.120) and only one sample, the Hainan Power Exchange Center, meets the basic characteristics, indicating its rarity in China's provincial electricity transaction market. In this configuration, the key to achieving transaction efficiency lies in "strong incentives and weak control," advocating for a more autonomous management and incentive system where the government provides appropriate regulation, delegating more autonomy and incentive authority to the electricity transaction platform market to promote efficiency improvement through a more dynamic competitive

market. As the sole sample of configuration H2, the Hainan Power Exchange Center's transaction efficiency realization logic highlights the progressive relationship of "policy relaxation - platform empowerment - market activation." Leveraging the policy advantages of the Hainan Free Trade Port's "first-mover advantage," Hainan's energy regulatory authorities implemented a moderate intervention model of "bottom-line regulation + innovation tolerance," pioneering the "full opening of the retail electricity market" nationwide. This involved eliminating user access capacity restrictions and clarifying the bottom line of anti-monopoly and fair competition solely through the "Hainan Power Market Supervision Measures." Authority for rule-making and entity access review was delegated to the platform, creating a "weak control" regulatory environment. Building upon this foundation, the platform fully leverages the three key elements of leadership: First, it drives model innovation through leadership, developing the nation's first "Green Electricity Transaction Cross-border Settlement Platform" to achieve cross-border mutual recognition of green electricity certificates in Southeast Asia. Second, it utilizes coordination to construct a "four-party collaboration" mechanism, uniting power grid companies, electricity generation groups, electricity sales companies, and key free trade port parks to establish a "demand-side response + energy storage auxiliary service" transaction zone, coordinating solutions to distributed power grid connection challenges. Third, it leverages its influence to create a "digital transaction ecosystem," launching a "one-click" intelligent matching system to further reduce transaction application time and attracting out-of-province electricity sales companies through free trade port policies, creating a "catfish effect" to stimulate competition. The platform's "lack" of control is reflected in abandoning traditional administrative intervention methods and instead using a "credit score + market-based exit" mechanism to constrain the behavior of stakeholders, ensuring both market flexibility and order. This logic of "government setting rules, platform building ecosystem, and market innovation" enables Hainan to continuously increase the marketization rate of electricity transaction with less regulatory intervention.

4.6.2.2 Non-high power transaction efficiency configuration

As shown in Table 4.1, the overall consistency of the configuration solution achieving low electricity transaction efficiency reaches 0.975 (greater than the threshold of 0.8), the coverage reaches 0.829, and the PRI values are all above 0.75, indicating that the configuration results can well explain low electricity transaction efficiency. More specifically, considering the configuration composition of low transaction efficiency, it stems more from the lack of dual forces of platform leadership and government regulation.

Configuration with the dual absence of platform leadership and government regulation. In configuration L1, both platform leadership (platform guidance, platform influence, platform coordination, platform control) and government regulation play a promoting role as "missing" conditions. Furthermore, looking at the cases covered by configuration L1, 13 provincial samples, accounting for 39.39%, are classified as having low transaction efficiency. This indicates significant compositional differences in China's provincial electricity transaction market. More specifically, all conditions in configuration L1 function as "missing" conditions, indicating that the low efficiency of provincial electricity transaction in China stems largely from the simultaneous absence of both government regulation and platform leadership. The case of the Heilongjiang Power Exchange Center vividly illustrates the inhibitory effect of the dual absence of platform leadership and government regulation on transaction efficiency. At the level of government regulation, the lag in policy supply and insufficient enforcement create a "regulatory vacuum." According to the "Key Points of Power Market Reform in 2025" (Heilongjiang Development and Reform Commission Energy [2025] No. 42), although the provincial electricity spot market started trial operation in 2025, the supporting "Heilongjiang Electricity Spot Transaction Rules" were not officially issued until November 2025, eight months later than the trial operation time, resulting in a lack of clear regulations for the transaction behavior of market participants. Furthermore, the Northeast Regulatory Bureau of the National Energy Administration's Q3 2025 report revealed that the handling rate for complaints regarding electricity generation companies manipulating prices through market power was only 62%, with regulatory response speed 35% slower than the national average. Moreover, a routine market power monitoring mechanism had not been established, creating a vicious cycle of "lagging rules - lax regulation - increased risk of violations by entities."

At the platform leadership level, the triple deficiency in guidance, coordination, and control further weakens market efficiency: The lack of platform guidance manifests as a lack of innovative practices. As of June 2025, Heilongjiang's electricity transaction products were still mainly annual and monthly medium- and long-term contracts, with no innovative businesses such as green electricity transaction and capacity compensation. This lags significantly behind provinces like Gansu and Shandong, which have achieved full-product transaction of "medium- and long-term + spot + ancillary services" during the same period. Insufficient coordination is reflected in the failure of inter-provincial resource integration. The lack of a cross-provincial and cross-regional transaction benefit coordination mechanism has resulted in the inefficient conversion of surplus electricity in the Northeast power grid into transaction resources. The lack of control manifests as a weakened constraint mechanism on market participants. The 2025

annual report of the Heilongjiang power exchange center shows that only a few companies that violated regulations were warned throughout the year, with no cases of forced withdrawal. The coverage rate of performance bonds was insufficient, significantly falling short of the requirements of the National Energy Administration.

The combined effect of these two deficiencies directly leads to low transaction efficiency, forming a closed loop of "unclear regulatory rules—lack of platform innovation—low willingness of participants—shrinking transaction volume—weak efficiency improvement." Therefore, the insufficient development of both platform leadership and government regulation capabilities may become significant factors hindering the improvement of electricity transaction efficiency.

4.7 Robustness test

To test the robustness of the research conclusions, following common practices in QCA research (Greckhamer et al., 2018; Ragin, 2008), this research conducts robustness tests in the following ways: First, robustness is tested by changing the original consistency threshold, adjusting it from 0.8 to 0.85 while keeping other parameters constant. Second, robustness is tested by changing the proportion of inconsistency reduction (PRI), adjusting the PRI threshold from 0.7 to 0.75 while keeping other parameters constant. Third, robustness is tested by changing the calibration, adjusting the calibration reference values for the conditional electricity transaction efficiency for fully affiliated, cross-fuzzy points, and completely non-affiliated entities from (75%, 50%, 25%) quantiles to (80%, 50%, 20%). After the calibration adjustment, the three calibration points for electricity transaction efficiency change to (4.618624337, 4.33015873, 4.163529412). The robustness test results based on the three methods are shown in Tables 4.2, 4.3, and 4.4. Overall, the results in the tables show a clear subset relationship between the configuration results of the robustness test and the original configuration results, or only minor changes in the coefficients. Therefore, the research conclusions are considered reliable.

Table 4.2 Robustness test (original consistency = 0.85)

Conditions	High TE			Non-high TE
	H1a	H1b	H2	L1
Platform Guidance		⊗	•	⊗
Platform Influence	•		•	⊗
Platform Coordination	●	●	●	⊗

Platform Control	•	•	⊗	⊗
Government Regulation	•	•	⊗	⊗
Consistency	0.936	0.974	0.970	0.975
PRI	0.922	0.882	0.854	0.969
Coverage	0.809	0.204	0.120	0.829
Unique coverage	0.639	0.040	0.012	0.829
Solution consistency	0.939			0.975
Solution coverage	0.861			0.829

Table 4.3 Robustness test (PRI=0.75)

Conditions	High TE			Non-high TE
	H1a	H1b	H2	L1
Platform Guidance		⊗	•	⊗
Platform Influence	•		•	⊗
Platform Coordination	●	●	●	⊗
Platform Control	•	•	⊗	⊗
Government Regulation	•	•	⊗	⊗
Consistency	0.936	0.974	0.970	0.975
PRI	0.922	0.882	0.854	0.969
Coverage	0.809	0.204	0.120	0.829
Unique coverage	0.639	0.040	0.012	0.829
Solution consistency	0.939			0.975
Solution coverage	0.861			0.829

Table 4.4 Robustness tests (changing TE calibration)

Conditions	High TE			Non-high TE
	H1a	H1b	H2	L1
Platform Guidance		⊗	•	⊗
Platform Influence	•		•	⊗
Platform Coordination	●	●	●	⊗
Platform Control	•	•	⊗	⊗
Government Regulation	•	•	⊗	⊗
Consistency	0.936	0.991	0.990	0.956
PRI	0.919	0.945	0.923	0.943
Coverage	0.787	0.202	0.119	0.836
Unique coverage	0.619	0.039	0.012	0.836
Solution consistency	0.939			0.956
Solution coverage	0.838			0.836

Furthermore, considering that data on platform leadership, government regulation, and transaction efficiency of electricity transaction platforms are derived from user-level questionnaires, there may be issues of societal expectations or limitations in perspective. For example, a certain group of users' judgments on the transaction efficiency of an electricity transaction platform may be more based on the transaction efficiency of the user company itself

and may not fully represent the platform's overall transaction efficiency in the market. Therefore, this research re-analyzes data collected at the platform level. Data collection was conducted in May 2025, using quota sampling to commission 33 electricity transaction platforms to conduct surveys among managers or frontline employees familiar with transaction operations within the platform companies. The authenticity of the sample was verified by using the IP addresses and company names provided in the questionnaires to avoid duplicate submissions. A total of 222 valid questionnaires were obtained. Among the respondents, 21 were senior managers (9.46%), 26 were middle managers (11.71%), 46 were junior managers (20.72%), and 129 were frontline employees (58.11%). The distribution of questionnaire data across various electricity transaction platforms is shown in Annex A, Table A4.3.

Based on data collected at the platform level, the scores for each variable were derived by averaging the measurement items of the same variable. Simultaneously, the scores for the 33 electricity transaction platforms were averaged based on the evaluations of their employees. Following the same data calibration method as before, the 75th, 50th, and 25th percentiles were used as calibration reference values for complete membership, cross-ambiguity points, and complete non-membership, respectively. The results are shown in Table A4.4 of Annex A.

Subsequently, a full row analysis was conducted based on the same threshold settings (case frequency of 1, original consistency of 0.8, and reduction of inconsistency of 0.7). The nested relationship between intermediate and simplified solutions is illustrated in Table 4.5. The results in the table show that the robustness test results after changing the data source still exhibit a clear subset relationship with the original configuration results, or only minor changes in coefficients. Therefore, the research conclusions are considered robust.

Table 4.5 Robustness tests (changing data sources)

Conditions	High TE			Non-high TE
	H1a	H1b	H2	L1
Platform Guidance		⊗	⊗	⊗
Platform Influence	•		●	⊗
Platform Coordination	●	●	⊗	⊗
Platform Control	●	●	⊗	⊗
Government Regulation	•	•	●	⊗
Consistency	0.907	0.961	0.919	0.958
PRI	0.893	0.873	0.708	0.943
Coverage	0.674	0.206	0.143	0.701
Unique coverage	0.525	0.057	0.040	0.701
Solution consistency		0.913		0.958
Solution coverage		0.771		0.701

4.8 Chapter conclusions

4.8.1 Research conclusions

1) There are three differentiated configuration paths to achieve high electricity transaction efficiency. Research found that in China's provincial electricity transaction markets, high transaction efficiency is mainly achieved through three models: First, the "platform leadership and government regulation collaborative driving model (H1a)," with platform influence, coordination, control, and government regulation as core conditions, achieving a coverage of 0.809 (e.g., Shandong Power Exchange Center), reflecting a dual-drive of "technology empowerment - institutional norms"; second, the "electricity regulation-driven platform leadership quality and efficiency improvement model (H1b)," relying on the coordination and control of regulation and the platform, but lacking leadership, with a coverage of 0.204 (e.g., Tianjin), ensuring efficiency through a complementary mechanism of "regulatory rules setting + platform implementation"; third, the "moderate regulation-incentive improvement model for platform leadership (H2)," with platform influence, coordination, and leadership as core, lacking regulation and control, with a coverage of only 0.120 (the only sample, Hainan), highlighting the logic of "policy relaxation - market activation."

2) Low electricity transaction efficiency mainly stems from the lack of both platform leadership and regulation. The L1 configuration (coverage 0.829) for low-efficiency electricity transaction reveals that 13 provinces, including Xinjiang and Heilongjiang, have formed a vicious cycle of "lagging rules - insufficient innovation - weak market participants" due to low platform influence, coordination, and regulatory deficiencies. For example, the lagging development of the spot market in Heilongjiang and the low proportion of market-based transactions confirm the inhibitory effect of the dual-element deficiency on efficiency.

3) The antecedent configurations of electricity transaction efficiency exhibit an asymmetric causal relationship. The study did not find a single necessary condition, but low platform influence (~PLI) and low coordination (~PLC) are necessary conditions leading to low efficiency (consistency > 0.9). Robustness tests (changing thresholds, calibrating anchor points, among others) further verify that there is no symmetrical relationship between high-efficiency and low-efficiency configuration paths; the same factor may have diametrically opposite effects in different regions. This means that the construction of provincial electricity transaction markets in China needs to be classified and managed according to provincial characteristics; otherwise, inappropriate policy management may lead to inefficient construction.

4.8.2 Research contributions

1) Breaking through the single-factor analysis framework, this study reveals a configurational causal mechanism. Unlike traditional regression analysis's reliance on linear relationships, this study, for the first time, uses the fsQCA method to identify multiple concurrent causal relationships in electricity transaction efficiency, verifying the complexity of "technology-institutional" synergy. For example, the H1a and H2 configurations show that different combinations of regulation and platform leadership can produce equivalent efficiency effects, compensating for the neglect of asymmetric relationships in existing research.

2) Expanding the application boundaries of platform leadership theory in the electricity sector. This study deconstructs platform leadership into four dimensions: influence, guidance, coordination, and control, empirically demonstrating its configurational interaction effect with government regulation. For example, this chapter studies the combination of platform guidance (such as cross-border green electricity transaction innovation) and regulatory decentralization in the Hainan case, providing a new explanation for the application of platform theory in electricity market reform.

3) Providing quantitative basis for differentiated policies in the electricity market. Through empirical analysis covering 33 provincial-level transaction platforms, the applicable scenarios for different configurations were clarified: the platform leadership and government regulation collaborative driving type (H1a) is suitable for provinces with strong platform and regulatory foundations (such as Shandong); the government regulation-driven platform leadership quality and efficiency improvement type (H1b) is suitable for regions with limited platform innovation capabilities but well-established regulation (such as Tianjin); and the platform leadership incentive improvement type under moderate regulation (H2) provides a reference for policy pilot areas (such as Hainan), thus breaking the dilemma of "one-size-fits-all" reform.

4.8.3 Research implications

1) Implementing differentiated combination optimization strategies is the core path to improving electricity transaction efficiency. For provinces configured as H1a, it is necessary to continuously strengthen platform and regulatory collaboration and promote the innovation of the "all-product transaction + green electricity consumption" mechanism; H1b regions should compensate for insufficient platform guidance through regulatory policies (such as ancillary service rules) and focus on improving process standardization; H2 pilot areas need to expand regulatory decentralization and explore the "negative list + innovation tolerance" model; L1

provinces (such as Heilongjiang) need to prioritize improving spot market rules and cross-provincial coordination mechanisms to overcome the bottleneck of dual-system deficiencies.

2) Strengthening the governance of non-essential conditions for high efficiency is key to reform. Addressing the two major bottlenecks of low platform influence and coordination capacity, it is recommended to establish a cross-provincial resource coordination fund (such as regional electricity market linkage) and use a "platform capability rating - regulatory accountability" mechanism to drive improvement. For example, it is necessary to accelerate the construction of the spot market and increase the proportion of market-based transactions to above the national average.

3) Dynamically balancing the "regulatory-platform" relationship is a long-term guarantee. Research indicates that there is no single "optimal model," and collaborative strategies must be dynamically adjusted based on regional endowments. Shandong achieved growth in green electricity transaction volume through "technological innovation + regulatory assessment," while Hainan attracted out-of-province electricity sales companies by relying on "policy relaxation + platform empowerment," demonstrating the collaborative logic of "government setting rules, platforms building ecosystems, and the market competing on innovation." At the same time, future efforts should be wary of "excessive regulation suppressing innovation" or "platforms crossing ethical boundaries," necessitating the construction of a flexible governance framework.

Chapter 5: Analysis of the Effect of Electricity Transaction Efficiency from Platform Leadership Perspective

5.1 Research question statement

In the "platform-user" dual relationship formed between electricity transaction platform enterprises and user enterprises (electricity generation enterprises, electricity sales enterprises, and industrial and commercial users), transaction efficiency is not only a crucial objective for platform enterprises (platform leaders) in building transaction platforms, but also a vital prerequisite for user enterprises to achieve performance targets. In a platform-managed transaction context, the effectiveness of platform leadership determines the overall efficiency of the transaction market, while improvements in market transaction efficiency further drive cost reduction and efficiency improvement for user enterprises, leading to performance enhancement. Therefore, the analysis of the effects of electricity transaction efficiency from the perspective of platform leadership has significant theoretical and practical value.

On the one hand, the core function of platform enterprises in exercising platform leadership lies in reducing market transaction costs through institutional design and technological empowerment (Cusumano et al., 2019). From the perspective of transaction cost theory, information asymmetry, contract negotiation complexity, and performance risks in electricity transaction are the main sources of efficiency losses (S. Q. Huang, 2022). Platforms can drive the standardization of transaction rules (such as unified contract templates and price formation mechanisms) through their leadership, reducing negotiation and information search costs for user companies (Murali et al., 2013); effectively integrate inter-provincial resources through their coordination capabilities (such as inter-provincial transmission channel scheduling and multi-regional market coupling) (F. Wang & Wu, 2016), reducing the additional costs associated with physical transaction barriers; and establish performance guarantee mechanisms (such as credit rating and margin systems) through their control capabilities (R. H. Huang et al., 2010; Mundaca, 2007; Signorini et al., 2015), reducing the post-arbitration costs caused by default risks.

On the other hand, reduced transaction costs can directly translate into improved operational performance for user companies. For example, electricity generation companies can

quickly match load demand through standardized contracts, reducing idle capacity (Z. Chen, 2020). For electricity retailers, increased transparency in platform transaction information can reduce bidding discrepancies and optimize cost structures (Serletis & Bianchi, 2007). For industrial and commercial users, simplified transaction processes can shorten decision-making cycles and improve the flexibility of electricity usage plans (Y. Zhang et al., 2024).

Overall, the platform leadership of electricity transaction platforms in reducing electricity transaction costs and improving transaction efficiency helps to further improve the performance of various user companies. However, although a logical closed loop of "platform leadership level - electricity transaction efficiency - user company performance" exists in theory, existing research often focuses on theoretical discussions and institutional design (Gu, 2022; S. Q. Huang, 2022; Q. S. Shi et al., 2022), rarely involving empirical analysis to verify this important theoretical relationship. Ignoring the analysis of the effects of electricity transaction efficiency from platform leadership perspective hinders the revelation of the platform empowerment mechanism in the electricity transaction market and obscures the participation motivations of electricity user companies. Therefore, building upon the configuration analysis conducted in the preceding sections, this chapter focuses on the sub-research question, "What effect does electricity transaction efficiency have on user enterprises, and what role does platform leadership play in this process?" It analyzes the effect of electricity transaction efficiency from the perspective of platform leadership, aiming to decipher the platform empowerment mechanism of the electricity transaction market and provide empirical reference for constructing a complete electricity transaction efficiency analysis framework in the context of digital platforms. Compared to the previous sections which focused on the analysis at the transaction platform level, this chapter pays more attention to the analysis at the user enterprise level, focusing on how user enterprises can leverage the benefits of platform transaction efficiency to transform them into their own performance advantages, thus promoting their sustainable growth.

5.2 Literature review and research hypotheses

5.2.1 Effect of electricity transaction efficiency

Electricity transaction efficiency is a core indicator for measuring the optimization of resource allocation in the electricity market. Its connotation mainly refers to the synergistic effect of transaction costs, information transmission, and resource allocation (R. H. Huang et al., 2010),

based on the efficient market hypothesis, pointed out that transaction efficiency is a comprehensive result of "the degree to which market prices respond to information, the excess profit rate, and the proportion of transaction costs," among which reducing transaction costs (such as information collection and negotiation/performance costs) is key to efficiency improvement. S. H. Shi et al. (2018) further emphasized through the G-SCP paradigm that transaction efficiency needs to take into account the dynamic balance of "market structure-behavior-performance," that is, optimizing market rules through government intervention (such as entry conditions and regulatory mechanisms), reducing the risk of market power abuse, and achieving the maximization of social welfare and the optimal allocation of resources across regions (Z. Chen, 2020).

From a theoretical perspective, high transaction efficiency can promote the accurate reflection of supply and demand relationships in price signals and reduce efficiency losses caused by information asymmetry (Guo, 2023). Meanwhile, standardized contracts and technological empowerment (such as the decentralized architecture of blockchain) enhance the transparency and fulfillment rate of transaction processes (Q. S. Shi et al., 2022), ultimately driving the evolution of the electricity market from a fragmented state to integration (Yu et al., 2010). Platform-based management of electricity transaction at the provincial level is a crucial manifestation of the integrated reform of the electricity market, and the effective leadership of the platform becomes a vital prerequisite for improving transaction efficiency and ultimately enhancing the performance of user enterprises.

5.2.2 The effect of electricity transaction efficiency from platform leadership perspective

5.2.2.1 Hypothesis regarding the effect of electricity transaction efficiency on user enterprise performance

Improving electricity transaction efficiency can directly enhance user enterprise performance by reducing operating costs and optimizing the decision-making environment. Yu et al. (2010)'s research on vertical transaction shows that high-efficiency transaction can reduce the "vertical dual-track pricing" dilemma caused by information asymmetry, avoid excessive vertical integration, and thus allow enterprises to focus on core technology innovation and specialized production. For electricity generation companies, improved transaction efficiency means more flexible electricity sales channels and price discovery mechanisms, which can reduce the risk of electricity price fluctuations through the synergy of medium- and long-term contracts and the spot market (Zhong, 2024). Electricity sales companies, due to simplified

transaction processes (such as automatic settlement via smart contracts) and increased market competition, need to improve their service differentiation capabilities to obtain excess profits (S. H. Shi et al., 2018). Industrial and commercial users, as the demand side, can achieve diversified electricity purchase options through efficient transaction platforms, reducing unit electricity purchase costs and optimizing electricity usage plans (R. H. Huang et al., 2010). Furthermore, improved transaction efficiency can alleviate market segmentation caused by administrative monopolies or regional barriers, prompting enterprises to enhance their comprehensive competitiveness through cross-provincial resource integration and technology spillover (Guo, 2023).

Therefore, this chapter proposes research hypothesis H1: Electricity transaction efficiency has a positive effect on user enterprise performance.

5.2.2.2 Hypothesis regarding the moderating effect of platform leadership on the relationship between electricity transaction efficiency and user enterprise performance

1) Hypothesis on the moderating role of platform guidance in the relationship between electricity transaction efficiency and user enterprise performance

Platform guidance manifests as the influence of platform enterprises in the platform market in terms of strategic control, responsiveness, and member followership (Gawer, 2000; Gawer & Cusumano, 2008). Specifically, strategic control, through standardized transaction rules (such as unified contract templates) and goal coordination (such as green electricity transaction guidance), reduces institutional losses in the efficiency improvement process, ensuring that cost savings for electricity generation companies, electricity sales companies, and users are directly translated into performance improvements (Guo, 2023; Q. S. Shi et al., 2022). Responsiveness, through dynamic rule adjustments (policy adaptation reforms) and risk tool innovation (diversified derivative design), enhances the stability of transaction efficiency under shocks such as electricity price fluctuations and policy changes, ensuring that efficiency dividends continuously adapt to enterprise needs (Z. Chen, 2020; Zhong, 2024). Member follow-up capabilities rely on trust mechanisms (credit rating systems) and value sharing (such as cross-regional revenue sharing) to drive user companies to transform efficiency improvements into collaborative innovation (such as virtual power plant aggregation), amplifying performance improvements through network effects (R. H. Huang et al., 2010; S. H. Shi et al., 2018). These three elements synergistically form a regulatory chain of “rule standardization - dynamic adaptation - network diffusion,” upgrading transaction efficiency improvements from simple cost savings to value co-creation.

Based on this, this chapter proposes research hypothesis H2a: The stronger the platform guidance of the electricity transaction platform, the more significant the positive effect of transaction efficiency on user company performance.

