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Coupling Coordination between Innovation Capability and Financial Competitiveness in China's Energy Enterprises under the Belt and Road Initiative

Anxin Chen
School of International Economics,
China Foreign Affairs University, Beijing, China
Ruikun Yan
Department of Diplomacy,
China Foreign Affairs University, Beijing, China

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Abstract

The Belt and Road Initiative has accelerated the overseas expansion of Chinese energy enterprises, yet the synergy between their technological innovation and financial competitiveness remains under-explored. This study examines the coupling mechanism between innovation capability(defined as a comprehensive embodiment of the dual dimensions of innovation resource input and innovation outcome output) and financial core competitiveness (defined as a composite of operational efficiency, profitability, and growth potential) of these firms. Using entropy-weighted TOPSIS, coupling coordination, and grey relational models, we analyse panel data from eight major energy enterprises from 2018 to 2024. The results show a stark asymmetry: innovation capability increased steadily, while financial competitiveness fluctuated sharply, plummeting to 0.103 in 2020 before rebounding to 0.270 in 2024. As a result, the coupling coordination degree evolved from a mild imbalance through antagonistic growth to short-term adjustment, indicating a fragile yet progressive synergy. This study concludes that enhancing the precision of technology investment and cross-border financial coordination are key to strengthening the innovation-finance nexus,

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offering quantitative insights for the sustainable growth of energy enterprises in complex international contexts.

Keywords: Coupled coordinated development; enterprise innovation; financial core competitiveness; “Belt and Road”; energy enterprises

Introduction

Since its proposal in 2013, the Belt and Road Initiative has grown into one of the most extensive and influential international cooperation platforms globally. As a core pillar of the Belt and Road Initiative, energy cooperation leverages complementary resource endowments along the routes to build a diversified and multi-level investment system. (National Energy Administration, 2024). Driven by both policy impetus and market demand, Chinese energy enterprises have continuously expanded their transnational investment layout. This trend not only enhances their capabilities in technology export and industrial chain integration, but also fosters a cooperative pattern featuring the coordinated development of traditional energy and new energy.

From the perspective of investment practice, Chinese enterprises have leveraged their technological advantages in oil and gas exploration, pipeline construction, and other fields to help resource-rich countries along the Belt and Road improve their energy development efficiency. In the new energy sector, they have delivered landmark projects through innovative models such as “EPC + financing”. Chinese energy equipment, exported to over 200 countries and regions, now supplies more than 80% of the photovoltaic modules and 70% of the wind power equipment to the “Belt and Road” region, significantly reducing the global levelized cost of electricity (LCOE) for renewable energy.

The Belt and Road energy partnership expanded from 29 countries in 2019 to 34 countries in 2024. The third Belt and Road Energy Ministers’ Meeting issued the “Belt and Road Green Energy Cooperation Action Plan (2024-2029)”, which identified green energy technology innovation cooperation and green energy financial services as core tasks. Currently, Chinese energy enterprises commonly lack sufficient synergy between technological innovation and core financial competitiveness in their investments under the Belt and Road Initiative, an issue that manifests in both the traditional energy and new energy sectors. Studies have shown that while technological innovation can enhance enterprises’ excess returns, it may inhibit short-term operational efficiency and has no significant positive impact on enterprise value, which reflects the contradiction between the input of innovation resources and short-term financial performance. (Zhang,Y.J et al.). Energy projects require substantial upfront investment and have long payback

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periods. The contradiction between short-term financial liquidity and the long-term nature of innovation investments leads to delayed updates in R&D equipment for some projects. The combination of technical compatibility and financial risks in multinational projects exacerbates financial instability. Addressing this issue is a policy requirement for the construction of the "Belt and Road" initiative and a key to achieving high-quality cooperation among enterprises.

Literature Review

Research on the Correlation of Enterprise Innovation Capability and the Core Competitiveness of Enterprise Finance

In the theoretical framework of corporate innovation, Lawson and Samson (2001) posited that innovation capability is the core competence enabling enterprises to continuously transform knowledge and creativity into new products, processes, and systems that benefit both themselves and stakeholders. The way organizations seek new ideas during innovation processes is critical. Laursen and Salter (2006) showed that the breadth and depth of firms' external knowledge search—key components of their external search strategies—are critical for innovation performance, and this external search complements rather than substitutes for internal R&D investments. To address the theoretical fragmentation in the study of innovation capability, Narcizo et al.(