2) Hypothesis regarding the moderating effect of platform influence on the relationship between electricity transaction efficiency and user enterprise performance

Platform influence is manifested in the platform enterprise's ability to influence the platform market in terms of status and prestige, leading by example, and goal achievement (Gawer & Cusumano, 2014; M. Luo & Du, 2018). Platform influence strengthens the conversion efficiency of transaction efficiency into corporate performance through three pathways: the trust endorsement of status and prestige, the behavioral guidance of leading by example, and the resource aggregation of goal achievement. Specifically, status and prestige stem from the platform's authoritative position as a market rule-maker and resource hub (such as the administrative endorsement and industry credibility of power exchange centers), which can reduce information asymmetry and opportunistic behavior among user enterprises, making it easier for improved transaction efficiency (optimized price signals, improved contract fulfillment rates) to translate into increased market share for electricity generation enterprises, enhanced user trust for electricity sales enterprises, and cost savings for industrial and commercial users (Z. Chen, 2020). Leading by example is reflected in the platform's establishment of industry benchmarks through technological innovation (such as blockchain transaction systems) and model exploration (such as green electricity transaction zones), guiding user enterprises to imitate efficient transaction behaviors and promoting the evolution of efficiency improvement from individual optimization to group collaboration (Guo, 2023). Achieving these goals relies on the platform's ability to coordinate market objectives (such as cross-provincial electricity consumption and increased renewable energy share), aggregating dispersed generation and consumption resources. This deeply couples improved transaction efficiency with corporate strategic needs (such as clean energy consumption for electricity generation companies and low-carbon transformation for users), transforming efficiency dividends into differentiated competitive advantages through optimized resource allocation (Zhong, 2024). These three elements synergistically construct a regulatory chain: "trust reduces conversion resistance—demonstration accelerates efficiency diffusion—goals focus on value orientation."

Based on this, this chapter proposes research hypothesis H2b: the stronger the electricity transaction platform's influence, the more significant the positive effect of transaction efficiency on user enterprise performance.

3) Hypothesis regarding the moderating effect of platform influence on the relationship between electricity transaction efficiency and user enterprise performance

Platform coordination capability manifests as the influence of platform enterprises in the platform market in terms of task coordination, relationship coordination, and goal promotion (Y. Zhang, 2019). Platform coordination capability strengthens the conversion efficiency of transaction efficiency into enterprise performance through three pathways: the resource integration effect of task coordination, the conflict resolution function of relationship coordination, and the synergistic evolution mechanism of goal promotion. Specifically, task coordination capability relies on the platform's overall allocation of physical and virtual resources, such as cross-regional electricity transmission channel scheduling and multi-market product coupling (Z. Chen, 2020), which can eliminate the spatiotemporal mismatch between the generation and consumption sides. This allows improvements in transaction efficiency (such as cross-regional optimal allocation of electricity resources) to directly translate into increased capacity utilization of electricity generation enterprises, stable electricity purchase and sales price differences for electricity retailers, and enhanced electricity supply reliability for industrial and commercial users. Relationship coordination capabilities, through the construction of benefit distribution mechanisms (such as revenue sharing in inter-provincial transactions) and negotiation platforms (such as electricity generation-sales price linkage negotiations), resolve conflicts of interest among market participants (R. H. Huang et al., 2010), reduce efficiency losses caused by game theory, and ensure that improvements in transaction efficiency (such as improved contract fulfillment rates) are effectively translated into cooperative stability and cost savings for user enterprises. Goal-driven capabilities, by guiding diverse stakeholders to focus on common goals (such as renewable energy consumption and peak-valley load regulation), promote the formation of a collaborative chain among electricity generation companies, sales companies, and users— "peak regulation on the generation side - package design on the sales side - demand response on the user side" (Guo, 2023)—upgrading transaction efficiency improvements from single-link optimization to full-chain value improvement.

Based on this, this chapter proposes the research hypothesis H2c: the stronger the platform coordination capability of the electricity transaction platform, the more significant the positive effect of transaction efficiency on the performance of user enterprises.

4) Hypothesis regarding the moderating effect of platform control on the relationship between electricity transaction efficiency and user enterprise performance

Platform control manifests as the influence exerted by platform enterprises in the platform

market through behavioral control, business control, and methodological control (Cusumano et al., 2019; Gawer & Cusumano, 2008). Platform control strengthens the conversion efficiency of transaction efficiency into corporate performance through three pathways: the compliance constraint effect of behavioral control, the process optimization function of business control, and the technical regulatory mechanism of methodological control. Specifically, behavioral control, relying on regulatory tools such as credit rating and penalties for violations (e.g., qualification review of electricity sales companies and performance bond system for electricity generation companies), can reduce opportunistic behavior of market participants (Signorini et al., 2015), directly translating improved transaction efficiency (e.g., higher contract fulfillment rates and enhanced price signal authenticity) into operational stability for user companies. Business control, through standardized transaction processes (e.g., unified settlement cycles and electronic transaction platforms) and risk hedging mechanisms (e.g., linkage between spot markets and ancillary service markets), reduces friction costs in the transaction process (Tai et al., 2017), ensuring that efficiency improvements for electricity generation companies, electricity sales companies, and users (e.g., shorter transaction times and cost savings) are effectively translated into performance gains. Method control, through technical standard regulations (blockchain data storage and automatic execution of smart contracts) and data security management, ensures the authenticity and confidentiality of transaction information (Gu, 2022; Y. Zhang et al., 2024), enhancing user companies' trust in improved transaction efficiency and encouraging them to transform efficiency dividends into long-term investments. These three elements work together to construct a regulatory chain of "compliance assurance—process cost reduction—technology empowerment."

Based on this, this chapter proposes the research hypothesis H2d: the stronger the platform control of the electricity transaction platform, the more significant the positive effect of transaction efficiency on user enterprise performance.

5.3 Research method

The empirical model studied in this chapter is shown in Figure 5.1. Unlike the previous sections which focused on the analysis of transaction platform levels, this chapter emphasizes revealing the causes of performance differences among user firms under different configurations (examining the main effects of four platform leadership types and the moderating effects of high/low transaction efficiency configurations, while controlling for other factors). In terms of analytical approach, compared to the more complex "configuration effect" of transaction

platforms, the analysis at the user firm level focuses on revealing the "net effect" of key factors, striving to clarify the effect of transaction efficiency and its applicability boundaries under different platform leadership roles (platform leadership). In the specific analysis, first, it explains whether there are significant differences in firm performance across different configurations due to platform leadership leading to transaction efficiency (by conducting an independent samples t-test between the performance of user firms in the high transaction efficiency configuration and those in the low transaction efficiency configuration). Kurtosis and skewness analysis of the sample data are used to determine whether the data conforms to a normal distribution, thus determining whether an independent samples t-test can be conducted, and conducting the independent samples t-test while satisfying the normality assumption. Second, based on multiple regression analysis, the direct effect of electricity transaction efficiency on user enterprise performance is tested to verify whether electricity transaction efficiency significantly and positively affects user enterprise performance. Finally, a moderating effect model is further used to analyze whether a significant moderating effect exists, analyze the level of the moderating effect, and reveal the performance improvement path and key boundary conditions of electricity transaction platforms empowering user firms.

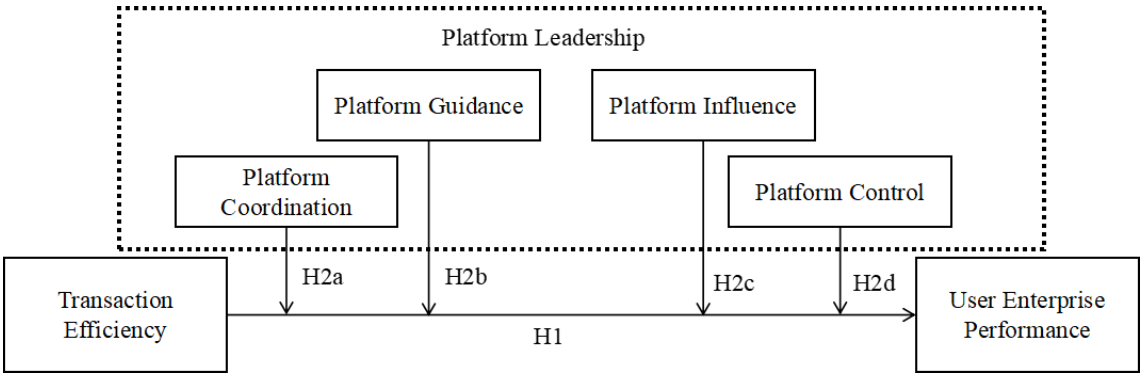


Figure 5.1 Empirical model of the study

Based on the methodology and key variable relationships, this study constructs two analytical models to verify the hypothesized relationships between the relevant variables. Specifically, Model (1) examines the main effect of transaction efficiency, and Model (2) tests the moderating effect of platform leadership.

$$PEF_i = \beta_0 + \beta_1 TE_i + \beta_2 UET_i + \beta_3 UES_i + \beta_4 UIA_i + \beta_5 GR_i + \beta_6 UMH_i + \varepsilon_i \quad (1)$$

$$PEF_i = \beta_0 + \beta_1 TE_i + \beta_2 PL_{i,j} + \beta_{3j} PL_{i,j} \times TE_i + \beta_4 UET_i + \beta_5 UES_i + \beta_6 UIA_i + \beta_7 GR_i + \beta_8 UMH_i + \varepsilon_i \quad (2)$$

In these models, $PL_{i,j}$ denotes the j-th type of platform leadership for sample i, where j=1,2,3,4. When j=1, $PL_{i,1}$ represents platform guidance (PLG); when j=2, $PL_{i,2}$ represents platform influence (PLI); when j=3, $PL_{i,3}$ represents platform coordination (PLC); when j=4,

$PL_{i,4}$ represents platform control (PLT).

5.4 Variable selection and measurement

Dependent Variable: User Enterprise Performance (PEF). Following the research of H. Y. Li and Atuahene-Gima (2001), this variable is measured by five items: firm profit, return on investment, market share, market growth rate, and performance exceeding the overall industry performance. A 5-point Likert scale is used, with scores from 1 to 5 representing the highest level of compliance. In this study, the Cronbach's α value of this scale is 0.946.

Independent Variable: Electricity Transaction Efficiency (TE). Following the research of Williamson (1979), Long et al. (2012), Duan and Wang (2018), this variable is reflected by questionnaire items on asset specificity, transaction frequency, and uncertainty. Dimensionless processing is then used to transform these into positive indicators. Asset specificity includes site specificity (e.g., a supplier setting up a factory near a customer), physical asset specificity (e.g., specialized equipment purchased to provide services to a specific customer), human asset specificity (e.g., proprietary knowledge and know-how), and dedicated assets (e.g., customizing body molds for an automaker). Higher asset specificity leads to higher transaction costs. Transaction frequency primarily reflects the quantity of goods exchanged, and can be measured by the frequency of collaborative projects, intellectual property transactions, and technical assistance between the transacting parties. Higher transaction frequency results in higher transaction costs. Uncertainty includes environmental uncertainty and behavioral uncertainty; the higher the degree of uncertainty, the weaker the binding force of the transaction contract on potential opportunistic behavior. In this study, the Cronbach's α value for this scale was 0.974.

Moderging variable: Platform leadership, including Platform Guidance (PLG), Platform Influence (PLI), Platform Coordination (PLC), and Platform Control (PLT). Drawing on the research of Y. Zhang (2019) and Y. Zhang et al. (2020), this study comprises 12 items related to platform guidance, platform influence, platform coordination, and platform control. Specifically, platform guidance includes items on strategic control, adaptability, and member followership; platform influence includes items on status and prestige, leading by example, and goal achievement; platform coordination includes items on task coordination, relationship coordination, and goal promotion; and platform control includes items on behavioral control, business control, and methodological control. Based on the preceding analysis, the Cronbach's α value for the platform leadership scale in this study is 0.984, and the Cronbach's α values for platform guidance, platform influence, platform coordination, and platform control are 0.942,

0.951, 0.955, and 0.932, respectively.

Control Variables. Considering the analytical context of a digital platform, this chapter primarily considers the following control variables:

1) User Enterprise Type (UET), used to distinguish whether the user enterprise belongs to an electricity generation enterprise, an electricity sales enterprise, or an industrial and commercial user. 2) User Enterprise Size (UES): Differentiates user enterprise size based on the number of employees.

3) User Enterprise Age (UIA): Used to differentiate between enterprises with different tenures.

4) Government Regulation (GR): As an important exogenous variable, used to differentiate differences in government regulation at the provincial level.

5) User Multi-Homing (UMH): Used to differentiate whether a user enterprise chooses a single affiliation (joining only one electricity transaction platform) or multiple affiliations (joining two or more electricity transaction platforms).

5.5 Data collection

The core data collection in this study was primarily achieved through the distribution of electronic questionnaires. The data survey adhered to the basic principle of quota sampling (i.e., through user-level surveys, each of the 33 provincial electricity transaction platforms involved in China distributed at least five questionnaires to electricity generation companies, electricity sales companies, and industrial and commercial users). Leveraging the author's professional network, the 33 provincial electricity transaction platforms were commissioned to randomly send questionnaire invitations to electricity generation companies, electricity sales companies, and industrial and commercial users within their platforms. The core period for distributing and collecting questionnaires was from March to May, 2025. After removing invalid questionnaires, a total of 737 valid questionnaires at the platform user level were obtained.

5.6 Data analysis

5.6.1 Independent samples T-test of user enterprise performance of electricity transaction platform under high and low configurations

5.6.1.1 Data filtering and grouping

Since this chapter continues the configuration analysis approach from the previous section to examine the effects of electricity transaction efficiency and efficiency, it is necessary to screen and group the configuration analysis samples based on the 737 questionnaires from 33 electricity transaction platforms obtained in the previous survey before conducting formal data analysis. First, based on the high and low configuration samples identified in the previous fsQCA analysis, 17 platforms (involving 3 configurations) matching the leadership configuration corresponding to high electricity transaction efficiency were selected, along with 13 platform samples (involving 1 configuration) matching the leadership configuration corresponding to low electricity transaction efficiency. The distribution of high and low platform samples is shown in Table 5.1. Second, based on the classification of the high and low electricity transaction efficiency platform samples, the questionnaire data belonging to the 17 high electricity transaction efficiency platforms were assigned a value of 1 (group 1), and the questionnaire data belonging to the 13 low electricity transaction efficiency platforms were assigned a value of 0 (group 2). Finally, 683 questionnaire samples were retained from both groups.

Table 5.1 Data grouping based on configuration analysis

Configuration type	Platform samples involved	Antecedents and result membership	Platform samples involved	Antecedents and result membership
High electricity transaction efficiency corresponds to platform leadership configuration	Shandong	(1,1)	Shanghai	(0.87,0.95)
	Hunan	(1,1)	Sichuan	(0.83,0.05)
	Northern Hebei	(0.99,0.98)	Henan	(0.81,0.97)
	Hubei	(0.98,1)	Jilin	(0.64,0.77)
	Hebei	(0.96,0.99)	Eastern Inner Mongolia	(0.501,0.52)
	Shanxi	(0.95,0.95)	Tianjin	(0.55,0.89)
	Qinghai	(0.95,0.9)	Jiangxi	(0.501,0.64)
	Ningxia	(0.95,0.99)	Hainan	(0.501,0.78)
	Tibet	(0.93,0.98)		
Low electricity transaction efficiency corresponds to platform	Xinjiang	(1,1)	Chongqing	(0.9,0.91)
	Kunming	(1,1)	Guangdong	(0.88,0.93)
	Guizhou	(1,1)	Guangxi	(0.86,0.99)
	Zhejiang	(0.99,0.99)	Shaanxi	(0.85,0.99)
	Anhui	(0.99,0.99)	Jiangsu	(0.84,0.77)
	Fujian	(0.93,0.93)	Heilongjiang	(0.65,0.77)

leadership configuration (group 2)	Gansu	(0.91,1)

Configuration type, platform samples involved, antecedents and result membership, platform samples involved, antecedents and result membership.

5.6.1.2 Normality test of data

Descriptive statistics were performed on 683 questionnaires regarding the efficiency of high and low electricity transaction, and the results are shown in Table 5.2. Combining the descriptive statistics results, the absolute values of skewness for all variables are less than 2, and the absolute values of kurtosis are less than 8, indicating that the sample data follows a normal distribution (Byrne & Van De Vijver, 2010), and an independent samples t-test can be performed.

Table 5.2 Normality test of data

	Minimum	Maximum	Mean	Standard Deviation	Skewness		Kurtosis	
					Statistics	Standard Error	Statistics	Standard Error
PLG	1.000	5.000	4.419	0.852	-1.955	0.094	4.439	0.187
PLI	1.000	5.000	4.416	0.858	-2.041	0.094	4.862	0.187
PLC	1.000	5.000	4.429	0.834	-2.022	0.094	4.889	0.187
PLT	1.000	5.000	4.421	0.817	-2.080	0.094	5.469	0.187
GR	1.000	5.000	4.445	0.785	-2.139	0.094	5.914	0.187
TE	1.000	5.000	4.347	0.815	-1.791	0.094	4.272	0.187
PEF	1.000	5.000	4.275	0.859	-1.344	0.094	2.038	0.187

5.6.1.3 Independent samples T-test

The results of the independent samples t-test conducted using SPSS 25.0 software are shown in Table A5.1 of Annex A. The table shows that the independent samples t-test investigated the differences in PEF between high and low electricity transaction efficiency configurations (group 1 and group 2). The table indicates that all groups showed significant differences in PEF ($p < 0.01$), meaning there were significant differences in PEF between the different groups. Specifically, the high and low configuration groups showed significant differences in PEF at the 0.01 level ($t = 5.630$, $p = 0.000$), and the average value of the high electricity transaction efficiency configuration group (4.48) was significantly higher than that of the low electricity transaction efficiency configuration group (4.02). Therefore, it can be concluded that all electricity transaction efficiency configuration groups showed significant differences in PEF, and the differences in electricity transaction efficiency configuration from the platform leadership perspective constitute an important variable explaining user enterprise performance.

5.6.2 Analysis of the effect interaction between transaction efficiency and user enterprise performance

Based on the grouped data, the benchmark regression analysis results of transaction efficiency on user enterprise performance are shown in Table 5.3. The VIF values of all variables in the table are below 10, indicating that the model does not have a serious multicollinearity problem. Meanwhile, the D-W ratio is close to 2, indicating that the model specification does not have a serious autocorrelation problem. From the benchmark regression results, after controlling for variables such as user enterprise type, transaction efficiency and user enterprise performance show a significant positive correlation (B=0.889***, p<0.001). Therefore, research hypothesis H1 holds.

Table 5.3 Benchmark regression analysis

	Unstandardized coefficients		Standardized coefficients	t	p	Collinearity diagnosis	
	B	Standard error	Beta			VIF	Tolerance
Constant	0.700	0.133	-	5.265	0.000	-	-
TE	0.889***	0.050	0.844	17.650	0.000	5.789	0.173
UET	-0.008	0.022	-0.007	-0.364	0.716	1.049	0.953
UES	-0.086***	0.024	-0.095	-3.572	0.000	1.781	0.561
UIA	-0.011	0.018	-0.016	-0.595	0.552	1.768	0.566
GR	-0.024	0.052	-0.022	-0.451	0.652	5.748	0.174
UMH	0.058	0.037	0.032	1.586	0.113	1.015	0.985
R2				0.733			
Adjust R^2				0.731			
F				F (6,676)=309.122***, p=0.000			
D-W value				1.874			

Note: Dependent variable = PEF; * p < 0.05, ** p < 0.01, *** p < 0.001.

5.6.3 Analysis of the moderating effect of platform leadership on the effect of electricity transaction efficiency on user enterprise performance

The preceding analysis revealed that configurational differences in electricity transaction efficiency from a platform leadership perspective constitute a significant variable explaining user firm performance. However, this is insufficient to clearly reveal two issues: first, does different transaction efficiency all have a significant performance-improving effect on user firms? Second, what moderating effect do high and low platform leadership configurations play on the effect of transaction efficiency on user firm performance?

Therefore, this research uses the SPSS PROCESS project (Hayes, 2013) method for verification, and plots the moderating interaction diagrams (Aiken & West, 1991) at high (mean + 1 standard deviation) and low (mean + 1 standard deviation) levels of platform leadership

(including platform guidance, platform influence, platform coordination, and platform control) using a simple slope method. This verifies the main effect of transaction efficiency on user firm performance and the moderating effects of the four platform leadership types.

In model specification, in addition to the independent variable (TE), dependent variable (PEF), and moderating variables (PLG, PLI, PLC, PLT), the influence of platform-level factors and user firm-level factors on the results also needs to be considered. To this end, User Enterprise Type (UET), User Enterprise Size (UES), User Enterprise Age (UIA), government regulation (GR), and user affiliation (UMH) were added as control variables to exclude the influence of related factors. The main effect of transaction efficiency on user firm performance and the moderating effect of the four platform leadership strategies are analyzed as follows.

5.6.3.1 Analysis of the moderating effect of platform guidance on the effect of electricity transaction efficiency on user enterprise performance

The effect of Transaction efficiency (TE) on User Enterprise Performance (PEF) and the moderating effect of Platform Guidance (PLG) on this relationship are shown in Table 5.4. The regression analysis results in the table show that transaction efficiency positively affects User Enterprise Performance (PEF) (Model 1: B=0.889***, p<0.001), indicating that transaction efficiency can significantly improve the performance of user firms on the electricity transaction platform. Meanwhile, the interaction term between platform guidance and transaction efficiency has a significant positive effect on user firm performance (Model 3: B=0.066***, p<0.001), indicating that platform leadership actively moderates the positive correlation between transaction efficiency and user firm performance. Further, a simple slope analysis is used to present the moderating effect of platform guidance, as shown in the figure. As shown in Figure A5.1 of Annex A, when the electricity transaction platform exhibits low platform leadership (below the mean+1 standard deviation) in configuration type, the positive effect of transaction efficiency on user firm performance is weak (B=0.847***, p<0.001); when the electricity transaction platform exhibits high platform leadership (above the mean+1 standard deviation) in configuration type, the positive effect of transaction efficiency on user firm performance becomes stronger (B=0.959***, p<0.001). Therefore, platform guidance actively moderates the positive correlation between transaction efficiency and user firm performance, and hypothesis H2a holds.

Table 5.4 Regression analysis results of the platform guidance moderating effect

Variable	Model 1		Model 2		Model 3	
	B	SE	B	SE	B	SE
Constant	4.565***	0.250	4.628***	0.278	4.394***	0.279
UET	-0.008	0.022	-0.009	0.022	-0.008	0.021
UES	-0.086***	0.024	-0.085***	0.024	-0.083***	0.024
UIA	-0.011	0.018	-0.011	0.018	-0.008	0.018
GR	-0.024	0.052	-0.038	0.059	0.003	0.059
UMH	0.058	0.037	0.059	0.037	0.056	0.036
TE	0.889***	0.050	0.883***	0.052	0.903***	0.051
PLG			0.022	0.042	0.064	0.042
PLG*TE					0.066***	0.015
R^2	0.733		0.733		0.741	
Adjust R^2	0.731		0.730		0.738	
F value	309.122***		264.715***		240.888***	
$\triangle R^2$	0.733		0.000		0.008	
$\triangle$F value	309.122***		0.272		20.518***	

Note: N=683; dependent variable is user enterprise performance (PEF); * p<0.05, ** p<0.01, *** p<0.001.

5.6.3.2 Analysis of the moderating effect of platform influence on the effect of electricity transaction efficiency on user enterprise performance

Table 5.5 shows the effect of transaction efficiency (TE) on user enterprise performance (PEF) and the moderating effect of platform influence (PLI) on this relationship. The regression analysis results in the table show that transaction efficiency positively affects user firm performance (Model 1: B=0.889***, p<0.001), indicating that transaction efficiency can significantly improve the performance of user firms on the electricity transaction platform. Meanwhile, the interaction term between platform influence and transaction efficiency has a significant positive effect on user firm performance (Model 3: B=0.061***, p<0.001), indicating that platform influence actively moderates the positive correlation between transaction efficiency and user firm performance. Further, a simple slope analysis is used to present the moderating effect of platform influence, as shown in the figure. As shown in Figure A5.2 of Annex A, when the electricity transaction platform exhibits low platform influence (below the mean + 1 standard deviation) in configuration type, the positive effect of transaction efficiency on user firm performance is weak (B=0.864***, p<0.001); when the electricity transaction platform exhibits high platform influence (above the mean + 1 standard deviation) in configuration type, the positive effect of transaction efficiency on user firm performance becomes stronger (B=0.969***, p<0.001). Therefore, platform influence actively moderates the positive correlation between transaction efficiency and user firm performance, and hypothesis H2b holds.

Table 5.5 Regression analysis results of the platform influence moderating effect

Variable	Model 1		Model 2		Model 3	
	B	SE	B	SE	B	SE
Constant	4.565***	0.250	4.432***	0.291	4.202***	0.293
UET	-0.008	0.022	-0.006	0.022	-0.006	0.021
UES	-0.086***	0.024	-0.087***	0.024	-0.085***	0.024
UIA	-0.011	0.018	-0.011	0.018	-0.008	0.018
GR	-0.024	0.052	0.006	0.062	0.047	0.062
UMH	0.058	0.037	0.057	0.037	0.056	0.036
TE	0.889***	0.050	0.899***	0.052	0.916***	0.051
PLI			-0.041	0.046	0.002	0.046
PLI*TE					0.061***	0.014
R^2	0.733		0.733		0.740	
Adjust R^2	0.731		0.730		0.737	
F value	309.122***		264.988***		239.885***	
$\triangle R^2$	0.733		0.000		0.007	
$\triangle$F value	309.122***		0.782		17.853***	

Note: N=683; dependent variable is user enterprise performance (PEF); * p<0.05, ** p<0.01, *** p<0.001.

5.6.3.3 Analysis of the moderating effect of platform coordination on the effect of electricity transaction efficiency on user enterprise performance

The effect of transaction efficiency (TE) on user enterprise performance (PEF) and the moderating effect of platform coordination (PLC) on this relationship are shown in Table 5.6. The regression analysis results in the table show that transaction efficiency positively affects user firm performance (Model 1: B=0.889***, p<0.001), indicating that transaction efficiency can significantly improve the performance of user firms on the electricity transaction platform. Meanwhile, the interaction term between platform coordination and transaction efficiency has a significant positive effect on user firm performance (Model 3: B=0.068***, p<0.001), indicating that platform coordination actively moderates the positive correlation between transaction efficiency and user firm performance. Further, a simple slope analysis is used to present the moderating effect of platform coordination, as shown in the figure. As shown in Figure A5.3 of Annex A, when the electricity transaction platform exhibits low platform coordination (below the mean + 1 standard deviation) in configuration type, the positive effect of transaction efficiency on user enterprise performance is weak (B = 0.839***, p < 0.001); when the electricity transaction platform exhibits high platform coordination (above the mean + 1 standard deviation) in configuration type, the positive effect of transaction efficiency on user enterprise performance becomes stronger (B=0.951***, p<0.001). Therefore, platform coordination actively moderates the positive correlation between transaction efficiency and user enterprise performance, and the research hypothesis H2c holds.

Table 5.6 Regression analysis results of the platform coordination moderating effect

Variable	Model 1		Model 2		Model 3	
	B	SE	B	SE	B	SE
Constant	4.565***	0.250	4.690***	0.293	4.466***	0.293
UET	-0.008	0.022	-0.009	0.022	-0.009	0.021
UES	-0.086***	0.024	-0.085***	0.024	-0.083**	0.024
UIA	-0.011	0.018	-0.011	0.018	-0.007	0.018
GR	-0.024	0.052	-0.052	0.063	-0.013	0.062
UMH	0.058	0.037	0.058	0.037	0.055	0.036
TE	0.889***	0.050	0.877***	0.052	0.895***	0.052
PLC			0.041	0.051	0.095	0.051
PLC*TE					0.068***	0.015
R^2	0.733		0.733		0.741	
Adjust R^2	0.731		0.730		0.738	
F value	309.122***		264.920***		241.233***	
$\triangle R^2$	0.733		0.000		0.008	
$\triangle$F value	309.122***		0.655		20.861***	

Note: N=683; dependent variable is user enterprise performance (PEF); * p<0.05, ** p<0.01, *** p<0.001.

5.6.3.4 Analysis of the moderating effect of platform control on the effect of electricity transaction efficiency on user enterprise performance

Table 5.7 shows the effect of transaction efficiency (TE) on user enterprise performance (PEF) and the moderating effect of platform control (PLT) on this relationship. The regression analysis results in the table show that transaction efficiency positively affects user firm performance (Model 1: B=0.889***, p<0.001), indicating that transaction efficiency can significantly improve the performance of user firms on the electricity transaction platform. Meanwhile, the interaction term between platform control and transaction efficiency has a significant positive effect on user firm performance (Model 3: B=0.066***, p<0.001), indicating that platform control actively moderates the positive correlation between transaction efficiency and user firm performance. Further, a simple slope analysis is used to present the moderating effect of platform control, as shown in the figure. As shown in Figure A5.4 of Annex A, when the electricity transaction platform exhibits low platform control (below the mean + 1 standard deviation) in configuration type, the positive effect of transaction efficiency on user firm performance is weak (B=0.858***, p<0.001); when the electricity transaction platform exhibits high platform control (above the mean + 1 standard deviation) in configuration type, the positive effect of transaction efficiency on user firm performance becomes stronger (B=0.965***, p<0.001). Therefore, platform control actively moderates the positive correlation between transaction efficiency and user firm performance, and the research hypothesis H2d holds.

Table 5.7 Regression analysis results of the platform control force modulation effect

Variable	Model 1		Model 2		Model 3	
	B	SE	B	SE	B	SE
Constant	4.565***	0.250	4.498***	0.317	4.301***	0.316
UET	-0.008	0.022	-0.007	0.022	-0.006	0.021
UES	-0.086***	0.024	-0.086***	0.024	-0.083**	0.024
UIA	-0.011	0.018	-0.011	0.018	-0.008	0.018
GR	-0.024	0.052	-0.008	0.069	0.023	0.068
UMH	0.058	0.037	0.058	0.037	0.057	0.036
TE	0.889***	0.050	0.893***	0.052	0.911***	0.051
PLT			-0.019	0.057	0.039	0.057
PLT*TE					0.066***	0.014
R^2	0.733		0.733		0.741	
Adjust R^2	0.731		0.730		0.738	
F value	309.122***		264.632***		240.855***	
$\triangle R^2$	0.733		0.000		0.008	
$\triangle$F value	309.122***		0.116		20.608***	

Note: N=683; dependent variable is user enterprise performance (PEF); * p<0.05, ** p<0.01, *** p<0.001.

5.7 Robustness test

Considering that other important factors may influence the results of the pre-set empirical model, this study uses the addition of control variables to test robustness. Specifically, in the current era of vigorous development of the digital economy, the digital transformation process driven by digital technology may have a significant impact on optimizing corporate operating processes and transforming innovative concepts, thereby improving corporate performance. Therefore, in the robustness test, digital transformation (DIG) is included as a control variable in the model while maintaining other variables set in the original model. For the outcome, user enterprise performance (PEF), the analysis results of the independent variable Transaction Efficiency (TE) and the moderating variables Platform Guidance (PLG), Platform Influence (PLI), Platform Coordination (PLC), and Platform Control (PLT) are shown in the table and figure below. The results show that transaction efficiency still has a significant positive effect on user firm performance (B=0.646***, p<0.001). Meanwhile, digital transformation also has a significant positive effect on user firm performance (B=0.517***, p<0.001).

Based on transaction efficiency, the moderating variable, platform leadership, also showed a significant positive moderating effect on the positive correlation between transaction efficiency and user firm performance. Specifically, when the electricity transaction platform exhibited low platform guidance (below the mean + 1 standard deviation) in configuration type, the positive effect of transaction efficiency on user firm performance was weak (B=0.614***, p<0.001); when the electricity transaction platform exhibited high platform guidance (above

the mean + 1 standard deviation) in configuration type, the positive effect of transaction efficiency on user firm performance was more significant (B=0.737***, p<0.001).

Regarding platform influence, when the electricity transaction platform exhibits low platform influence (below the mean + 1 standard deviation) in configuration type, the positive effect of transaction efficiency on user enterprise performance is weak (B=0.620***, p<0.001); when the electricity transaction platform exhibits high platform influence (above the mean + 1 standard deviation) in configuration type, the positive effect of transaction efficiency on user enterprise performance is more significant (B=0.737***, p<0.001).

Regarding platform coordination, when the electricity transaction platform exhibits low platform coordination (below the mean + 1 standard deviation) in configuration type, the positive effect of transaction efficiency on user enterprise performance is weak (B= 0.610***, p<0.001); when the electricity transaction platform exhibits high platform coordination (above the mean + 1 standard deviation) in configuration type, the positive effect of transaction efficiency on user enterprise performance is more significant (B= 0.727***, p<0.001).

Regarding platform control, when the electricity transaction platform exhibits low platform control (below the mean + 1 standard deviation) in configuration type, the positive effect of transaction efficiency on user firm performance is weak (B=0.622***, p<0.001); when the electricity transaction platform exhibits high platform control (above the mean + 1 standard deviation) in configuration type, the positive effect of transaction efficiency on user firm performance is more significant (B=0.732***, p<0.001).

In summary, the above analysis shows that after adding the control variable Digital Transformation (DIG), the positive effect of transaction efficiency on user enterprise performance (PEF) and the positive moderating effect of the four platform leadership types (platform guidance, platform influence, platform coordination, and platform control) on this relationship remain unchanged. Therefore, the conclusions of this study are considered reliable. Robustness test data and graphs for the moderating effects of platform guidance, platform influence, platform coordination, and platform control are shown in Annex A, Tables A5.2 to A5.5, and Figures A5.5 to A5.8, respectively.

5.8 Research conclusion of this chapter

5.8.1 Research conclusions

1) Electricity transaction efficiency has a significant positive effect on user enterprise

performance. Independent samples t-tests show that user enterprise performance under high electricity transaction efficiency configuration (mean 4.48) is significantly higher than that under low efficiency configuration (mean 4.02). Benchmark regression further confirms this, finding that for every 1 unit increase in transaction efficiency, user enterprise performance improves by an average of 0.889 units. This indicates that the advantages of electricity transaction efficiency in reducing transaction costs and optimizing resource allocation can be directly translated into an intrinsic driving force for profit growth and operational optimization for electricity generation companies, electricity sales companies, and industrial and commercial users, verifying the theoretical logic that "transaction efficiency is the core prerequisite for improving user enterprise performance."

2) All four dimensions of platform leadership positively moderate the relationship between transaction efficiency and user enterprise performance. Moderating effect analysis shows that enhancements in platform leadership (platform guidance, platform influence, platform coordination, and platform control) significantly amplify the positive effect of transaction efficiency on user enterprise performance, with coordination showing the strongest moderating effect. This indicates that platforms, through mechanisms such as strategic control, resource integration, and compliance supervision, can reduce institutional losses in the conversion of efficiency dividends, forming a closed-loop transmission path of "transaction efficiency - corporate performance" driven by high platform leadership.

3) Differences in transaction efficiency configurations constitute a key explanatory variable for the differentiation of user enterprise performance. High-efficiency electricity transaction configurations (17 platforms) achieve optimal performance through the synergistic configuration of "leadership + coordination + control," while low-efficiency configurations (13 platforms) fall into a predicament of "rule lag - resource misallocation - poor performance" due to a lack of platform leadership. This confirms that the role of electricity transaction efficiency depends on the configuration adaptation of platform leadership; improvements in a single dimension are insufficient to maximize efficiency dividends. In other words, improvements in user enterprise performance do not simply come from increased transaction efficiency, but are based on the positive output of a well-adapted platform leadership configuration. Improving transaction efficiency based on platform leadership development is not only an inherent requirement of electricity market reform, but also a crucial prerequisite for the performance of electricity transaction platform user enterprises.

5.8.2 Research contributions

1) This study fills the empirical gap in understanding the mechanism of electricity transaction efficiency from the perspective of platform leadership. Existing research largely focuses on the institutional design and theoretical framework of the electricity market (S. Q. Huang, 2022; Q. S. Shi et al., 2022), but neglects the systematic verification of the "transaction efficiency-corporate performance" chain driven by different platform leadership in the context of digital platform management. This study, through multiple regression analysis based on a configuration perspective, empirically tests this logical loop for the first time, confirming that transaction efficiency is the core variable for platform-empowered user enterprises, and responding to the research call from Gu (2022) to "reveal the efficiency transmission path in the platform context."

2) This study expands the application boundaries of platform leadership theory in the electricity energy field. Based on Gawer and Cusumano (2008)'s platform leadership framework, this study deconstructs platform leadership into four dimensions: platform guidance, platform influence, platform coordination, and platform control, and verifies their moderating effects. This breaks through the limitations of traditional research's overall "black box" treatment of platform leadership (M. Luo & Du, 2018; Y. Zhang, 2019).Furthermore, by introducing transaction cost theory (Williamson, 1979) to explain the micro-mechanisms of efficiency improvement, this study provides an operational theoretical tool for energy market analysis in the context of digital platforms.

5.8.3 Research implications

1) Strengthen the platform's guidance and influence, and promote the standardization of rules and the construction of trust mechanisms. Platform enterprises need to reduce institutional losses through unified contract templates (such as standardization of medium- and long-term transaction contracts) and dynamic rule adjustments (such as priority policies for green electricity transactions), while enhancing user trust through credit rating systems (differentiated collection of performance bonds) and technological demonstrations (pilot projects of blockchain transaction systems). For example, the "standardized contract + credit score" model can drive the efficiency dividend from "cost savings" to "value co-creation."

2) Optimize the platform's coordination and control capabilities, focusing on resource integration and compliance supervision. In terms of coordination, it is necessary to eliminate spatiotemporal mismatches through joint dispatching of inter-provincial transmission channels

(inter-provincial load coordination) and coupling of multiple market products (linkage between spot and ancillary service markets). In terms of control, it is necessary to improve the violation punishment mechanism (such as dynamic review of electricity sales enterprise qualifications) and technical regulations (such as automatic performance of smart contracts) to reduce the risk of opportunistic behavior. Through the dual-drive of "resource integration + process regulation." the decision-making cycle of user enterprises can be shortened and response efficiency improved.

3) Dynamically adapt platform leadership combinations to achieve differentiated efficiency improvement paths. For provinces with high platform leadership, the synergy of "leadership + coordination" should be strengthened, and innovative models such as green electricity transaction zones should be explored to improve transaction efficiency and corporate performance. For provinces with low platform leadership, priority should be given to addressing shortcomings in coordination and control through regulatory policies, such as establishing cross-provincial resource coordination funds and standardized guidelines for transaction processes. Through "categorized policies + dynamic adjustments," the dilemma of "one-size-fits-all" reforms can be overcome, promoting the transformation of the electricity market from segmented operation to collaborative operation.

Chapter 6: Conclusions and Discussion

This chapter serves as a summary and discussion of the entire study, aiming to systematically distill the core findings of the preceding chapters and place them within a broader theoretical and practical context for in-depth dialogue. In its specific analysis, this chapter will first outline the key conclusions that run throughout the text, then clarify the theoretical expansion and contributions of this research, followed by providing actionable management insights for diverse participants in the electricity market based on solid empirical results. Finally, it will critically examine the inherent limitations of the research and point out potential paths for future exploration.

6.1 Main research conclusions

This study, from the perspective of platform leadership, systematically reveals the complex mechanism of electricity transaction efficiency and its transmission path to user enterprise performance through a multi-level empirical analysis of 33 provincial-level electricity transaction platforms and their user enterprises in China. The research conclusions are not linear findings of a single dimension, but rather a three-dimensional picture interwoven with influencing factors, configuration paths, and effects, profoundly reflecting the inherent logic of the electricity market as a deeply coupled "physical-economic-regulatory" system.

First, the study confirms that improving electricity transaction efficiency is a complex process driven by multiple factors, and there is no single "magic bullet." The results of the Necessary Condition Analysis (NCA) clearly indicate that neither the four dimensions of platform leadership (platform guidance, platform influence, platform coordination, and platform control) nor government regulation in the external environment can individually constitute a necessary condition for high transaction efficiency. This finding fundamentally challenges the simplistic thinking that previously attempted to eradicate electricity transaction efficiency problems by optimizing a single element (such as simply improving technology or strengthening regulation) (X. F. Shi et al., 2023). Meanwhile, a deeper analysis of bottleneck levels further reveals the priority order for efficiency improvement: In the nascent stage of electricity transaction efficiency, where it is developing from scratch, platform coordination and government regulation constitute the earliest bottleneck factors. This means that in the early

stages of efficiency building, resources must be prioritized to build the platform's credibility and authority, and to ensure a clear, stable, and robust regulatory framework. When efficiency levels rise to a moderate stage (e.g., 40%), all factors begin to work together, with the need for platform coordination becoming paramount. This indicates that as market complexity increases, the ability to integrate resources across entities and regions and resolve conflicts becomes crucial for sustained efficiency gains. This conclusion profoundly illustrates that optimizing electricity transaction efficiency is a systematic project, requiring platforms and governments to dynamically adjust the priority and combination strategies of resource allocation according to different stages of market development.

Secondly, this study, through fuzzy set qualitative comparative analysis (fsQCA), identifies three differentiated paths to achieving high electricity transaction efficiency, namely, configuration solutions that "lead to the same destination through different paths." The first path is the "platform-led and government regulation-driven collaborative model" (H1a), characterized by the comprehensive strengthening of the platform's influence, coordination, and control, along with power regulation. This model is prominent in provinces with a strong foundation, such as Shandong, where technological innovation by the platform and precise government assessments work together to effectively promote the large-scale development of emerging businesses such as green electricity transaction. The second path is the "government regulation-driven platform leadership quality and efficiency improvement model" (H1b), characterized by a combination of strong government regulation and the platform's coordination and control when the platform's guidance is relatively weak. A complementary mechanism of "regulatory rules setting, platform implementation" ensures basic transaction efficiency. Provinces like Tianjin are typical examples of this model. The third path is the "platform leadership incentive improvement model under moderate regulation" (H2), which is relatively rare, appearing only in policy pilot areas such as Hainan. Its core is that, under the background of moderate regulatory decentralization, the platform, with its strong influence and coordination, stimulates market vitality through model innovation (such as cross-border green electricity transaction), achieving a breakthrough improvement in transaction efficiency. In stark contrast, the inefficient configuration (L1) exhibits a high degree of consistency, namely the simultaneous absence of platform influence, coordination, and government regulation. This constitutes a significant component of the suppression of transaction efficiency, as seen in provinces such as Heilongjiang and Xinjiang. This lack of dual power—platform leadership and government regulation—leads to a vicious cycle of lagging rules, weak innovation, and sluggish participation. Furthermore, configuration analysis confirms that low platform

influence and low coordination are necessary conditions for inefficiency, providing a clear target for overcoming the inefficiency dilemma.

Finally, the effect study clearly outlines the complete chain of action: "platform leadership—transaction efficiency—user enterprise performance," revealing the crucial moderating role of platform leadership in this transmission process. Regression analysis strongly demonstrates that electricity transaction efficiency has a significant positive effect on user enterprise performance; for every unit increase in transaction efficiency, user enterprise performance improves by an average of 0.889 units. Independent samples t-tests further revealed that user companies in high-efficiency electricity transaction configurations (mean 4.48) had significantly better perceived performance than those in low-efficiency configurations (mean 4.02). This indicates that the efficiency benefits brought by the transaction platform through reduced transaction costs and optimized resource allocation can be effectively translated into profit growth and operational improvements for electricity generation companies, electricity sales companies, and industrial and commercial users. More importantly, all four dimensions of platform leadership significantly amplified the positive effect of transaction efficiency on user company performance, with the moderating effect of platform coordination being particularly prominent. This means that a electricity transaction platform with strong leadership can not only create transaction efficiency but also reduce the "leakage" of efficiency benefits in the process of translating into corporate performance through its strategic control (platform guidance), trust endorsement (platform influence), resource integration (platform coordination), and compliance assurance (platform control), thereby constructing an efficient value co-creation closed loop.

6.2 Theoretical contributions

Based on a data survey and analysis of provincial-level electricity transaction platforms across China, this study deeply reveals the influencing factors, implementation paths (antecedent configurations), and effect on user enterprise performance of electricity transaction platforms. It provides reliable theoretical references for expanding the boundaries and innovating the paradigms of research fields such as transaction efficiency theory and platform leadership theory.

First, this study achieves a new breakthrough in research perspective. Based on the platform leadership perspective, it constructs an integrated analytical framework for electricity transaction efficiency driven by a dual "platform-government" model, thus transcending the

explanatory boundaries of traditional theories. While classic transaction cost economics (Williamson, 1985) profoundly reveals the endogeneity of transaction costs, its analytical framework is often embedded in a "market-bureaucratic" dichotomy, making it difficult to fully explain the complex governance of multilateral markets in the digital platform era. While emerging platform leadership theory (Cusumano et al., 2019; Gawer, 2014) focuses on the ecological coordination capabilities of platform enterprises, it often treats government regulation as an exogenous variable or disruptive factor. This study innovatively places platform leadership and government regulation within the same analytical framework, viewing them as endogenous dual forces jointly shaping electricity transaction efficiency. This profoundly addresses the unique governance challenges of electricity transaction platforms as a deeply coupled "physical-economic-regulatory" system possessing both public goods attributes and market operation mechanisms. This shift in perspective allows the research to transcend the traditional e-commerce scenario of "no physical constraints," extending transaction efficiency theory to the new electricity market scenario of "strong physical constraints + real-time balance." It constructs a boundary analysis framework for transaction efficiency under complex constraints, opening a new branch of transaction efficiency theory under energy physical constraints.

Secondly, drawing on data from provincial-level platforms across China, this study examines the differentiated impacts of different platform leadership on electricity transaction efficiency, thereby enriching the application of platform leadership theory in the context of public electricity transactions. Prior research on platform leadership has predominantly centered on how platform leadership strategies within commercial platforms reshape business models and cultivate competitive advantages, with the traded commodities being competitive products characterized by "delayed consumption and storability". In contrast, China's electricity transaction platforms must simultaneously accommodate both public and commercial attributes, while the electricity traded exhibits the inherent characteristics of "instant consumption and non-storability". Consequently, the findings derived from existing platform leadership studies focusing on commercial platforms fail to fully account for the unique contextual features of China's electricity transaction platforms. Against this backdrop, this study adopts a platform leadership perspective rooted in the specific scenario of China's electricity transactions. Not only does it deconstruct the antecedents of electricity transaction efficiency within a novel contextual framework, but it also offers valuable insights for future platform leadership research involving products with special attributes and diverse types of platforms.

6.3 Management insights

The empirical findings of this study not only have theoretical value but also contain rich practical wisdom, providing concrete and actionable decision-making references for diverse participants in the electricity market—including electricity transaction platforms, government regulatory authorities, and a wide range of user enterprises. Therefore, this study proposes targeted management implications and policy recommendations based on the different participants in electricity transaction platforms.

6.3.1 Leaders of electricity transaction platforms should implement precise strategies based on their own strengths to systematically enhance the platform's leadership

First, leaders of electricity transaction platforms must prioritize building platform leadership, allocating limited resources to the most critical aspects. Based on the necessary conditions analysis, this research finds that platform influence and coordination are the most significant bottlenecks hindering efficiency improvement at present. Therefore, platforms should focus their development efforts on these two areas. Regarding enhancing platform influence, platforms should strive to become a hub for market data and a think tank for policy formulation. Specifically, this can involve building a nationwide electricity big data center to deeply analyze key information such as user electricity consumption behavior, electricity supply structure, and peak-valley load characteristics, generating forward-looking market analysis reports, and regularly providing decision-making support to government regulatory departments, such as suggestions for dynamically adjusting peak-valley electricity pricing policies. Simultaneously, by publishing industry white papers, hosting high-level forums, and showcasing successful cases, platforms should actively cultivate their authoritative position and credibility within the industry, becoming a trusted leader for market participants. Regarding strengthening platform coordination, the core lies in breaking down barriers and integrating resources. The platform should proactively establish cross-provincial and cross-regional transaction coordination mechanisms. For example, it could set up inter-provincial transaction zones, utilize intelligent algorithms to automatically match electricity surpluses and shortages between supply and demand provinces, and design reasonable profit-sharing models to incentivize participation in cross-regional transactions. Furthermore, a regular multi-party consultation platform should be established to promptly resolve conflicts of interest among electricity generation, sales, and users, particularly on sensitive issues such as renewable energy consumption and ancillary

service cost sharing, promoting consensus.

Secondly, the platform needs to adopt differentiated leadership strategies based on its efficiency configuration type (implementation path type). For provinces with a similar configuration of "platform leadership and government regulation collaborative driving type" (H1a), such as Shandong, where the platform already has a good foundation, the focus should shift to deepening "leadership + control," driving a second leap in efficiency through technological innovation. For example, it can actively explore the application of blockchain technology in green electricity traceability, electronic signatures, and automatic settlement to build an immutable transaction trust system; deploy artificial intelligence algorithms to monitor market transaction behavior in real time, accurately identify abnormal transactions such as price manipulation and abuse of market power, and improve risk prevention and control capabilities. For provinces like Tianjin, which employ a similar "government regulation-driven platform leadership efficiency improvement" (H1b) configuration, the platform may lack strategic foresight. In this case, the focus should be on strengthening "coordination and control," transforming regulatory intent into market efficiency through excellent execution. Specific measures include: comprehensively streamlining and simplifying transaction processes to shorten user entry cycles; developing standardized contract templates and risk hedging tools to lower the participation threshold and risks for small and medium-sized users; and establishing strict performance guarantee mechanisms, such as credit rating systems and margin systems, to ensure market stability. For provinces like Hainan, which employ a similar "moderate regulation-driven platform leadership incentive improvement" (H2) configuration, the platform possesses valuable policy innovation space and should boldly leverage its "influence and coordination" advantages to become a "testing ground" for market innovation. For example, it could pioneer a "negative list + innovation tolerance" management model, implement a registration system for new transaction products (such as capacity markets and financial derivatives), and actively promote cross-border green electricity transaction pilots with neighboring countries in Southeast Asia to build a new pattern of regional energy interconnection.

6.3.2 Electricity regulators should focus on a shift in their role and implement precise, collaborative, and dynamic regulatory strategies

For governments and regulatory bodies, the core lesson lies in how to shift from a "regulator" to an "enabler", implementing precise, collaborative, and dynamic regulatory strategies. On the

one hand, regulatory policies must abandon the "one-size-fits-all" approach and shift towards differentiated policies based on provincial characteristics. Research shows that different provinces' electricity markets are at different stages of development and face different bottlenecks. Therefore, regulation should be more flexible and targeted. For provinces with high-efficiency configurations, regulation should tend towards "bottom-line regulation + innovation tolerance," clearly defining red lines such as anti-monopoly and supply security, but within these limits, giving platforms ample room for independent innovation and encouraging them to explore cutting-edge models. For provinces with low-efficiency configurations, regulation needs to be more proactive, playing the role of "rule provider" and "market cultivator." For example, for regions like Heilongjiang with lagging spot market rules, the National Energy Administration and local regulatory departments should accelerate the issuance of supporting detailed rules, clarifying the price formation mechanism, price limits, and settlement rules of the spot market; establish a normalized market power monitoring and evaluation system; and severely punish abuse of market dominance to create conditions for fair competition.

On the other hand, the focus of regulation should shift from intra-provincial segmentation to inter-provincial collaboration, striving to build a unified national electricity market. The widespread existence of inefficient configurations largely stems from resource misallocation caused by inter-provincial barriers. Therefore, regulatory authorities need to design and coordinate systems at a higher level. Specifically, efforts should be made to break down hidden barriers to inter-provincial transactions, eliminate unnecessary approval levels for inter-provincial transactions, and promote online registration and one-click transactions through electricity transaction platforms, significantly improving the convenience of inter-regional transactions. Simultaneously, a unified national electricity data interface standard, information sharing specification, and green certificate certification system should be developed to lay the foundation for data interconnection and business collaboration between different provincial platforms. Furthermore, consideration could be given to establishing a special fund for the construction of an inter-provincial electricity market to compensate provinces or entities that suffer losses due to inter-provincial transactions, incentivizing all parties to participate in the optimal allocation of resources nationwide.

6.3.3 Electricity user companies should focus on strategic planning to transform transaction efficiency into internal performance

For electricity user companies (electricity generation companies, electricity retailers, and industrial and commercial users, among others), the core lesson is how to proactively adapt to the platform trend and transform external efficiency into internal performance. Electricity generation companies should fully utilize the diversified transaction tools provided by the platform to optimize their business strategies. Faced with the increased transaction efficiency brought by the platform, electricity generation companies can no longer rely solely on the traditional planned electricity allocation model. They should actively participate in medium- and long-term transactions, spot transactions, and ancillary service markets on the platform, effectively hedging against electricity price fluctuation risks and locking in reasonable profits through a combination strategy of "long-term contracts + spot transactions." Simultaneously, they should leverage the data services provided by the platform, such as load forecasting and renewable energy output forecasting, to optimize unit start-up and shutdown and electricity generation plans, improving equipment utilization efficiency. For electricity generation companies with clean energy resources, they should actively participate in green electricity transaction on the platform, utilizing the platform's credibility and influence to realize environmental value.

Electricity retailers, on the other hand, need to transform from simple "electricity transporters" to "integrated energy service providers." The information transparency and transaction convenience brought by the platform are continuously squeezing the profit margins of the simple electricity purchase and sale price difference model. Electricity retailers must leverage platform data to deeply analyze user electricity consumption characteristics and develop customized energy-saving services, demand response agency services, distributed energy operation and maintenance, and other value-added services to build new profit growth points. Simultaneously, they should actively participate in the platform's credit rating activities to enhance their own reputation, thereby gaining stronger bargaining power and trust endorsement when representing small and medium-sized users.

Industrial and commercial users, as the end-users of electricity, should view the platform as a strategic tool for reducing energy costs and improving energy management. Users should proactively learn to use the platform's transaction system, participate in centralized bidding or listing transactions, and strive for better electricity purchase prices. More importantly, they should actively respond to the platform's demand response initiatives by adjusting production

plans and activating backup electricity sources to reduce load during peak electricity consumption periods, thereby obtaining economic compensation and contributing to peak shaving and valley filling of the power grid. For users with distributed photovoltaic, energy storage, and other resources, they should participate in “behind-the-scenes electricity sales” through the platform or participate in market transactions as part of a virtual power plant, converting idle energy resources into revenue.

6.4 Discussion

After summarizing the research findings and implications, this research reflects on the inherent limitations of this study with a cautious and critical attitude in the discussion section, and based on this, looks forward to future research directions to promote the accumulation and improvement of knowledge in academic research on electricity transaction efficiency.

6.4.1 Research limitations

Despite its rigorous and comprehensive approach, this study has several inherent limitations that need to be considered when interpreting its conclusions. The primary limitation lies in the cross-sectional nature of the study. The data primarily focuses on a specific timeframe (March-May, 2025). While this reveals correlations and configurational logic among variables, it fails to capture the long-term evolution of the dynamic electricity market system. The policy environment, technological level, and market participant behavior in the electricity market are all rapidly changing. For example, at the time of this study, the spot market rules in Heilongjiang were still under development, and their implementation may alter the relationship between market efficiency and platform leadership. Therefore, the conclusions of this study are more like a snapshot within a specific timeframe, and their long-term validity requires continuous longitudinal research for verification.

Secondly, while the sample scope covers all provincial-level platforms, the depth of downward extension is insufficient. The study focuses on the core hub of the provincial power exchange center, but fails to include emerging forms such as county-level electricity transaction and park-level microgrid transaction at the grassroots level within the analytical framework. These grassroots platforms play an increasingly important role in serving distributed energy and promoting local supply-demand balance, and their efficiency influencing factors may differ from those of provincial platforms. Therefore, the conclusions of this study should be applied with caution when extending to the grassroots market.

Third, regarding variable measurement, some core variables rely on subjective questionnaire data. Although this study made significant efforts in scale development, data calibration, and reliability and validity testing, key variables such as enterprise performance were still measured using Likert scales, reflecting respondents' subjective perceptions. While this measurement method can capture soft performance aspects (such as market position and strategic synergy) that are difficult to cover with financial data, it may deviate from objective financial indicators (such as profit margin and return on assets). Future research that incorporates objective data for cross-validation will make the conclusions more convincing.

6.4.2 Future research prospects

Based on the aforementioned limitations and the new considerations raised by this study, future research can seek breakthroughs in the following directions:

First, conduct longitudinal tracking studies to dynamically depict the evolutionary trajectory of electricity transaction efficiency. Future research could design a tracking survey program lasting several years or even decades, regularly collecting relevant data from provincial electricity transaction platforms. Using panel data analysis or event system analysis, it could explore the dynamic evolution of the relationship between platform leadership, government regulation, and transaction efficiency. For example, it could track the changes in various dimensions of platform leadership before and after the introduction of a major regulatory policy (such as the formal operation of the spot market) and its short-term and long-term impacts on efficiency, thereby revealing the complete causal chain of "policy shock—platform response—efficiency change."

Second, conduct interdisciplinary integrated research to deepen the understanding of the "physical-economic" coupling mechanism. This study mainly approaches the issue from the perspectives of management and economics, and has relatively simplified the physical constraints of the electricity system (such as grid topology, safety criteria, and electricity flow distribution). Future research could actively introduce theories and methods from disciplines such as electricity system engineering and complex systems science to construct a multi-layered coupling model of "physical layer—information layer—market layer." For example, high-precision power grid simulation data can be used to quantify the effect of different transaction models on power grid security and stability, or complex network theory can be applied to analyze how platform leadership can improve system resilience and efficiency by optimizing the transaction network structure.

Third, international comparative studies should be expanded to extract universal laws governing platform-based governance in the electricity market. This study focuses on the Chinese context, and its conclusions have distinct national characteristics. Future research can broaden its scope to a global perspective, selecting representative electricity market models such as the US PJM, Europe's EPEX Spot, and Australia's AEMO for systematic comparative case studies. By comparing the interaction patterns between platform leadership and government regulation under different institutional backgrounds and technological paths, a deeper understanding can be gained of which are common laws governing platform-based governance in the electricity market and which are special products of specific institutional environments, thus contributing more universal theoretical wisdom and practical solutions to the global energy transition.

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Annex A: Annex Tables and Figures

Table A2.1 Comparison of the concepts of transaction efficiency and transaction cost

Comparison of Content	Transaction Efficiency	Transaction Costs
Assessment Focus	Speed and efficiency, and are not measured by currency	Cost size, monetary unit, and time value involved.
Assessment Challenges	The difficulty level is low, and it does not involve unit conversions between different countries and regions	The difficulty level is high, involving price conversions at different times and between different countries' currency units
Scope	Overall situation including systems, technology and education	Overall situation including systems, technology and education
Relationship with Economic Development	Proportional	Inverse

Table A3.1 Preliminary survey sample distribution

Statistical Indicators	Statistical Option	Frequency	Percentage
User Enterprise Type	Power Generation Enterprises	109	35.2
	Power Sales Enterprises	93	30.0
	Commercial and Industrial Users	108	34.8
Multiple Ownership	Members of Only One Power Transaction Platform	207	66.8
	Members of Two or More Power transaction Platforms	103	33.2
Respondent Level	Senior Managers	46	14.8
	Middle Managers	85	27.4
	Primary Managers	76	24.5
	Ordinary Employees	103	33.2
User Enterprise Size	1,000 or More Employees	66	21.3
	300 or More but Less than 1,000 Employees	76	24.5
	20 or More but Less than 300 Employees	112	36.1
	Less than 20 Employees	56	18.1
Years of User Enterprise Experience	20 years or More	53	17.1
	15 years or more and less than 20 years	47	15.2
	10 years or more and less than 15 years	82	26.5
	5 years or more and less than 10 years	87	28.1
	5 years or less	41	13.2

Table A3.2 Normality test for initial scale items

	Skewness		Kurtosis	
	Statistics	Standard Error	Statistics	Standard Error
PLG1	-1.784	0.138	3.473	0.276
PLG2	-1.682	0.138	2.868	0.276

PLG3	-1.762	0.138	3.116	0.276
PLI1	-1.793	0.138	3.174	0.276
PLI2	-1.780	0.138	3.274	0.276
PLI3	-1.763	0.138	3.050	0.276
PLC1	-1.759	0.138	3.070	0.276
PLC2	-1.820	0.138	3.571	0.276
PLC3	-1.817	0.138	3.402	0.276
PLT1	-1.783	0.138	3.473	0.276
PLT2	-1.774	0.138	3.422	0.276
PLT3	-1.781	0.138	3.827	0.276
GRP-1	-1.859	0.138	4.219	0.276
GRP-2	-1.767	0.138	3.365	0.276
GRE-1	-1.800	0.138	3.628	0.276
GRE-2	-1.736	0.138	3.398	0.276
GRT-1	-1.746	0.138	3.603	0.276
GRT-2	-1.658	0.138	2.788	0.276
GRT-3	-1.859	0.138	4.219	0.276
GRT-4	-1.654	0.138	3.097	0.276
GRO-1	-1.831	0.138	3.570	0.276
GRO-2	-1.730	0.138	3.055	0.276
TEF-1	-1.564	0.138	2.362	0.276
TEF-2	-1.630	0.138	2.564	0.276
TEF-3	-1.663	0.138	3.176	0.276
TES-1	-1.548	0.138	2.512	0.276
TES-2	-1.588	0.138	2.591	0.276
TES-3	-1.505	0.138	2.120	0.276
TES-4	-1.709	0.138	3.161	0.276
TES-5	-1.643	0.138	3.016	0.276
TES-6	-1.588	0.138	2.717	0.276
TES-7	-1.513	0.138	2.481	0.276
TES-8	-1.651	0.138	3.288	0.276
TES-9	-1.625	0.138	2.596	0.276
TEU-1	-1.170	0.138	.539	0.276
TEU-2	-1.100	0.138	.313	0.276
TEU-3	-1.148	0.138	.471	0.276

Table A3.3 High and low sample segmentation thresholds

Item	27% quantile	73% quantile	Item	27% quantile	73% quantile
PLG1	4	5	GRO-2	4	5
PLG2	4	5	GRT-3	4	5
PLG3	4	5	GRT-4	4	5
PLI1	4	5	TEF-1	4	5
PLI2	4	5	TEF-2	4	5
PLI3	4	5	TEF-3	4	5
PLC1	4	5	TES-1	4	5
PLC2	4	5	TES-2	4	5
PLC3	4	5	TES-3	4	5
PLT1	4	5	TES-4	4	5
PLT2	4	5	TES-5	4	5
PLT3	4	5	TES-6	4	5
GRP-1	4	5	TES-7	4	5
GRP-2	4	5	TES-8	4	5
GRE-1	4	5	TES-9	4	5

GRE-2	4	5	TEU-1	4	5
GRT-1	4	5	TEU-2	3	5
GRT-2	4	5	TEU-3	4	5
GRO-1	4	5			

Table A3.4 Independent samples T-Test for each item

Item	Degrees of Freedom	F-Value	T-Value	Significance
PLG1	308	235.968	-22.168	0.000
PLG2	308	303.747	-23.544	0.000
PLG3	308	313.136	-23.403	0.000
PLI1	308	307.258	-22.684	0.000
PLI2	308	269.978	-22.277	0.000
PLI3	308	299.332	-22.325	0.000
PLC1	308	316.136	-23.297	0.000
PLC2	308	271.282	-23.228	0.000
PLC3	308	283.480	-22.690	0.000
PLT1	308	253.504	-22.953	0.000
PLT2	308	244.859	-22.299	0.000
PLT3	308	210.268	-23.841	0.000
GRP-1	308	189.874	-22.736	0.000
GRP-2	308	260.059	-23.425	0.000
GRE-1	308	260.007	-23.872	0.000
GRE-2	308	236.550	-22.906	0.000
GRT-1	308	238.429	-24.061	0.000
GRT-2	308	295.533	-23.361	0.000
GRT-3	308	189.874	-22.736	0.000
GRT-4	308	249.232	-23.624	0.000
GRO-1	308	280.591	-23.369	0.000
GRO-2	308	291.915	-23.074	0.000
TEF-1	308	315.322	-23.561	0.000
TEF-2	308	294.006	-22.248	0.000
TEF-3	308	226.790	-23.024	0.000
TES-1	308	265.380	-22.820	0.000
TES-2	308	275.940	-22.852	0.000
TES-3	308	310.465	-23.172	0.000
TES-4	308	270.301	-23.459	0.000
TES-5	308	259.710	-23.786	0.000
TES-6	308	261.587	-23.301	0.000
TES-7	308	252.258	-22.771	0.000
TES-8	308	221.780	-23.314	0.000
TES-9	308	295.486	-22.889	0.000
TEU-1	308	332.519	-22.060	0.000
TEU-2	308	95.095	-30.519	0.000
TEU-3	308	310.419	-21.739	0.000

Table A3.5 Correlation coefficients between platform leadership items and total score

Item	Total Score for Platform Leadership	Item	Total Score for Platform Leadership
PLG1	0.883**	PLC1	0.944**
PLG2	0.940**	PLC2	0.925**
PLG3	0.935**	PLC3	0.934**

PLI1	0.935**	PLT1	0.921**
PLI2	0.938**	PLT2	0.902**
PLI3	0.927**	PLT3	0.895**

Note: ** indicates a significant correlation at the 0.01 level (two-tailed).

Table A3.6 Correlation coefficients between government regulatory items and total score

Item	Total Score for Government Regulation	Item	Total Score for Government Regulation
GRP-1	0.900**	GRT-2	0.942**
GRP-2	0.897**	GRT-3	0.924**
GRE-1	0.930**	GRT-4	0.933**
GRE-2	0.926**	GRO-1	0.942**
GRT-1	0.941**	GRO-2	0.928**

Note: ** indicates a significant correlation at the 0.01 level (two-tailed).

Table A3.7 Correlation coefficients between transaction efficiency items and total score

Item	Total Score for Transaction Efficiency	Item	Total Score for Transaction Efficiency
TEF-1	0.875**	TES-6	0.880**
TE-1	0.874**	TES-7	0.908**
TE-2	0.881**	TES-8	0.898**
TES-1	0.892**	TES-9	0.891**
TES-2	0.883**	TEU-1	0.779**
TES-3	0.891**	TEU-2	0.765**
TES-4	0.878**	TEU-3	0.748**
TES-5	0.906**		

Note: ** indicates a significant correlation at the 0.01 level (two-tailed).

Table A3.8 Initial scale item reliability test

Item	Scale mean after deleting items	CITC	Cronbach's α after deleting	Item	Scale mean after deleting items	CITC	Cronbach's α after deleting
PLG1	47.92	0.861	0.984	PLC1	47.91	0.932	0.982
PLG2	47.92	0.928	0.982	PLC2	47.89	0.911	0.983
PLG3	47.90	0.921	0.983	PLC3	47.90	0.921	0.983
PLI1	47.91	0.925	0.983	PLT1	47.90	0.905	0.983
PLI2	47.93	0.912	0.982	PLT2	47.94	0.882	0.983
PLI3	47.91	0.932	0.983	PLT3	47.87	0.877	0.983
GRP-1	39.31	0.876	0.981	GRO-1	39.30	0.928	0.979
GRE-1	39.29	0.913	0.979	GRO-2	39.34	0.910	0.980
GRT-1	39.31	0.927	0.979	GRT-3	39.31	0.906	0.980
GRT-2	39.35	0.927	0.979	GRT-4	39.34	0.916	0.979
GRE-2	39.34	0.908	0.980	GRP-2	39.30	0.873	0.981
TEF-1	59.48	0.856	0.971	TES-6	59.49	0.861	0.971
TEF-1	59.49	0.854	0.971	TES-7	59.51	0.894	0.971
TEF-2	59.45	0.863	0.971	TES-8	59.46	0.883	0.971
TES-1	59.50	0.875	0.971	TES-9	59.49	0.874	0.971
TES-2	59.49	0.864	0.971	TEU-1	59.72	0.739	0.974
TES-3	59.52	0.873	0.971	TEU-2	59.79	0.721	0.974

TES-4	59.44	0.860	0.971	TEU-3	59.75	0.703	0.974
TES-5	59.44	0.892	0.971				

Table A3.9 Analysis of platform leadership factors

Component	Initial Eigenvalue			Sum of Squares of Extracted Loadings		
	Total	Percentage of Variance	Cumulative %	Total	Percentage of Variance	Cumulative %
1	2.375	23.028	23.028	2.303	23.028	23.028
2	2.124	22.782	45.810	2.278	22.782	45.810
3	1.732	22.324	68.134	2.232	22.324	68.134
4	1.061	12.311	80.445	1.231	12.311	80.445
5	0.694	6.865	87.310			
6	0.422	4.613	91.923			
7	0.386	3.300	95.223			
8	0.141	1.232	96.455			
9	0.117	1.035	97.490			
10	0.073	0.923	98.413			
11	0.042	0.801	99.214			
12	0.026	0.786	100.000			

Extraction method: principal component analysis

Table A3.10 Platform leadership factor loadings

	1	2	3	4
PLG1	0.883			
PLG2	0.940			
PLG3	0.935			
PLI1		0.935		
PLI2		0.938		
PLI3		0.927		
PLC1			0.944	
PLC2			0.926	
PLC3			0.934	
PLT1				0.921
PLT2				0.901
PLT3				0.896

Table A3.11 Analysis of government regulatory factors

Component	Initial Eigenvalue			Sum of Squares of Extracted Loadings		
	Total	Percentage of Variance	Cumulative %	Total	Percentage of Variance	Cumulative %
1	3.281	32.808	32.808	3.281	32.808	32.808
2	1.552	15.523	48.331	1.552	15.523	48.331
3	1.131	11.313	59.644	1.131	11.313	59.644
4	1.008	10.083	69.727	1.008	10.083	69.727
5	0.986	9.862	79.588			
6	0.746	7.456	87.044			
7	0.627	6.273	93.317			
8	0.365	3.648	96.965			
9	0.176	1.759	98.724			
10	0.128	1.276	100.000			

Table A3.12 Government regulatory factor loads

	1	2	3	4
GRP-1	0.923			
GRP-2	0.928			
GRE-1		0.936		
GRE-2		0.868		
GRT-1			0.810	
GRT-2			0.794	
GRT-3			0.832	
GRT-4			0.786	
GRO-1				0.874
GRO-2				0.913

Table A3.13 Analysis of transaction efficiency factors

Component	Initial Eigenvalue			Sum of Squares of Extracted Loadings		
	Total	Percentage of Variance	Cumulative %	Total	Percentage of Variance	Cumulative %
1	3.144	33.052	33.052	3.144	33.052	33.052
2	2.433	27.912	60.964	2.433	27.912	60.964
3	1.113	13.918	74.881	1.113	13.918	74.881
4	0.836	10.446	85.327			
5	0.449	5.618	90.945			
6	0.362	4.524	95.469			
7	0.188	2.351	97.821			
8	0.174	2.179	100.000			

Table A3.14 Transaction efficiency factor loadings

	1	2	3
TES-1	0.849		
TES-2	0.824		
TES-3	0.842		
TES-4	0.863		
TES-5	0.895		
TES-6	0.811		
TES-7	0.832		
TES-8	0.857		
TES-9	0.872		
TEF-1		0.838	
TEF-2		0.856	
TEF-3		0.860	
TEU-1			0.888
TEU-2			0.912
TEU-3			0.923

Table A3.15 Sample distribution of the second round of survey

Statistical Indicators	Statistical Option	Frequency	Percentage
User Enterprise Type	Power Generation Enterprises	159	36.8
	Power Sales Enterprises	150	34.7
	Commercial and Industrial Users	123	28.5

Multiple Ownership	Members of Only One Power Transaction Platform	288	66.7
	Members of Two or More Power Transaction Platforms	144	33.3
Respondent Level	Senior Managers	53	12.3
	Middle Managers	126	29.2
	Primary Managers	131	30.3
	Ordinary Employees	122	28.2
User Enterprise Size	1,000 or More Employees	68	15.7
	300 or More but Less than 1,000 Employees	140	32.4
	20 or More but Less than 300 Employees	158	36.6
	Less than 20 Employees	66	15.3
Years of User Enterprise Experience	20 years or More	54	12.5
	15 years or more and less than 20 years	88	20.3
	10 years or more and less than 15 years	114	26.4
	5 years or more and less than 10 years	120	27.8
	5 years or less	56	13.0

Table A3.16 Platform leadership AVE and CR values

Factor	AVE	CR
Platform Guidance	0.886	0.959
Platform Influence	0.892	0.961
Platform Coordination	0.854	0.946
Platform Control	0.835	0.938

Table A3.17 Government regulatory AVE and CR values

Factor	AVE	CR
Pricing Regulation	0.851	0.920
Transaction Regulation	0.869	0.964
Operational Regulation	0.902	0.949
Power Regulation	0.855	0.922

Table A3.18 Transaction efficiency AVE and CR values

Factor	AVE	CR
Asset Specificity	0.887	0.969
Uncertainty	0.875	0.955
Transaction Frequency	0.883	0.974

Table A3.19 Common method bias test

Model	$\chi 2$	df	$\Delta\chi 2$	CFI	TLI	RMSEA	SRMR
Single-factor Model	5255.862	629	—	0.842	0.833	0.131	0.038

Note: N=432. Single-factor model (platform leadership + government regulation + transaction efficiency).

Table A3.20 Sample allocation of the third round of questionnaire survey across different platforms

The Name of Power Transaction Platform	Power Generation Enterprise Questionnaire	Power Sales Enterprise Questionnaire	Industrial and Commercial User Questionnaire	Total

Sichuan Power Transaction Center	15(28.30%)	24(45.28%)	14(26.42%)	53
Chongqing Power Transaction Center	7(33.33%)	5(23.81%)	9(42.86%)	21
Tibet Power Transaction Center	5(29.41%)	6(35.29%)	6(35.29%)	17
Capital Power Transaction Center	5(31.25%)	6(37.5%)	5(31.25%)	16
Tianjin Power Transaction Center	6(35.29%)	5(29.41%)	6(35.29%)	17
Northern Hebei Power Transaction Center	7(33.33%)	7(33.33%)	7(33.33%)	21
Hebei Power Transaction Center	7(33.33%)	8(38.10%)	6(28.57%)	21
Shanxi Power Transaction Center	6(35.29%)	5(29.41%)	6(35.29%)	17
Shandong Power Transaction Center	7(38.89%)	6(33.33%)	5(27.78%)	18
Shanghai Power Transaction Center	5(29.41%)	6(35.29%)	6(35.29%)	17
Jiangsu Power Transaction Center	8(42.11%)	5(26.32%)	6(31.58%)	19
Zhejiang Power TransactionCenter	5(25%)	8(40%)	7(35%)	20
Anhui Power Transaction Center	5(29.41%)	6(35.29%)	6(35.29%)	17
Fujan Power Transaction Center	5(26.32%)	7(36.84%)	7(36.84%)	19
Hubei Power Transaction Center	5(20.83%)	14(58.33%)	5(20.83%)	24
Hunan Power Transaction Center	5(27.78%)	8(44.44%)	5(27.78%)	18
Henan Power Transaction Center	6(33.33%)	7(38.89%)	5(27.78%)	18
Jiangxi Power Transaction Center	8(40%)	6(30%)	6(30%)	20
Liaoning Power Transaction Center	9(42.86%)	7(33.33%)	5(23.81%)	21
Jilin Power Transaction Center	13(30.23%)	15(34.88%)	15(34.88%)	43
Heilongjiang Power Transaction Center	8(36.36%)	9(40.91%)	5(22.73%)	22
Eastern Inner Mongolia Power Transaction Center	15(45.45%)	11(33.33%)	7(21.21%)	33
Shanxi Power Transaction Center	20(58.82%)	8(23.53%)	6(17.65%)	34
Gansu Power Transaction Center	6(30%)	9(45%)	5(25%)	20
Inner Mongolia Power Transaction Center	5(29.41%)	5(29.41%)	7(41.18%)	17
Qinghai Power Transaction Center	9(47.37%)	5(26.32%)	5(26.32%)	19
Ningxia Power Transaction Center	10(41.67%)	7(29.17%)	7(29.17%)	24

Xinjiang Power Transaction Center	8(32%)	8(32%)	9(36%)	25
Guangdong Power Transaction Center	6(20%)	6(20%)	18(60%)	30
Guangxi Power Transaction Center	8(36.36%)	8(36.36%)	6(27.27%)	22
Kunming Power Transaction Center	5(29.41%)	5(29.41%)	7(41.18%)	17
Guizhou Power Transaction Center	5(33.33%)	5(33.33%)	5(33.33%)	15
Hainan Power Transaction Center	11(50%)	5(22.73%)	6(27.27%)	22

Table A3.21 Sample distribution of the third round of questionnaire survey

Statistical Indicators	Statistical Option	Frequency	Percentage
User Enterprise Type	Power Generation Enterprises	255	34.6
	Power Sales Enterprises	252	34.2
	Commercial and Industrial Users	230	31.2
Multiple Ownership	Members of Only One Power Transaction Platform	496	67.3
	Members of Two or More Power Transaction Platforms	241	32.7
Respondent Level	Senior Managers	104	14.1
	Middle Managers	193	26.2
	Primary Managers	209	28.4
	Ordinary Employees	231	31.3
User Enterprise Size	1,000 or More Employees	128	17.3
	300 or More but Less than 1,000 Employees	217	29.4
	20 or More but Less than 300 Employees	285	38.7
	Less than 20 Employees	107	14.5
Years of User Enterprise Experience	20 years or More	104	14.1
	15 years or more and less than 20 years	133	18.0
	10 years or more and less than 15 years	183	24.8
	5 years or more and less than 10 years	222	30.1
	5 years or less	95	12.9

Table A3.22 Single necessary conditions based on uncalibrated data

Condition	Estimation Method	Precision	Upper Region	Range	Effect Size	p-Value
PLG	CR	78.8%	0.649	1.000	0.377	0.000
	CE	100%	0.664	1.000	0.386	0.000
PLI	CR	78.8%	0.815	1.000	0.412	0.000
	CE	100%	0.888	1.000	0.449	0.000
PLC	CR	69.7%	0.825	1.000	0.454	0.000
	CE	100%	0.883	1.000	0.486	0.000
PLT	CR	75.8%	0.622	1.000	0.395	0.000
	CE	100%	0.640	1.000	0.407	0.000
GR	CR	66.7%	0.873	1.000	0.480	0.000
	CE	100%	0.951	1.000	0.523	0.000

Table A3.23 Bottleneck level analysis based on uncalibrated data

TE	PLG	PLI	PLC	PLT	GR
0	NN	NN	NN	NN	NN
10	NN	NN	4.1	NN	7.0
20	2.3	7.4	14.4	6.8	17.2
30	13.5	18.4	24.7	17.4	27.5
40	24.7	29.3	34.9	28.0	37.7
50	35.9	40.2	45.2	38.6	48.0
60	47.2	51.2	55.5	49.2	58.2
70	58.4	62.1	65.8	59.8	68.5
80	69.6	73.1	76.0	70.4	78.7
90	80.8	84.0	86.3	81.0	88.9

Table A4.1 Calibration of key variables involved in configuration analysis

Condition	Completely Affiliated	Cross-Ambiguity	Completely Unaffiliated
Platform Leadership	4.611111110	4.411764706	4.264705882
Platform Influence	4.686274510	4.424242424	4.253968254
Platform Coordination	4.628930818	4.454545455	4.298245614
Platform Control	4.592592590	4.400000000	4.300000000
Government Regulation	4.636842105	4.448484848	4.294736842
Transaction Efficiency	4.564705882	4.330158730	4.225157233

Table A4.2 Necessity analysis

Condition	TE		~TE	
	Consistency	Coverage	Consistency	Coverage
PLG	0.859024	0.872445	0.250821	0.262546
~PLG	0.273891	0.261839	0.878142	0.865227
PLI	0.865301	0.915435	0.221446	0.241456
~PLI	0.282998	0.260729	**0.922443**	**0.87590**
PLC	**0.908990**	**0.926609**	0.255538	0.268473
~PLC	0.282383	0.269023	**0.930145**	**0.913296**
PLT	**0.913236**	**0.880197**	0.266882	0.265109
~PLT	0.237524	0.239172	0.879396	0.912634
GR	**0.928005**	**0.920078**	0.245388	0.250747
~GR	0.244293	0.239027	**0.921786**	**0.929556**

Table A4.3 Data distribution of platform-level questionnaire survey

Power Transaction Platform	Senior Managers	Middle Managers	Primary Managers	Ordinary Employees	Total
Sichuan Power Transaction Center	1(20%)	3(60%)	0(0.00%)	1(20%)	5
Chongqing Power Transaction Center	0(0.00%)	0(0.00%)	2(25%)	6(75%)	8
Tibet Power Transaction Center	0(0.00%)	0(0.00%)	1(33.33%)	2(66.67%)	3

Capital Power Transaction Center	0(0.00%)	3(100%)	0(0.00%)	0(0.00%)	3
Tianjin Power Transaction Center	0(0.00%)	2(66.67%)	0(0.00%)	1(33.33%)	3
Northern Hebei Power Transaction Center	8(72.73%)	0(0.00%)	0(0.00%)	3(27.27%)	11
Hebei Power Transaction Center	0(0.00%)	0(0.00%)	1(25%)	3(75%)	4
Shanxi Power Transaction Center	0(0.00%)	1(9.09%)	5(45.45%)	5(45.45%)	11
Shandong Power Transaction Center	0(0.00%)	2(15.38%)	2(15.38%)	9(69.23%)	13
Shanghai Power Transaction Center	0(0.00%)	3(60%)	1(20%)	1(20%)	5
Jiangsu Power Transaction Center	0(0.00%)	0(0.00%)	6(75%)	2(25%)	8
Zhejiang Power Transaction Center	0(0.00%)	0(0.00%)	0(0.00%)	3(100%)	3
Anhui Power Transaction Center	0(0.00%)	0(0.00%)	1(33.33%)	2(66.67%)	3
Fujan Power Transaction Center	0(0.00%)	0(0.00%)	0(0.00%)	3(100%)	3
Hubei Power Transaction Center	0(0.00%)	0(0.00%)	2(28.57%)	5(71.43%)	7
Hunan Power Transaction Center	0(0.00%)	0(0.00%)	0(0.00%)	4(100%)	4
Henan Power Transaction Center	0(0.00%)	0(0.00%)	1(20%)	4(80%)	5
Jiangxi Power Transaction Center	0(0.00%)	0(0.00%)	2(50%)	2(50%)	4
Liaoning Power Transaction Center	0(0.00%)	0(0.00%)	1(33.33%)	2(66.67%)	3
Jilin Power Transaction Center	0(0.00%)	2(20%)	1(10%)	7(70%)	10
Heilongjiang Power Transaction Center	0(0.00%)	0(0.00%)	0(0.00%)	4(100%)	4
Eastern Inner Mongolia Power Transaction Center	0(0.00%)	1(25%)	3(75%)	0(0.00%)	4
Shanxi Power Transaction Center	0(0.00%)	0(0.00%)	1(16.67%)	5(83.33%)	6
Gansu Power Transaction Center	3(60%)	0(0.00%)	1(20%)	1(20%)	5
Inner Mongolia Power Transaction Center	0(0.00%)	0(0.00%)	1(25%)	3(75%)	4
Qinghai Power Transaction Center	0(0.00%)	0(0.00%)	1(20%)	4(80%)	5
Ningxia Power Transaction Center	0(0.00%)	0(0.00%)	2(40%)	3(60%)	5
Xinjiang Power Transaction Center	1(20%)	0(0.00%)	0(0.00%)	4(80%)	5
Guangdong Power Transaction Center	1(3.23%)	5(16.13%)	4(12.90%)	21(67.74%)	31
Guangxi Power Transaction Center	0(0.00%)	0(0.00%)	1(16.67%)	5(83.33%)	6
Kunming Power	1(25%)	1(25%)	0(0.00%)	2(50%)	4

Transaction Center					
Guizhou Power Transaction Center	3(21.43%)	1(7.14%)	4(28.57%)	6(42.86%)	14
Hainan Power Transaction Center	3(23.08%)	2(15.38%)	2(15.38%)	6(46.15%)	13

Table A4.4 Platform-level data calibration

Condition	Completely Affiliated	Cross-Ambiguity	Completely Unaffiliated
Platform Leadership	4.755555556	4.500000000	4.113095238
Platform Influence	4.763888889	4.564102564	4.366666667
Platform Coordination	4.763888889	4.533333333	4.332258065
Platform Control	4.758974359	4.500000000	4.400000000
Government Regulation	4.743846154	4.527272727	4.305000000
Transaction Efficiency	4.633333333	4.440000000	4.203333333

Table A5.1 Independent samples T-Test

Results of t-test analysis				
	group (Mean ± Standard Deviation)		t	p
	group 1 (n=17)	group 2 (n=13)		
PEF	4.48±0.20	4.02±0.25	5.630	0.000**

Note：* p<0.05 ** p<0.01

Table A5.2 Robustness test of platform guidance moderating effect

Variable	Model 1		Model 2		Model 3	
	B	SE	B	SE	B	SE
Constant	3.209***	0.252	3.023***	0.283	2.740***	0.282
UET	0.010	0.020	0.012	0.020	0.013	0.019
UES	-0.075**	0.022	-0.076**	0.022	-0.073**	0.021
UIA	-0.011	0.016	-0.011	0.016	-0.008	0.016
GR	-0.250***	0.051	-0.218***	0.055	-0.175**	0.055
DIG	0.517***	0.042	0.527***	0.043	0.536***	0.042
UMH	0.075**	0.033	0.074**	0.033	0.071**	0.033
TE	0.646***	0.050	0.657***	0.050	0.676***	0.049
PLG			-0.054	0.038	-0.009	0.038
PLG*TE					0.072***	0.013
R^2	0.781		0.782		0.791	
Adjusted R^2	0.779		0.779		0.789	
F Value	344.306***		301.986***		283.536***	
$\triangle R^2$	0.781		0.001		0.009	
$\triangle F$ Value	344.306***		2.038		30.435***	

Note: N=683; dependent variable is user enterprise performance (PEF); * p<0.05, ** p<0.01, *** p<0.001.

Table A5.3 Robustness test of the platform influence moderating effect

Variable	Model 1		Model 2		Model 3	
	B	SE	B	SE	B	SE
Constant	3.209***	0.252	2.930***	0.290	2.644***	0.289
UET	0.010	0.020	0.013	0.020	0.014	0.019
UES	-0.075**	0.022	-0.078***	0.022	-0.075**	0.021
UIA	-0.011	0.016	-0.010	0.016	-0.007	0.016
GR	-0.250***	0.051	-0.193**	0.058	-0.152**	0.058
DIG	0.517***	0.042	0.523***	0.042	0.533***	0.042
UMH	0.075**	0.033	0.073**	0.033	0.073**	0.033
TE	0.646***	0.050	0.664***	0.050	0.678***	0.050
PLI			-0.081	0.042	-0.034	0.042
PLI*TE					0.069***	0.013
R^2	0.781		0.782		0.791	
Adjusted R^2	0.779		0.780		0.788	
F Value	344.306***		302.968***		283.086***	
$\triangle R^2$	0.781		0.001		0.009	
$\triangle F$ Value	344.306***		3.758		27.767***	

Table A5.4 Robustness test of the platform coordination moderating effect

Variable	Model 1		Model 2		Model 3	
	B	SE	B	SE	B	SE
Constant	3.209***	0.252	3.136***	0.295	2.895***	0.293
UET	0.010	0.020	0.010	0.020	0.011	0.019
UES	-0.075**	0.022	-0.076**	0.022	-0.074**	0.021
UIA	-0.011	0.016	-0.011	0.016	-0.007	0.016
GR	-0.250***	0.051	-0.236***	0.059	-0.197**	0.058
DIG	0.517***	0.042	0.519***	0.043	0.522***	0.042
UMH	0.075**	0.033	0.076**	0.033	0.073**	0.033
TE	0.646***	0.050	0.652***	0.051	0.669***	0.050
PLC			-0.022	0.046	0.033	0.046
PLC*TE					0.070***	0.013
R^2	0.781		0.781		0.790	
Adjusted R^2	0.779		0.779		0.787	
F Value	344.306***		00.952***		281.083***	
$\triangle R^2$	0.781		0.000		0.009	
$\triangle F$ Value	344.306***		0.228		27.494***	

Table A5.5 Robustness test of the platform control moderating effect

Variable	Model 1		Model 2		Model 3	
	B	SE	B	SE	B	SE
Constant	3.209***	0.252	2.930***	0.290	2.644***	0.289
UET	0.010	0.020	0.013	0.020	0.014	0.019
UES	-0.075**	0.022	-0.078***	0.022	-0.075**	0.021
UIA	-0.011	0.016	-0.010	0.016	-0.007	0.016
GR	-0.250***	0.051	-0.193**	0.058	-0.152**	0.058
DIG	0.517***	0.042	0.523***	0.042	0.533***	0.042
UMH	0.075**	0.033	0.073**	0.033	0.073**	0.033
TE	0.646***	0.050	0.664***	0.050	0.678***	0.050
PLT			-0.081	0.042	-0.034	0.042
PLT*TE					0.069***	0.013

R^2	0.781	0.782	0.791
Adjusted R^2	0.779	0.780	0.788
F Value	344.306***	302.968***	283.086***
$\triangle R^2$	0.781	0.001	0.009
$\triangle F$ Value	344.306***	3.758	27.767***

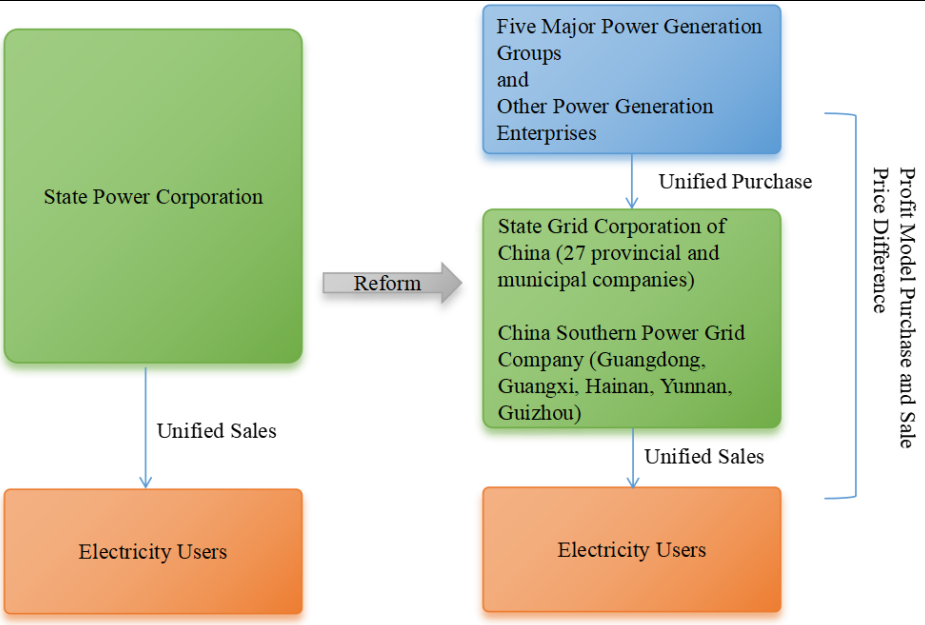


Figure A1.1 Schematic diagram of the separation of power plants and grids in the first round of electricity sector reform in 2002

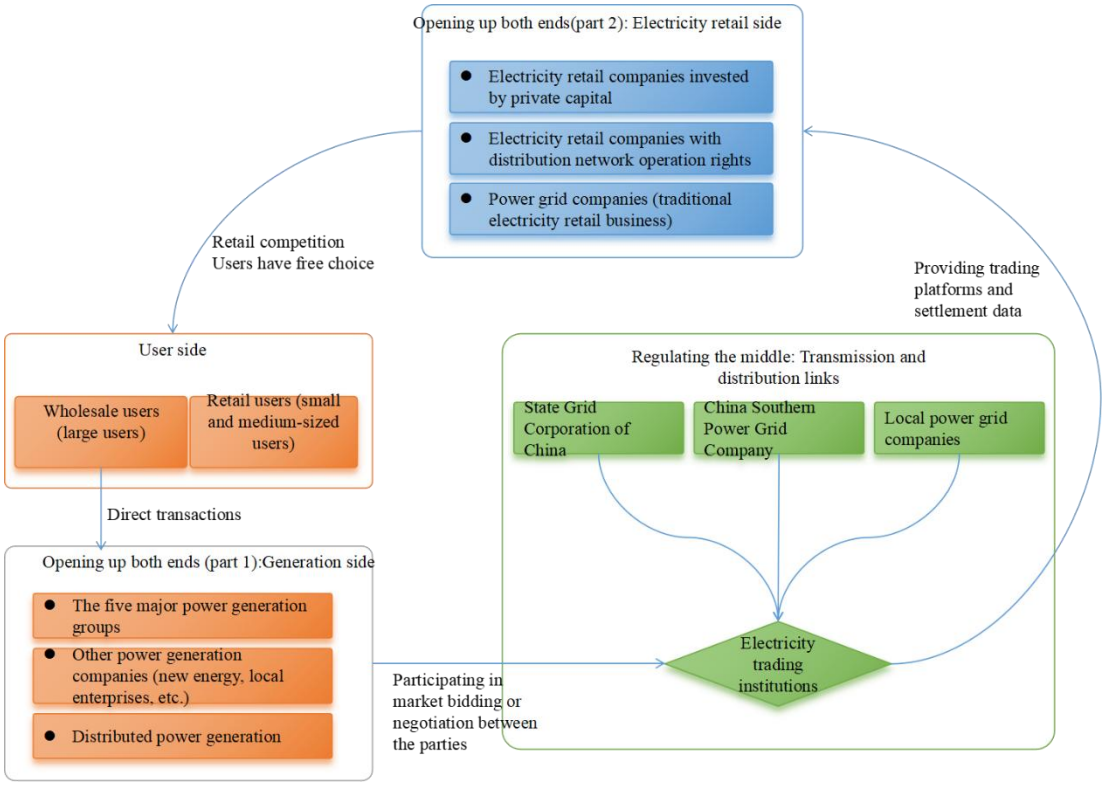


Figure A1.2 Electricity market organization diagram in the new round of power reform in 2015

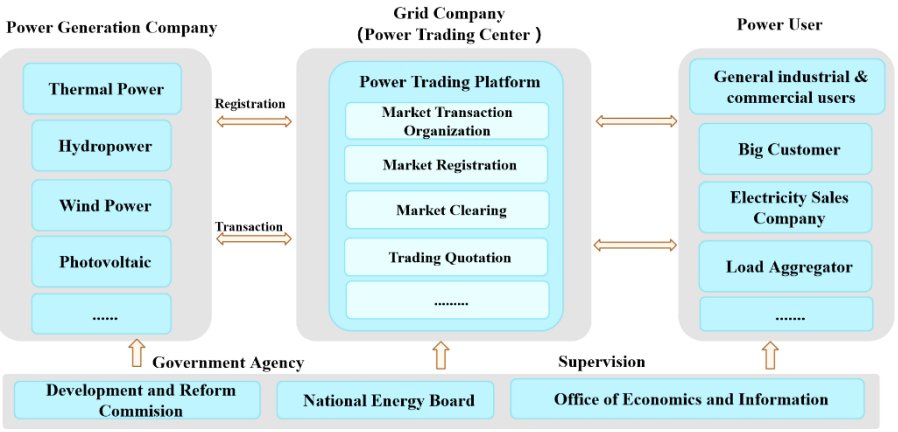


Figure A1.3 Overview of the electricity transaction platform

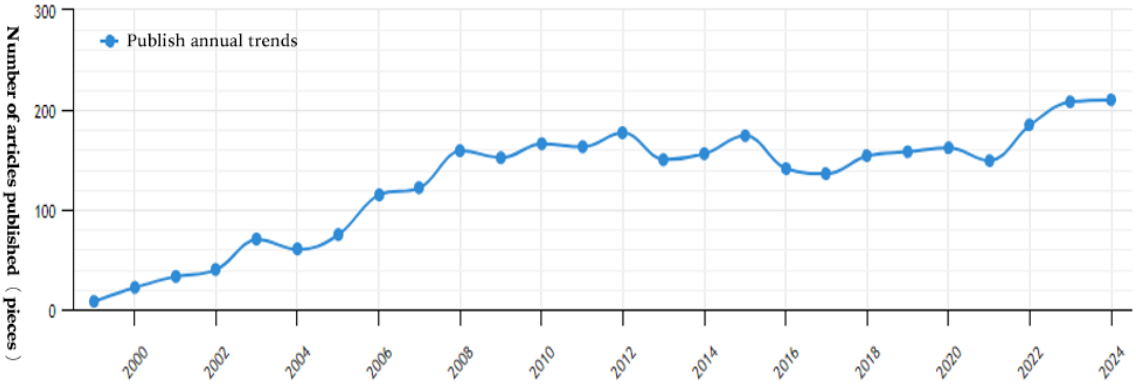


Figure A2.1 Distribution of CSSCI publications per year

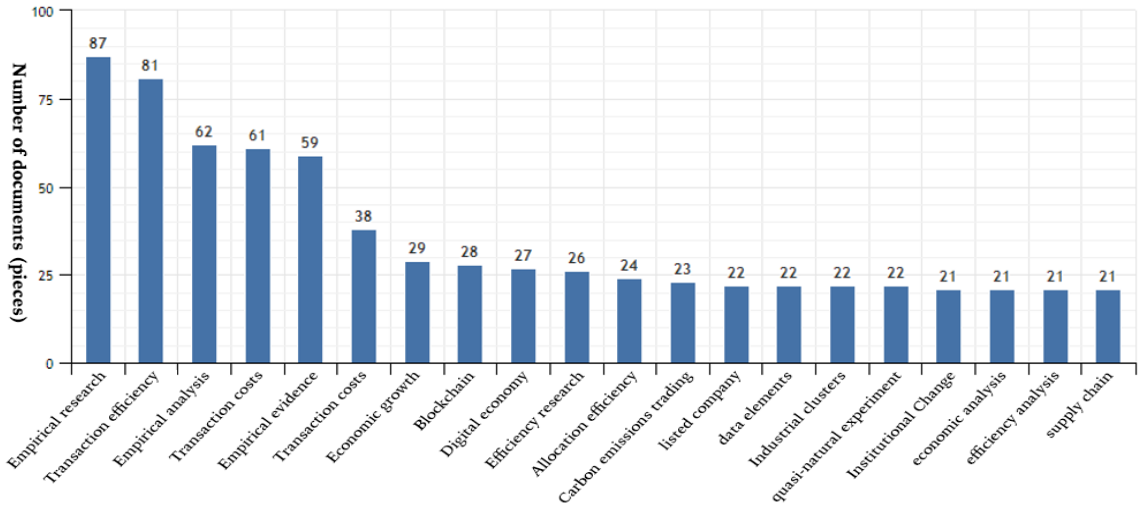


Figure A2.2 Distribution of CSSCI publications topics

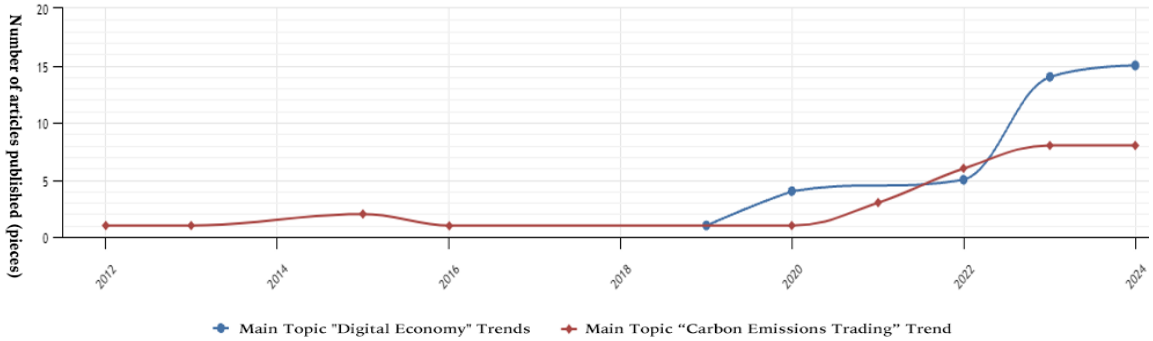


Figure A2.3 Distribution of annual publications for the keywords "digital economy" and "carbon emissions trading"

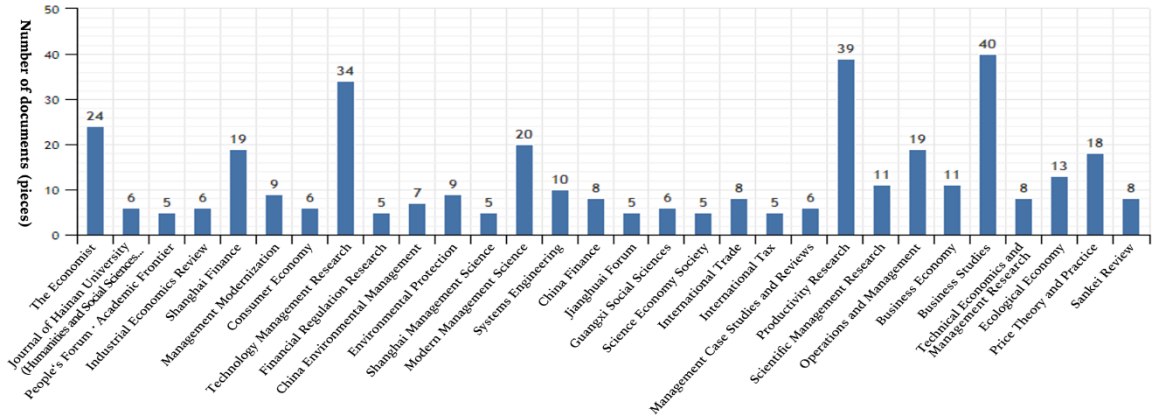


Figure A2.4 Distribution of CSSCI-indexed publications journals

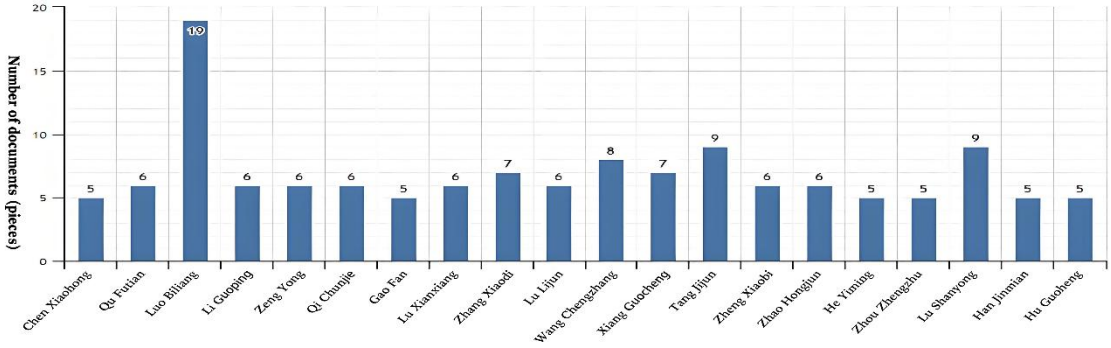


Figure A2.5 Distribution of authors of CSSCI publications

Authors	Year	Strength	Begin	End	1999 - 2024
Yang Xiaokai	1999	1.91	1999	2000	
Yang Liyan	2001	2.04	2001	2001	
Cheng Hongbo	2003	1.98	2003	2003	
Li Bingxiang	2003	1.98	2003	2003	
Xiang Guocheng	2005	2.3	2005	2007	
Zhao Hongjun	2005	2	2005	2005	
Li Guoping	2006	3.05	2006	2007	
Wang Chengzhang	2006	3.05	2006	2007	
He Xionglang	2006	2.63	2006	2006	
Li Jing	2007	2.45	2007	2008	
Gao Fan	2007	1.95	2007	2007	
Luo Yongmin	2008	1.97	2008	2008	
Cheng Shiyong	2009	1.99	2009	2009	
Li Weiqun	2009	1.99	2009	2009	
Li Huai	2010	2.41	2010	2011	
Xiong Qi	2011	2.92	2011	2012	
Sun Liangyuan	2011	1.94	2011	2011	
Yao Wei	2011	1.94	2011	2011	
Zou Wei	2011	1.94	2011	2011	
He Juan	2012	2.54	2012	2012	
Zhang Peng	2013	1.96	2013	2013	
Huo Guoheng	2013	1.96	2013	2013	
Luo Biliang	2015	4.34	2015	2018	
Fang Zhenming	2011	2.54	2018	2020	
Lu Shanyong	2019	1.96	2019	2019	

Figure A2.6 Emergence analysis of authors publishing in CSSCI publications

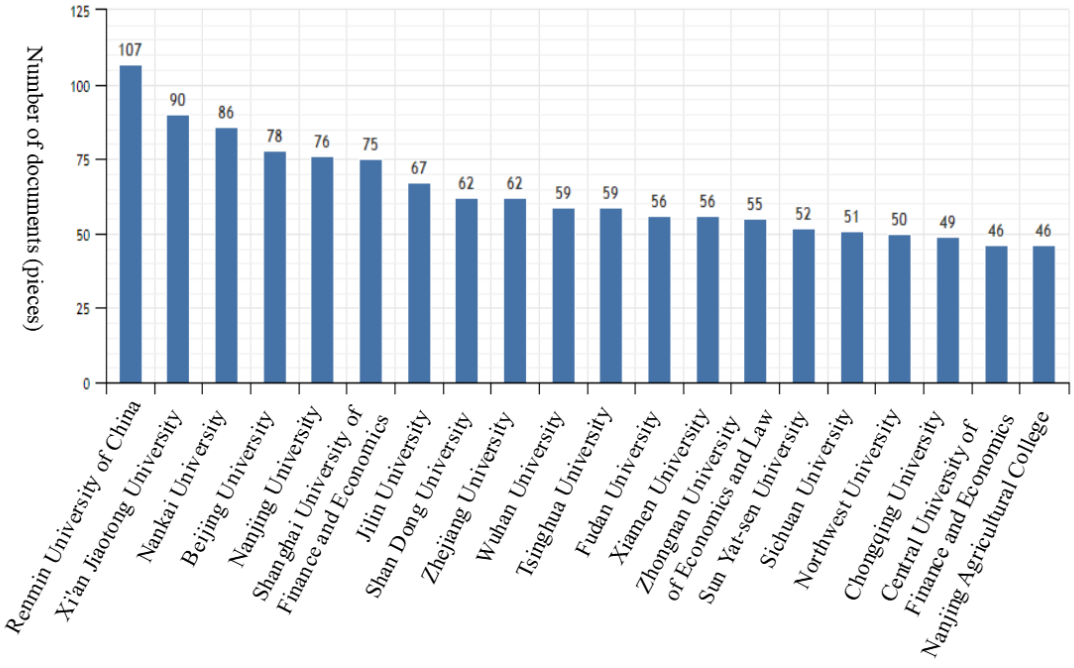


Figure A2.7 Distribution of institutions publishing CSSCI literature

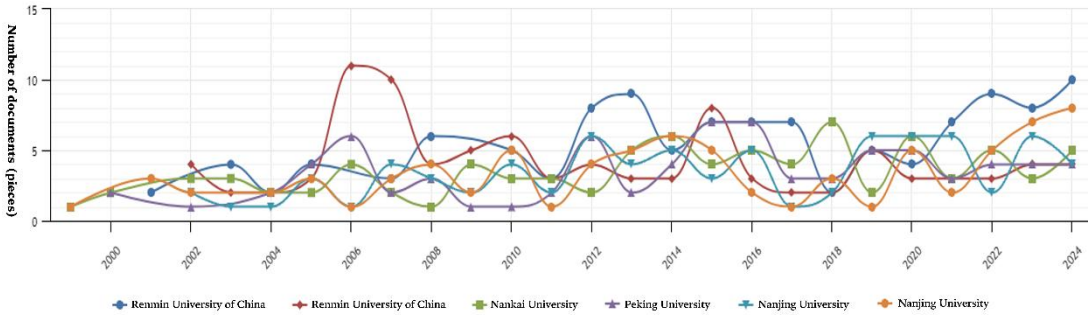


Figure A2.8 Distribution of annual publications by highly prolific research institutions in CSSCI literature

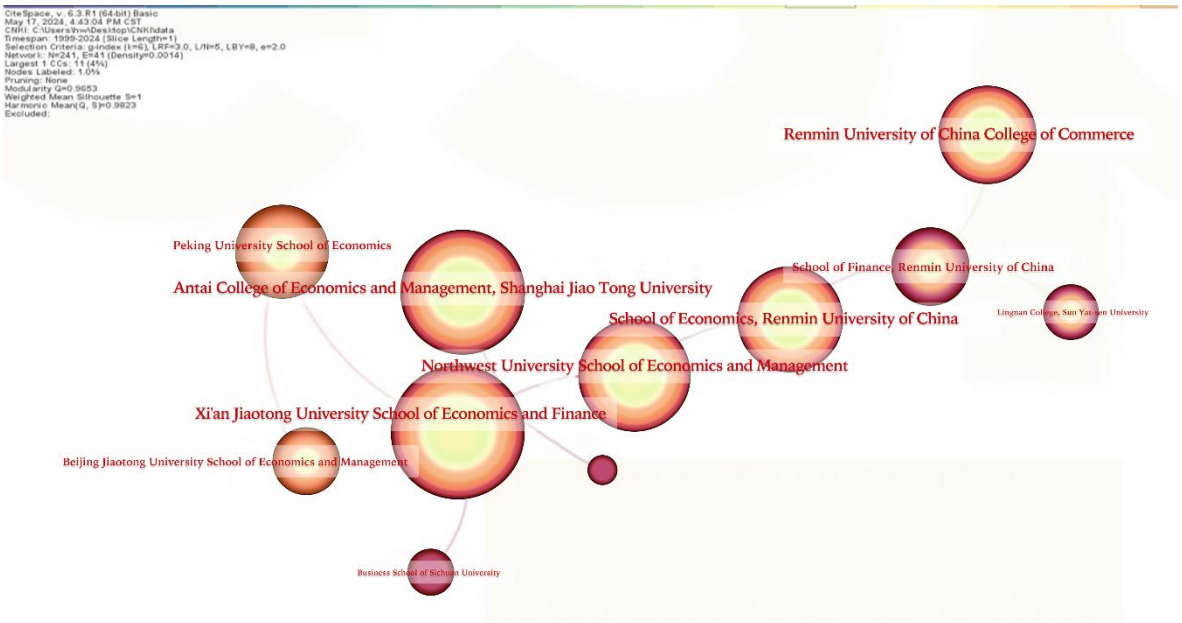


Figure A2.9 Network clustering of CSSCI publication institutions

Institutions	Year	Strength	Begin	End	1999 - 2024
Shanghai Jiao Tong University School of Management	2002	4.17	2002	2006	
Sun Yat-sen University School of Management	2003	5.23	2003	2013	
Xi'an Jiaotong University School of Economics and Finance	2005	3.85	2005	2007	
Southwest Jiaotong University School of Economics and Management	2006	6.05	2006	2007	
Shandong University School of Economics	2007	4.89	2007	2009	
Huazhong Agricultural University School of Economics and Management	2007	4.06	2007	2009	
Antai College of Economics and Management, Shanghai Jiao Tong University	2008	4.41	2008	2012	
Renmin University of China College of Commerce	2008	3.61	2008	2016	
Chongqing University School of Economics and Business Administration	2007	6.14	2010	2012	
South China Agricultural University School of Economics and Management	2011	5.81	2011	2016	
Northwest University School of Economics and Management	1999	4.17	2011	2012	
Peking University Law School	2012	3.98	2012	2013	
Peking University School of Economics	2006	4.4	2015	2019	
Department of Management and Economics, Dalian University of Technology	2016	3.38	2016	2018	
Central South University Business School	2006	4.33	2018	2020	
Wuhan University School of Economics and Management	2009	3.67	2018	2021	
Xiamen University School of Economics	2012	4.49	2019	2021	
School of Finance, Central University of Finance and Economics	2020	4.2	2020	2021	
Hohai University Business School	2009	3.34	2020	2022	
China University of Political Science and Law, School of Civil, Commercial and Economic Studies	2021	3.88	2021	2021	
Institute of Industrial Economics, Chinese Academy of Social Sciences	2006	5.49	2022	2024	
Hunan University of Science and Technology Business School	2022	3.42	2022	2024	

Figure A2.10 Emergence analysis of CSSCI publication institutions

Keywords	Year	Strength	Begin	End	1999 - 2024
Trade	2000	5.95	2000	2004	
Transaction Fee	1999	7.36	2001	2005	
Property	2002	9.43	2002	2008	
System	1999	6.81	2002	2006	
Division of Labor	2003	8.59	2003	2011	
Industrial Clusters	2004	6	2004	2012	
Social Capital	2005	7.68	2005	2008	
Related Party Transactions	2006	6.77	2006	2014	
Market Efficiency	2007	5.77	2007	2009	
Institutional Change	2005	6.57	2008	2014	
Low-carbon Economy	2010	6.86	2010	2015	
Information Efficiency	2012	5.57	2012	2020	
Stock Index Futures	2012	5.48	2012	2018	
Carbon Trading	2013	6.72	2013	2024	
Margin Margin Trading	2014	11.44	2014	2019	
E-Commerce	2000	5.7	2014	2019	
Pricing Efficiency	2013	9.46	2015	2022	
Sharing Economy	2016	6.8	2016	2021	
Economic Growth	2004	6.84	2017	2022	
Blockchain	2017	24.17	2018	2022	
Data Elements	2020	10.65	2020	2024	
Smart Contract	2020	5.37	2020	2022	
Carbon Neutral	2021	7.24	2021	2024	
Digital Economy	2020	20.77	2022	2024	
Digital Technology	2022	5.1	2022	2024	

Figure A2.11 Keyword surge analysis in CSSCI literature

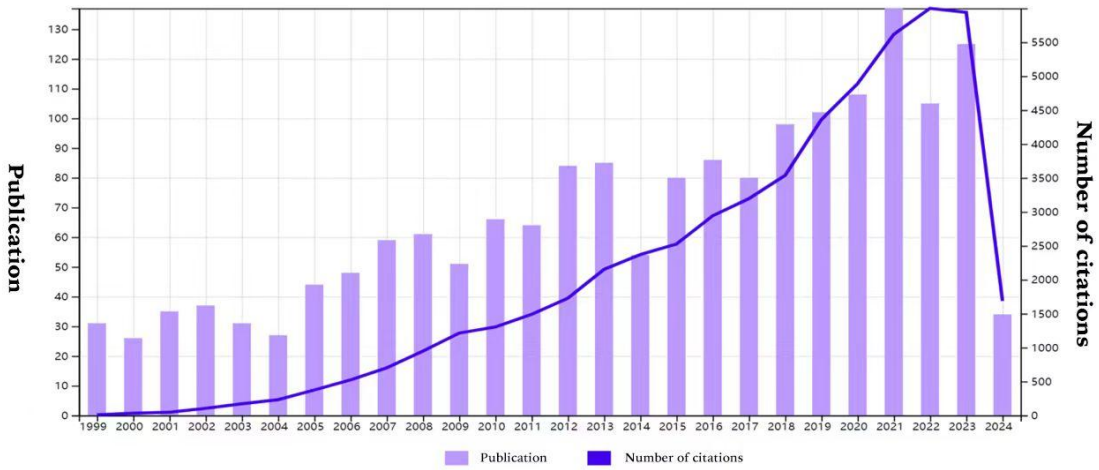


Figure A2.12 Distribution of annual SSCI publications and citations

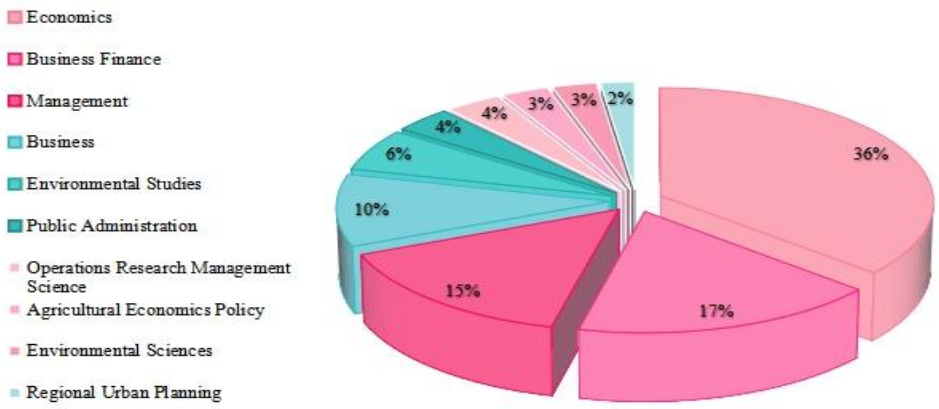


Figure A2.13 Distribution of research fields in SSCI literature

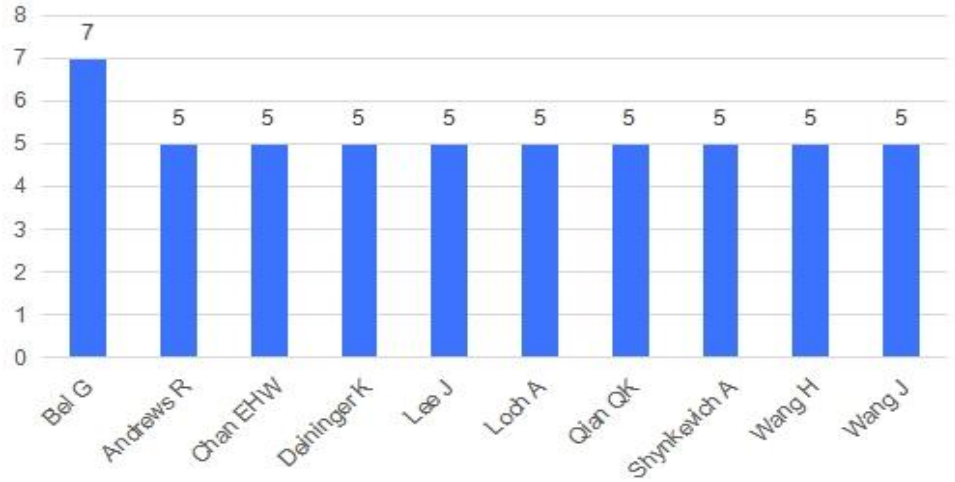


Figure A2.14 Distribution of authors of SSCI publications

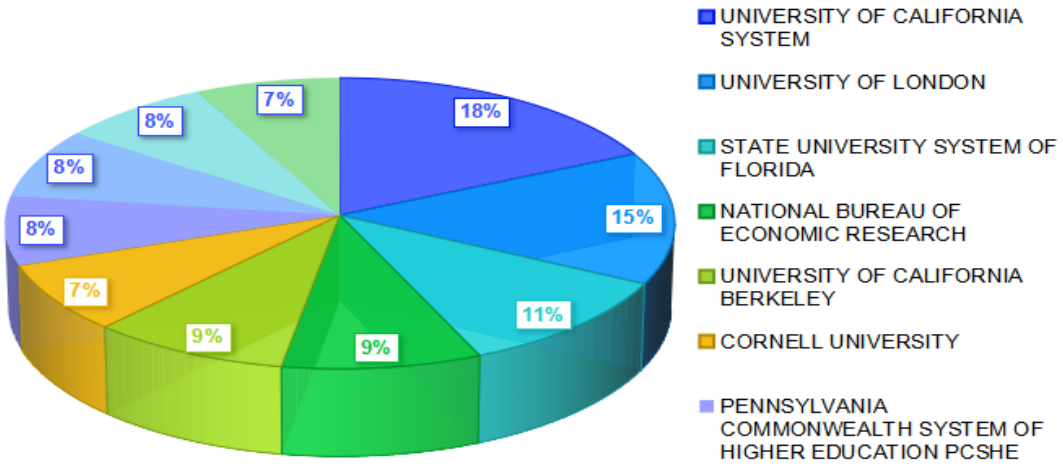


Figure A2.15 Distribution of SSCI publication institutions

Institutions	Year	Strength	Begin	End	1999 - 2024
Cornell Univ	1999	2.64	1999	2000	
Harvard Univ	1999	2.3	1999	2007	
Univ Calif Berkeley	2001	5.49	2001	2010	
Purdue Univ	2003	2.04	2003	2003	
Australian Natl Univ	2004	2.62	2004	2012	
NBER	2011	2.87	2011	2015	
City Univ Hong Kong	2008	3.06	2016	2020	
Univ Oxford	2017	2.6	2017	2017	
Univ Econ Ho Chi Minh City	2021	2.6	2021	2021	
Southwestern Univ Finance & Econ	2023	2.6	2023	2024	

Figure A2.16 Emergence of SSCI publication institutions



Figure A2.17 SSCI literature publication country network clustering

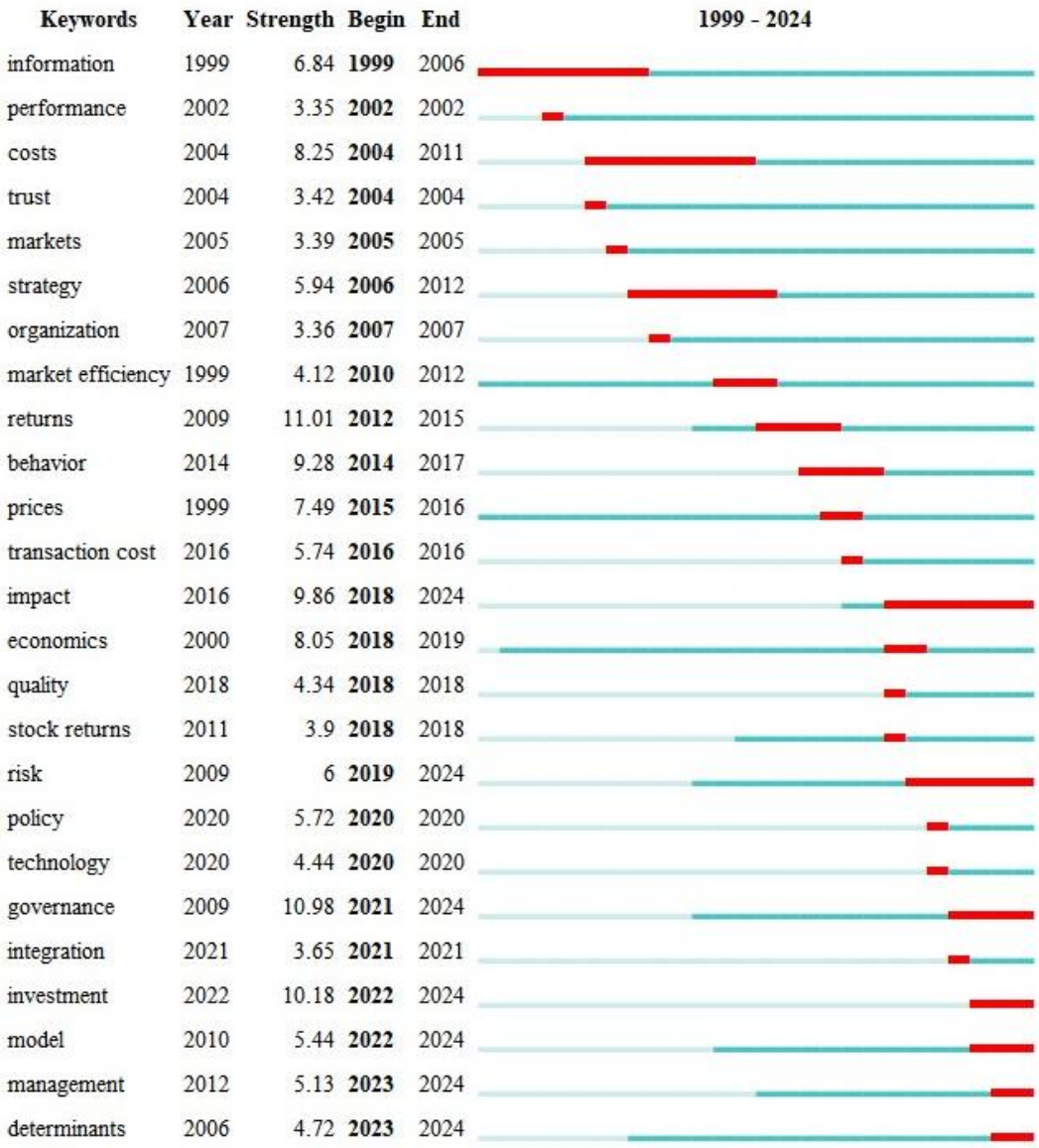


Figure A2.18 Keyword surge in SSCI literature

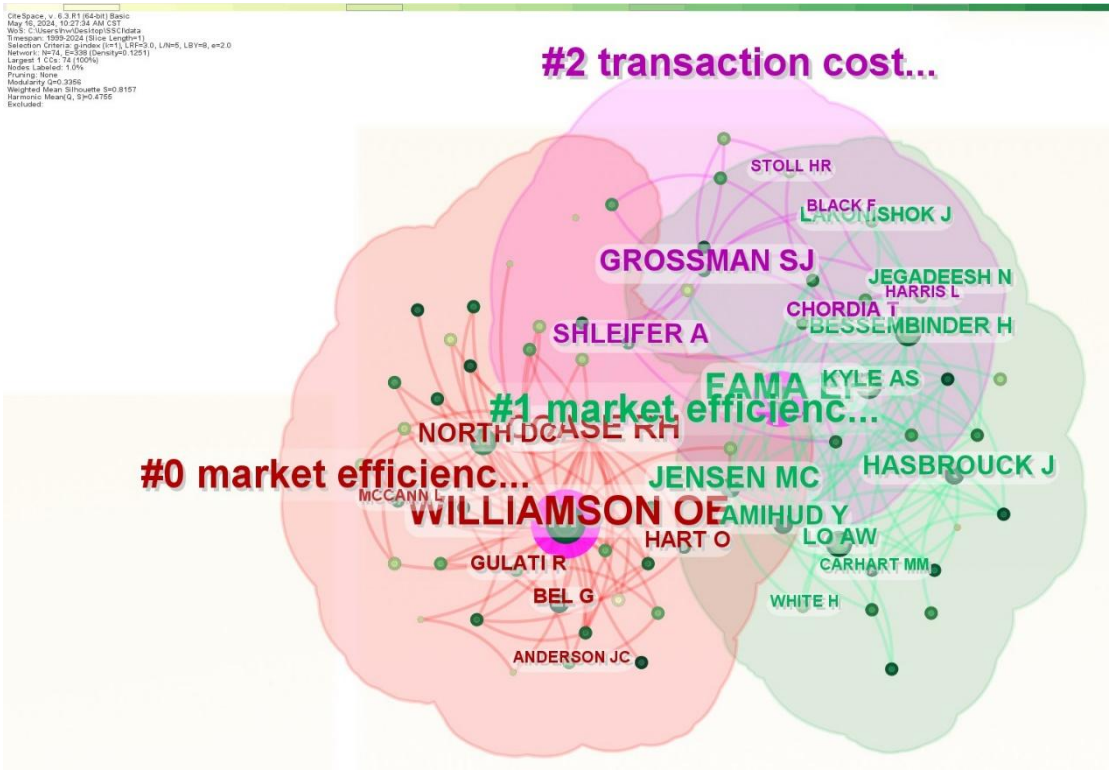


Figure A2.19 Clustering of highly cited authors in SSCI publications

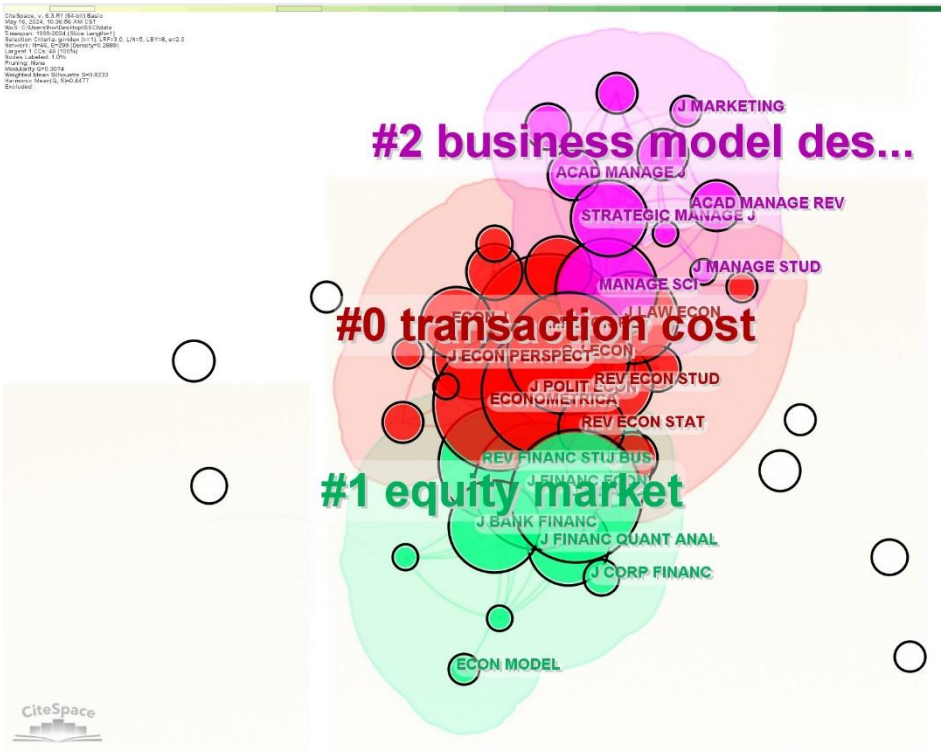


Figure A2.20 Clustering of highly cited SSCI journals

References	Year	Strength	Begin	End	1999 - 2024
Fama EF, 1998, J FINANC ECON, V49, P283, DOI 10.1016/S0304-405X(98)00026-9, DOI	1998	2.68	2004	2004	
Keim DB, 1997, J FINANC ECON, V46, P265, DOI 10.1016/S0304-405X(97)00031-7, DOI	1997	2.05	2005	2005	
Gompers PA, 2001, Q J ECON, V116, P229, DOI 10.1162/003355301556392, DOI	2001	2.05	2006	2006	
Teo HH, 2003, MIS QUART, V27, P19, DOI 10.2307/30036518, DOI	2003	2.04	2007	2007	
DiMaggio PJ, 2000, ADV STRATEG MANAGE, V 17, P143, DOI 10.2307/2095101, DOI	2000	2.04	2007	2007	
Lesmond DA, 2004, J FINANC ECON, V71, P349, DOI 10.1016/S0304-405X(03)00206-X, DOI	2004	3.82	2008	2009	
Jacobides MG, 2005, STRATEGIC MANAGE J, V26, P395, DOI 10.1002/smj.460, DOI	2005	2	2009	2009	
Amihud Y, 2002, J FINANC MARK, V5, P31, DOI 10.1016/S1386-4181(01)00024-6, DOI	2002	2	2009	2009	
Hefetz A, 2004, J PUBL ADM RES THEOR, V14, P171, DOI 10.1093/jopart/muh012, DOI	2004	2.66	2010	2010	
Habermeier K, 2003, IMF STAFF PAPERS, V50, P165	2003	2.05	2011	2011	
Park CH, 2007, J ECON SURV, V21, P786, DOI 10.1111/j.1467-6419.2007.00519.x, DOI	2007	5.37	2012	2015	
Hansen PR, 2005, J BUS ECON STAT, V23, P365, DOI 10.1198/073500105000000063, DOI	2005	2.64	2012	2012	
McCann L, 2005, ECOL ECON, V52, P527, DOI 10.1016/j.ecolecon.2004.08.002, DOI	2005	3.35	2013	2013	
Petersen MA, 2009, REV FINANC STUD, V22, P435, DOI 10.1093/rfs/hhn053, DOI	2009	2.68	2014	2014	
Griffin JM, 2010, REV FINANC STUD, V23, P3225, DOI 10.1093/rfs/hhq044, DOI	2010	3.48	2015	2017	
Hyland M, 2013, ENERG ECON, V40, P943, DOI 10.1016/j.eneco.2013.07.020, DOI	2013	2	2016	2016	
Kahn ME, 2014, REG SCI URBAN ECON, V47, P25, DOI 10.1016/j.regsciurbeco.2013.07.001, DOI	2014	2	2016	2016	
Brounen D, 2011, J ENVIRON ECON MANAG, V62, P166, DOI 10.1016/j.jeem.2010.11.006, DOI	2011	2	2016	2016	
Brogaard J, 2014, REV FINANC STUD, V27, P2267, DOI 10.1093/rfs/hhu032, DOI	2014	3.48	2017	2021	
Fama EF, 2015, J FINANC ECON, V116, P1, DOI 10.1016/j.jfineco.2014.10.010, DOI	2015	4.54	2019	2024	
Shahab S, 2018, LAND USE POLICY, V70, P263, DOI 10.1016/j.landusepol.2017.09.028, DOI	2018	2.66	2020	2020	
Wang YL, 2019, SUPPLY CHAIN MANAG, V24, P62, DOI 10.1108/SCM-03-2018-0148, DOI	2019	2	2022	2022	
Voorn B, 2019, PUBLIC ADMIN, V97, P671, DOI 10.1111/padm.12587, DOI	2019	3.11	2023	2024	
Harvey CR, 2016, REV FINANC STUD, V29, P5, DOI 10.1093/rfs/hhv059, DOI	2016	3.11	2023	2024	
Aldag A, 2020, J PUBL ADM RES THEOR, V30, P275, DOI 10.1093/jopart/muz023, DOI	2020	2.47	2023	2024	

Figure A2.21 Surge of SSCI cited literature

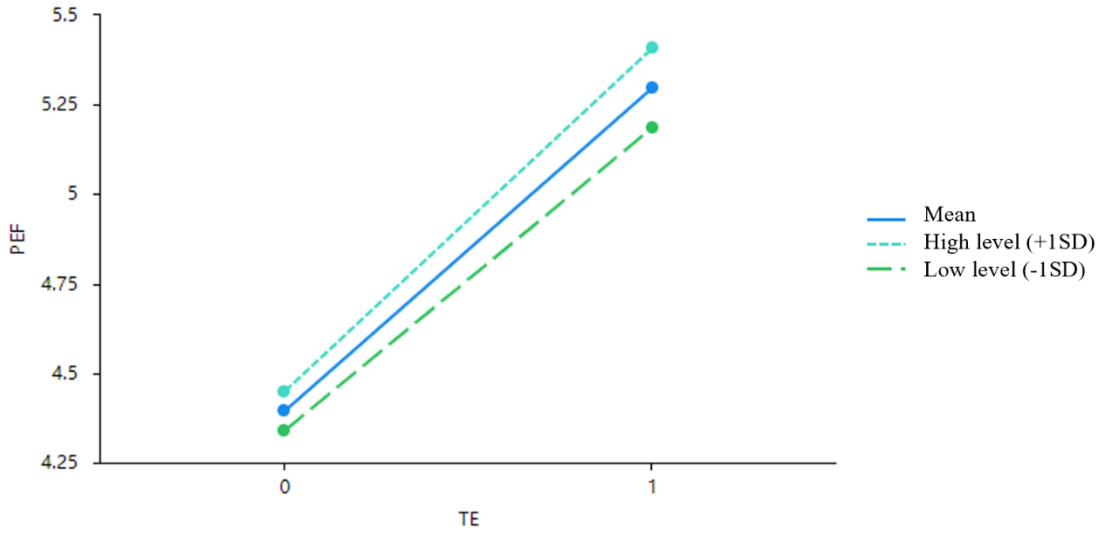


Figure A5.1 Schematic diagram of the platform guidance modulation effect

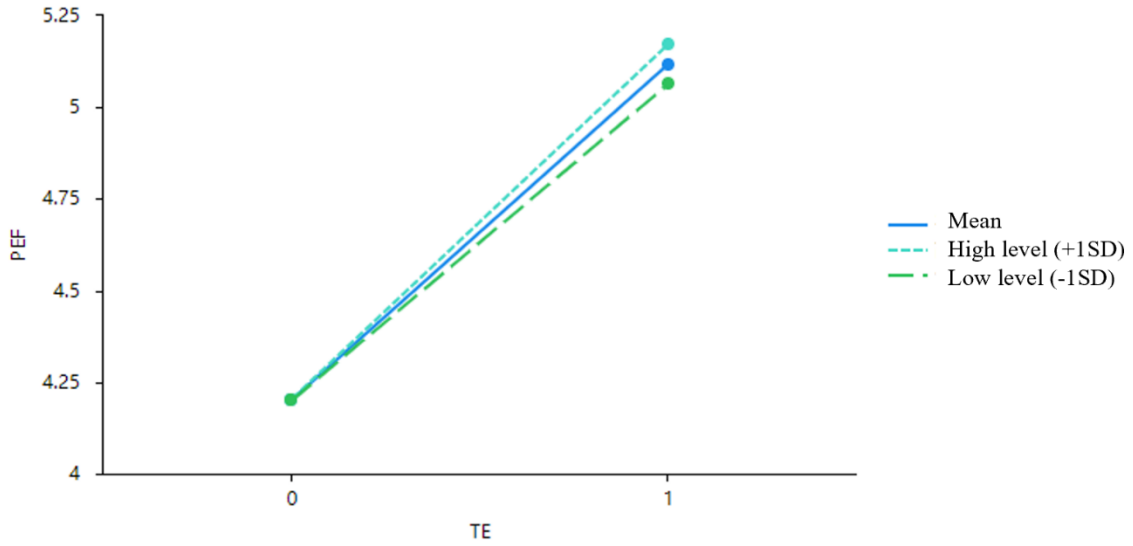


Figure A5.2 Schematic diagram of the moderating effect of platform influence

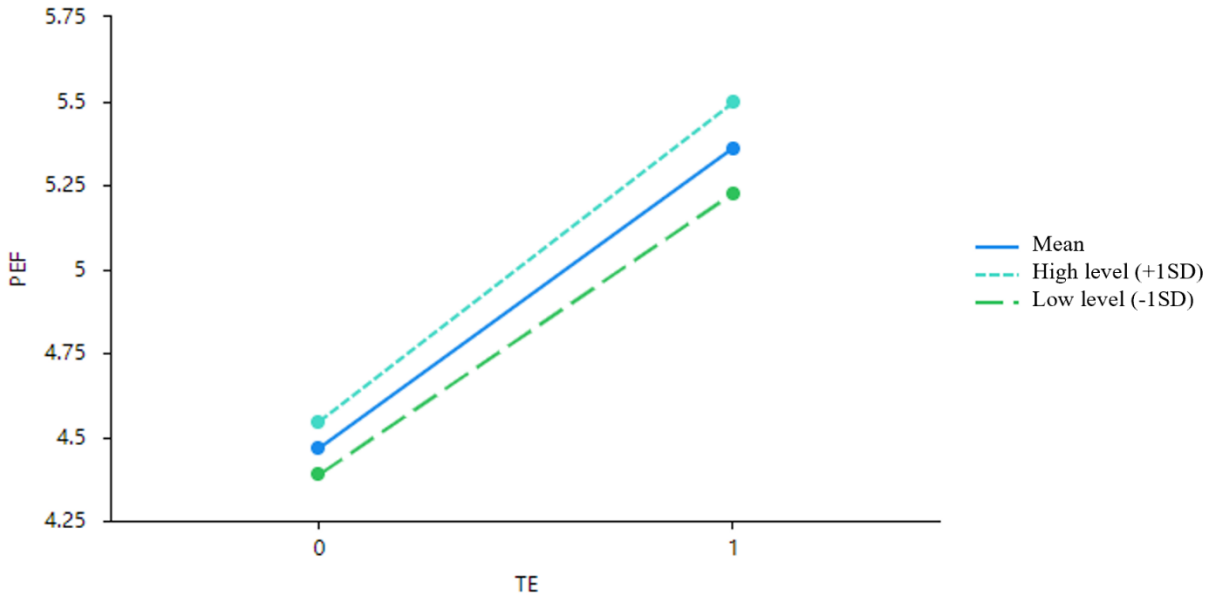


Figure A5.3 Schematic diagram of the platform coordination force adjustment effect

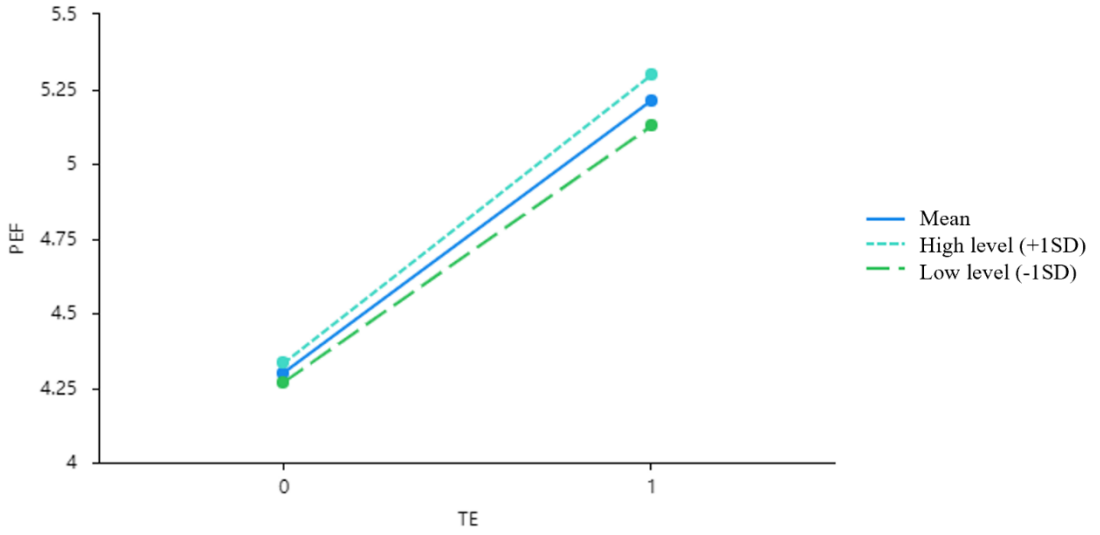


Figure A5.4 Schematic diagram of platform control force adjustment effect

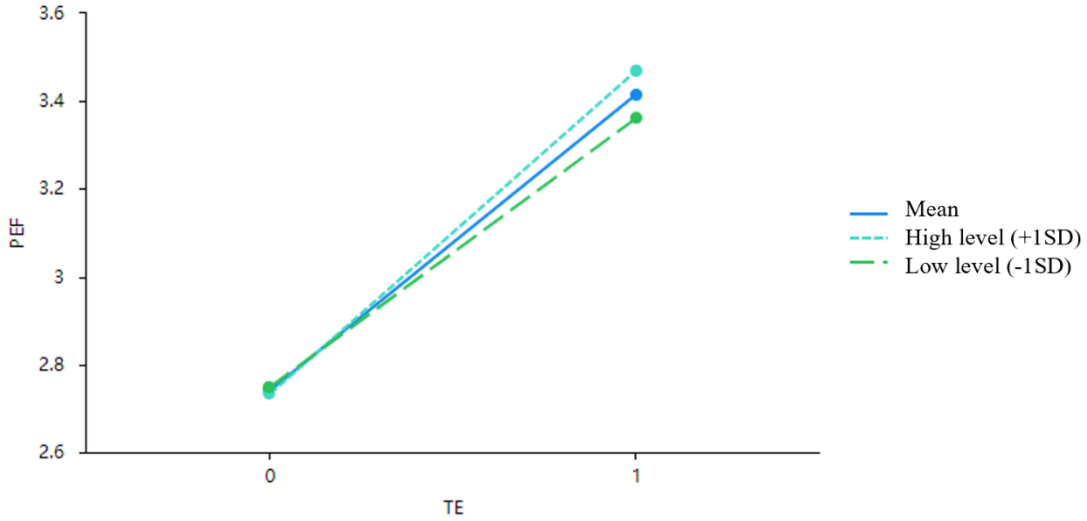


Figure A5.5 Schematic diagram of the platform guidance moderating effect (robustness test)

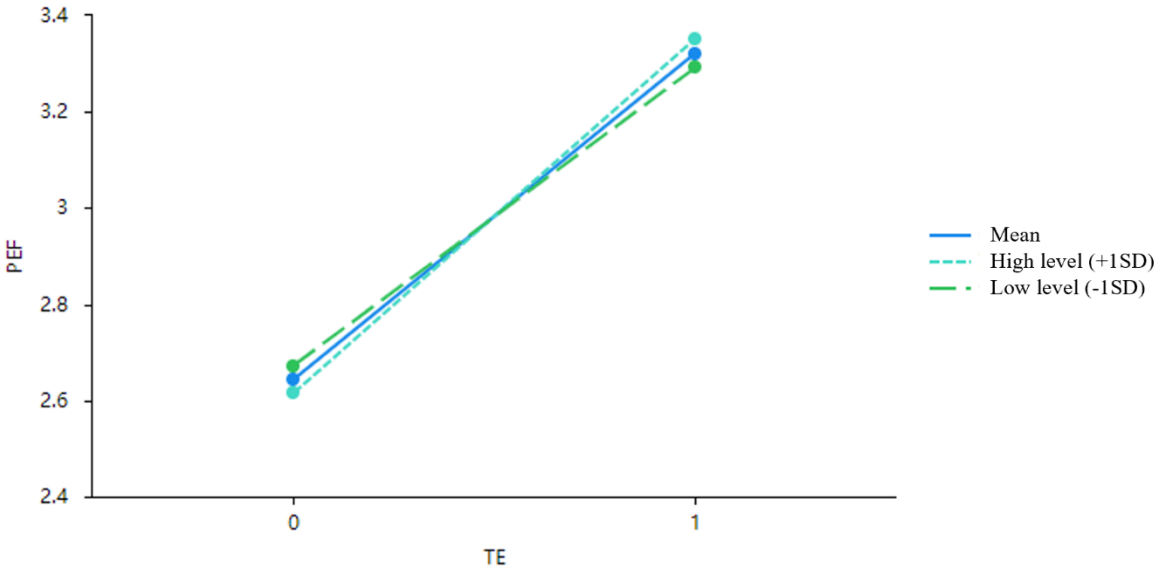


Figure A5.6 Schematic diagram of the moderating effect of platform influence (robustness test)

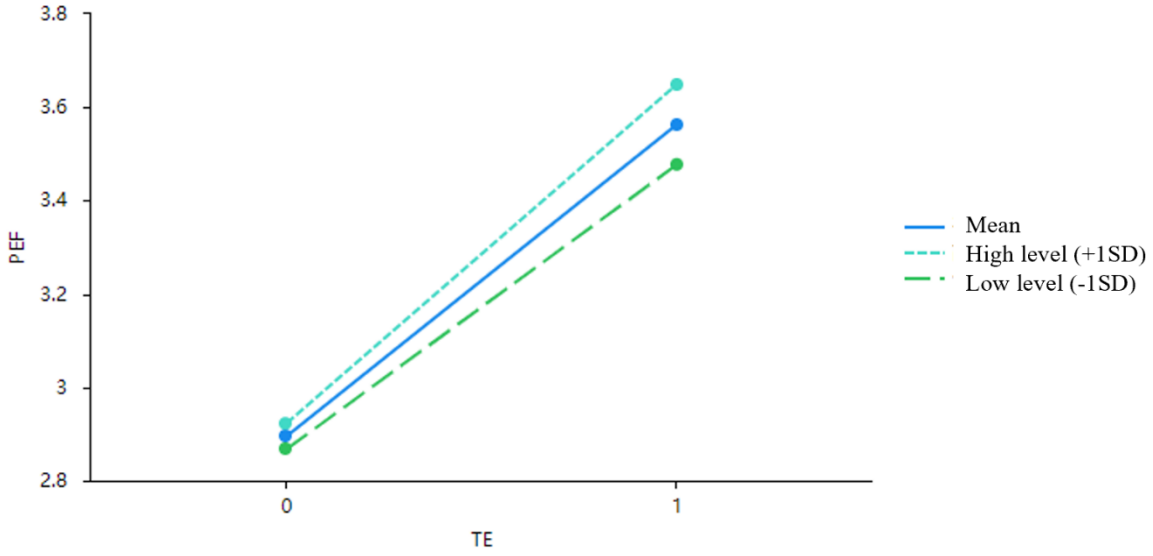


Figure A5.7 Schematic diagram of the platform coordination force modulation effect (robustness test)

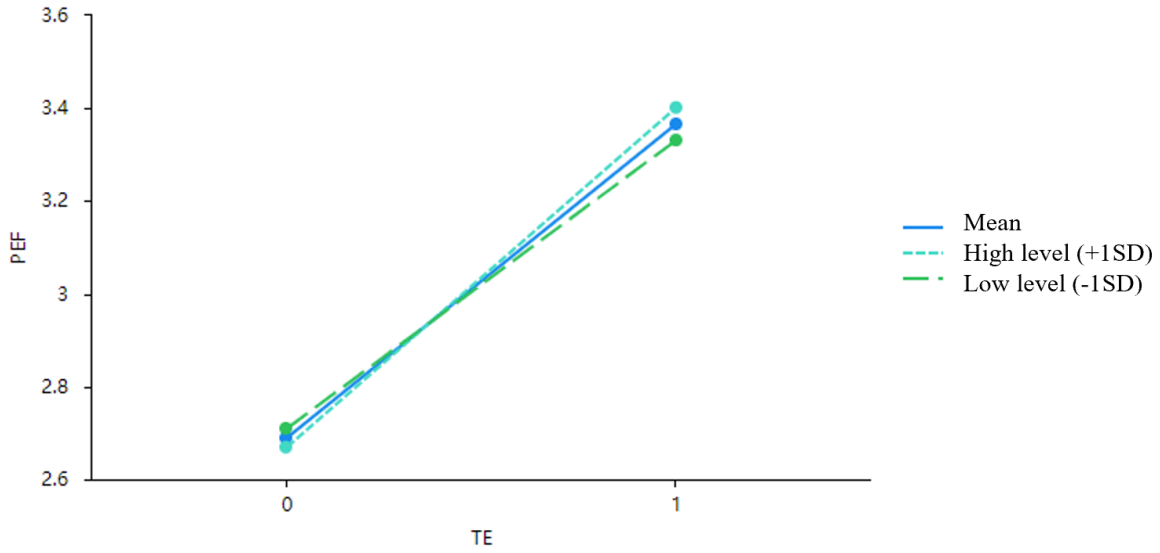


Figure A5.8 Schematic diagram of the platform control force adjustment effect (robustness test)

Annex B: Questionnaire on the Transaction Efficiency of the Electricity Transaction Platform (Platform Version)

Dear Respondent:

Hello! This survey is mainly aimed at the employees of the power transaction center to which the power transaction platform belongs, and aims to understand the relevant content of the power transaction platform's transaction efficiency and platform leadership from the perspective of employees. **This questionnaire is filled out anonymously** and it takes about 10 minutes to complete the questionnaire. We promise that **all the information you fill out will be strictly confidential in accordance with relevant laws and academic ethics, and all information materials will only serve as the basis for statistical analysis of the research data.** Thank you very much for your support!

Explanation of Terms

Platform Leadership: The power transaction platform's leadership over platform participants (power generation companies, power sales companies, and industrial and commercial users) can guide the transaction cooperation among all parties on the power transaction platform through leading demonstration, relationship coordination, goal promotion, business control, among others, thereby promoting transaction completion and improving transaction efficiency.

Transaction Efficiency: the maximum market transaction volume that can be achieved per unit cost. For example, in a market transaction, for every unit of product purchased, the buyer can actually only get k units of goods, of which 1-k units of goods are consumed in the transaction process, mainly including transaction costs such as transportation costs, transaction execution costs, storage costs, among others, then k can be called transaction efficiency.

Illustration

All of the following questions are multiple-choice. Please choose the answer that you think is relatively appropriate based on your understanding of your company and the power transaction platform of your province. There is no right or wrong answer.

1. Basic information of the company to which the power transaction platform belongs

1. The power transaction center which you belong to is:

☐Sichuan Power Transaction Center

☐Chongqing Power Transaction Center

☐Tibet Power Transaction Center

☐Capital Power Transaction Center

☐Tianjin Power Transaction Center

☐Jibei Power Transaction Center

☐Hebei Power Transaction Center

☐Shanxi Power Transaction Center

☐Shandong Power Transaction Center

☐Shanghai Power Exchange Center

☐Jiangsu Power Exchange Center

☐Zhejiang Power Exchange Center

☐Anhui Power Transaction Center

☐Fujian Power Transaction Center

☐Hubei Power Transaction Center

☐Hunan Power Transaction Center

☐Henan Power Transaction Center

☐Jiangxi Power Transaction Center

☐Liaoning Power Transaction Center

☐Jilin Power Transaction Center

☐Heilongjiang Power Transaction Center

☐Inner Mongolia Eastern Power Transaction Center

☐Shaanxi Power Transaction Center

☐Gansu Power Transaction Center

☐Inner Mongolia Power Transaction Center

☐Qinghai Power Transaction Center

☐Ningxia Power Transaction Center

☐Xinjiang Power Transaction Center

☐Guangdong Power Transaction Center

☐Guangxi Power Transaction Center

☐Kunming Power Transaction Center

☐Guizhou Power Transaction Center

☐Hainan Power Transaction Center

2. What is the level of your position?

A. Senior managers

B. Middle managers

C. Grassroots managers

D. Ordinary employees

3. What is the size of your company's workforce?

A. The number of employees is greater than or equal to 100

B. The number of employees is greater than or equal to 50 and less than 100

C. The number of employees is greater than or equal to 20 and less than 50

D. The number of employees is less than 20

4. On your company's power transaction platform, the proportion of power generation enterprises with annual power generation and grid-connected hours of more than 4,000 hours to the total number of power generation enterprises is approximately

A.20% or more

B. Greater than or equal to 10% and less than 20%

C. Greater than or equal to 1% and less than 10%

D. Less than 1%

5. On your company's electricity transaction platform, the proportion of industrial and commercial users to the total number of electricity users is approximately

A.20% or more

B. Greater than or equal to 10% and less than 20%

C. Greater than or equal to 1% and less than 10%

D. Less than 1%

2. Regarding the electricity transaction platform where your company is located, please fill in the following information about the platform's leadership based on your comprehensive understanding of the platform's electricity transaction situation.

Question	Very inconsistent	Not compliant	Generally	Consistent	Very consistent
1. The power transaction platform has a certain reputation, popularity or word of mouth among users (including registered power generation enterprises, power sales companies, industrial and commercial users, among others) (Status and prestige)	1	2	3	4	5
2. Certain aspects of the power transaction platform (such as	1	2	3	4	5

certain platform technical architecture, transaction rules, transaction support capabilities, among others) are leading or have a leading demonstration role (leading demonstration) domestically or internationally					
3. The power transaction work plan formulated by the power transaction center will be implemented in coordination with the registered users on the platform (target achievement)	1	2	3	4	5
4. The power transaction center can make correct development strategy deployment (strategic control) according to the social and economic development environment and actual conditions	1	2	3	4	5
5. When the external environment changes, the power transaction platform can make correct decisions such as setting up new transaction products and adjusting transaction rules to adapt to the environment (resilience)	1	2	3	4	5
6. When the power transaction platform undergoes changes and adjustments, the registered users of the platform will continue to use the platform (members follow)	1	2	3	4	5
7. The power transaction platform can organize and coordinate the interests of all parties on the transaction platform in accordance with the rules, and divide and coordinate the business (task coordination)	1	2	3	4	5
8. The power transaction platform can effectively adjust and formulate rules according to the changes in the needs of platform users to balance the relationship between platform users and promote transactions and communication (relationship coordination) between users on the platform.	1	2	3	4	5
9. The power transaction platform can promote the realization of the platform's	1	2	3	4	5

power transaction goals by formulating effective power transaction work plans (goal promotion)					
10. The power transaction platform can cooperate with the government to guide or influence the behavior of platform participants by formulating policies and rules (behavior control)	1	2	3	4	5
11. The power transaction platform can well execute and complete the business requirements put forward by the platform's participating users, such as demand response policies (business control)	1	2	3	4	5
12. The power transaction platform can cooperate with the government to lead or influence the cooperation or interaction between platform users by formulating policies and rules (mode control)	1	2	3	4	5

3. Based on the supervision and guidance of electricity transaction in the province where your electricity transaction platform is located, fill in the following relevant information.

Question	Very inconsistent	Not compliant	Generally	Consistent	Very consistent
1. The province or city fully solicits opinions from the power transaction center and all user entities on the platform before issuing policies on power pricing and regulation.	1	2	3	4	5
2. The province or city has relatively loose market access conditions for registered users participating in the electricity market, which can attract a sufficient number of electricity transaction users to participate in the electricity market and form competitive vitality.	1	2	3	4	5
3. The provincial or municipal policies have relatively relaxed restrictive policies on electricity transaction and all parties involved in electricity transaction, while ensuring electricity safety.	1	2	3	4	5
4. The provincial or municipal	1	2	3	4	5

policy has certain incentive mechanisms for clean energy consumption in terms of power transaction policies and has been implemented					
5. The provincial or municipal policy has certain requirements for the registration, entry and exit of power generation enterprises, power sales companies and industrial and commercial users on the transaction platform.	1	2	3	4	5
6. The provincial or municipal policy provides good policy guidance for the connection of various links in power transaction	1	2	3	4	5
7. The provincial or municipal policy helps to actively promote the construction of cross-regional power markets	1	2	3	4	5
8. The provincial or municipal policy is conducive to actively promoting the cost reduction and efficiency improvement of the power transaction center, so as to better implement power transaction and promotes the construction of the power market with the existing institutional personnel and software and hardware configuration.	1	2	3	4	5
9. The provincial or municipal policy imposes strict penalties on transaction violations by all parties involved in the power transaction platform.	1	2	3	4	5
10. The provincial or municipal policy provides a certain amount of matching and listing price space for power platform transactions	1	2	3	4	5

4. Based on the basic situation of your company's management of the electricity transaction platform, fill in the following information on electricity transaction efficiency, among others.

Question	Very inconsistent	Not compliant	Generally	Consistent	Very consistent
1. The transaction frequency and volume of the power transaction platform managed by our company are very high	1	2	3	4	5

2. The user experience of the power transaction platform managed by our company is very good	1	2	3	4	5
3. The power transaction platform managed by our company can help registered users of the platform to significantly reduce the transaction costs such as communication and coordination between the two parties through digital means.	1	2	3	4	5
4. Our company provides a dedicated production or service site for the power transaction platform	1	2	3	4	5
5. Our company provides special equipment and instruments for the power transaction platform	1	2	3	4	5
6. Our company has registered trademarks and brands for the power transaction platform and applied for relevant patents to form intangible assets	1	2	3	4	5
7. Our company brings its own advanced management processes and digital technologies into the power transaction platform	1	2	3	4	5
8. Our company has invested a large number of professional and technical personnel in the power transaction platform	1	2	3	4	5
9. Our company has invested a large number of management personnel in the power transaction platform	1	2	3	4	5
10. Our company has invested a large number of power market business personnel in the power transaction platform	1	2	3	4	5
11. Our company has achieved full access to the market for all industrial and commercial users, and some users participate in power transaction by purchasing electricity through power grid companies.	1	2	3	4	5
12. Our company often organizes training on power transaction policies and business development	1	2	3	4	5
13. The transaction behaviors of all parties involved in our	1	2	3	4	5

company's power transaction platform are highly certain.					
14. The technology upgrade of our company's power transaction platform has a strong regularity	1	2	3	4	5
15. Our company's electricity transaction market has a strong certainty	1	2	3	4	5

5. Based on your company's digital transformation intentions and execution strategies, please fill in the following basic information about your company's digital transformation.

Question	Very inconsistent	Not compliant	Generally	Consistent	Very consistent
1. The company is operating various process platforms and systems based on digital technology	1	2	3	4	5
2. Companies are integrating digital technologies to change our business processes	1	2	3	4	5
3. The company's development is changing towards continuous optimization through the use of digital technology	1	2	3	4	5
4. The company strategically applies digital technology to business operations management	1	2	3	4	5
5. Companies have high expectations for the effectiveness of using digital technology	1	2	3	4	5
6. Digital technology is an essential element in the business operation process	1	2	3	4	5
7. I believe that adopting digital technology can improve business efficiency	1	2	3	4	5
8. I think digital technology will be very helpful in business operations	1	2	3	4	5

The questionnaire ends here, thank you for your cooperation!

Annex C: Questionnaire on the Transaction Efficiency of the Electricity Transaction Platform (Platform User Version)

Dear Respondent:

Hello! This survey is mainly aimed at employees of enterprises participating in the power transaction platform (including power generation enterprises, power sales enterprises and industrial and commercial users) , aiming to understand the relevant content of power transaction platform transaction efficiency and platform leadership from the perspective of platform participating enterprises (respondents) . **This questionnaire is filled out anonymously** and it takes about 10 minutes to complete the questionnaire. We promise that **all the information you fill out will be strictly confidential in accordance with relevant laws and academic ethics, and all information materials will only serve as the basis for statistical analysis of research data.** Thank you very much for your support!

Explanation of Terms

Platform Leadership: The power platform companies' leadership over the respondents' companies can guide the respondents' companies (entities) to engage in power transaction and supply-demand cooperation through leading by example, relationship coordination, goal promotion, business control, among others, so as to create greater value.

Transaction Efficiency: the maximum market transaction volume that can be achieved per unit cost. For example, in a market transaction, for every unit of product purchased, the buyer can actually only get k units of goods, of which 1-k units of goods are consumed in the transaction process, mainly including transaction costs such as transportation costs, transaction execution costs, storage costs, among others, then k can be called transaction efficiency.

Illustration

All the following questions are single-choice. Please choose the answer that you think is relatively appropriate based on your understanding of your company and the power transaction platform in your province. There is no right or wrong answer. **If your company has joined multiple power transaction platforms, you can complete and submit the questionnaire for one power transaction platform, and then enter the questionnaire page again to fill in the questionnaire for another power transaction platform.**

1. Basic Information

1. The power transaction platform your company has joined is

☐Sichuan Power Transaction Center

☐Chongqing Power Transaction Center

☐Tibet Power Transaction Center

☐Capital Power Transaction Center

☐Tianjin Power Transaction Center

☐Jibei Power Transaction Center

☐Hebei Power Transaction Center

☐Shanxi Power Transaction Center

☐Shandong Power Transaction Center

☐Shanghai Power Exchange Center

☐Jiangsu Power Exchange Center

☐Zhejiang Power Exchange Center

☐Anhui Power Transaction Center

☐Fujian Power Transaction Center

☐Hubei Power Transaction Center

☐Hunan Power Transaction Center

☐Henan Power Transaction Center

☐Jiangxi Power Transaction Center

☐Liaoning Power Transaction Center

☐Jilin Power Transaction Center

☐Heilongjiang Power Transaction Center

☐Inner Mongolia Eastern Power Transaction Center

☐Shaanxi Power Transaction Center

☐Gansu Power Transaction Center

☐Inner Mongolia Power Transaction Center

☐Qinghai Power Transaction Center

☐Ningxia Power Transaction Center

☐Xinjiang Power Transaction Center

☐Guangdong Power Transaction Center

☐Guangxi Power Transaction Center

☐Kunming Power Transaction Center

☐Guizhou Power Transaction Center

☐Hainan Power Transaction Center

2. According to the user categories of the power transaction platform, your company belongs to

☐Power generation companies

☐Electricity Sales Enterprises

☐Industrial and commercial users

3. What is the level of your position?

A. Senior managers

B. Middle managers

C. Grassroots managers

D. Ordinary employees

4. What was the choice when your company joined the power transaction platform?

A. Join only one power transaction platform

B. Join two or more power transaction platforms

5. What is the size of your company's workforce?

A. The number of employees is greater than or equal to 1,000

B. The number of employees is greater than or equal to 300 and less than 1000

C. The number of employees is greater than or equal to 20 and less than 300

D. The number of employees is less than 20

6. Years of establishment of your company

A. 20 years and above

B. Greater than or equal to 15 years and less than 20 years

C. Greater than or equal to 10 years and less than 15 years

D. Greater than or equal to 5 years and less than 10 years

E. Less than 5 years

2. Regarding the power transaction platform your company has joined, please fill in the following information about the platform's leadership based on your comprehensive understanding of the platform's electricity transaction situation.

Question	Very inconsistent	Not compliant	Generally	Consistent	Very consistent
1. The power transaction platform has a certain reputation, popularity or word of mouth (status and prestige) among users (including registered power generation enterprises, power sales companies, industrial and commercial users, among	1	2	3	4	5

others)					
2. Certain aspects of the power transaction platform (such as certain platform technical architecture, transaction rules, transaction support capabilities, among others) are leading or have a leading demonstration role (leading demonstration) domestically or internationally	1	2	3	4	5
3. The power transaction work plan formulated by the power transaction center will be implemented in coordination with the registered users on the platform (target achievement)	1	2	3	4	5
4. The power transaction center can make correct development strategy deployment (strategic control) according to the social and economic development environment and actual conditions	1	2	3	4	5
5. When the external environment changes, the power transaction platform can make correct decisions such as setting up new transaction products and adjusting transaction rules to adapt to the environment (resilience)	1	2	3	4	5
6. When the power transaction platform undergoes changes and adjustments, as a registered user of the platform, you will continue to use the platform (member follow-up)	1	2	3	4	5
7. The power transaction platform can organize and coordinate the interests of all parties on the transaction platform in accordance with the rules, and divide and coordinate the business (task coordination)	1	2	3	4	5
8. The power transaction platform can effectively adjust and formulate rules according to the changes in the needs of platform users to balance the relationship between platform users and promote transactions and communication (relationship coordination) between users on the platform.	1	2	3	4	5

9. The power transaction platform can promote the realization of the platform's power transaction goals by formulating effective power transaction work plans (goal promotion)	1	2	3	4	5
10. The power transaction platform can cooperate with the government to guide or influence the behavior of platform participants by formulating policies and rules (behavior control)	1	2	3	4	5
11. The business requirements put forward by the power transaction platform to the platform's participating users, such as demand response policies, among others, can be well executed and completed by the platform's registered users (business control)	1	2	3	4	5
12. The power transaction platform can cooperate with the government to lead or influence the cooperation or interaction between platform users by formulating policies and rules (mode control)	1	2	3	4	5

3. Based on the supervision and guidance of the power industry in the province where your company is located, please fill in the following information about power supervision.

Question	Very inconsistent	Not compliant	Generally	Consistent	Very consistent
1. The province or city fully solicits opinions from the power transaction center and all user entities on the platform before issuing policies on power pricing and regulation.	1	2	3	4	5
2. The province or city has relatively loose market access conditions for registered users participating in the electricity market, which can attract a sufficient number of electricity transaction users to participate in the electricity market and form competitive vitality.	1	2	3	4	5
3. The provincial or municipal policies have relatively relaxed restrictive policies on electricity	1	2	3	4	5

transaction and all parties involved in electricity transaction, while ensuring electricity safety.					
4. The provincial or municipal policy has certain incentive mechanisms for clean energy consumption in terms of power transaction policies and has been implemented	1	2	3	4	5
5. The provincial or municipal policy has certain requirements for the registration, entry and exit of power generation enterprises, power sales companies and industrial and commercial users on the transaction platform.	1	2	3	4	5
6. The provincial or municipal policy provides good policy guidance for the connection of various links in power transaction	1	2	3	4	5
7. The provincial or municipal policy helps to actively promote the construction of cross-regional power markets	1	2	3	4	5
8. The provincial or municipal policy is conducive to actively promoting the cost reduction and efficiency improvement of the power transaction center, so as to better implement power transaction and promote the construction of the power market based on the existing institutional personnel and software and hardware configuration.	1	2	3	4	5
9. The provincial or municipal policy imposes strict penalties on transaction violations by all parties involved in the power transaction platform.	1	2	3	4	5
10. The provincial or municipal policy provides a certain amount of matching and listing price space for power platform transactions.	1	2	3	4	5

4. Based on your company's transaction experience on the electricity transaction platform, fill in the following information on electricity transaction efficiency and other information.

Question	Very inconsistent	Not Compliant	Generally	Consistent	Very consistent

1. The transaction frequency and volume of the power transaction platform are very high	1	2	3	4	5
2. The user experience of this power transaction platform is very good	1	2	3	4	5
3. The power transaction platform can help us significantly reduce the transaction costs such as communication and coordination between the two parties through digital means.	1	2	3	4	5
4. Our company provides a dedicated production or service location for power transaction	1	2	3	4	5
5. Our company provides specialized equipment and devices for power transaction	1	2	3	4	5
6. Our company provides intangible assets such as trademarks, brands, patents for power transaction	1	2	3	4	5
7. Our company brings its own advanced management processes and digital technologies into power transaction	1	2	3	4	5
8. Our company has invested a large number of professional and technical personnel in power transaction	1	2	3	4	5
9. Our company has invested a large number of management personnel in power transaction	1	2	3	4	5
10. Our company has invested a lot of marketing personnel in electricity transaction	1	2	3	4	5
11. Our company brings its existing customers into the power transaction cooperation	1	2	3	4	5
12. Our company often organizes training on power transaction policies and business development	1	2	3	4	5
13. The behavior of our company's power transaction partners is highly uncertain	1	2	3	4	5
14. Our company's electricity transaction technology platform has a strong uncertainty	1	2	3	4	5
15. The power transaction	1	2	3	4	5

market of our company is highly uncertain					

5. Based on your company's performance results, fill in the following basic information on corporate performance.

Question	Very inconsistent	Not compliant	Generally	Consistent	Very consistent
1. The company's sales profit margin has exceeded the industry average in the past three years	1	2	3	4	5
2. The company's return on investment exceeds the industry average	1	2	3	4	5
3. The company's market share exceeds the industry average	1	2	3	4	5
4. The company's sales growth rate exceeds the industry average	1	2	3	4	5
5. The company's overall performance is above the industry average	1	2	3	4	5

5. Based on your company's digital transformation intentions and execution strategies, please fill in the following basic information about your company's digital transformation.

Question	Very inconsistent	Not compliant	Generally	Consistent	Very consistent
1. The company is operating various process platforms and systems based on digital technology	1	2	3	4	5
2. Companies are integrating digital technologies to change our business processes	1	2	3	4	5
3. The company's development is changing towards continuous optimization through the use of digital technology	1	2	3	4	5
4. The company strategically applies digital technology to business operations management	1	2	3	4	5
5. Companies have high expectations for the effectiveness of using digital technology	1	2	3	4	5
6. Digital technology is an essential element in the business operation process	1	2	3	4	5
7. I believe that adopting digital technology can	1	2	3	4	5

improve business efficiency					
8. I think digital technology will be very helpful in business operations	1	2	3	4	5

The questionnaire ends here, thank you for your cooperation!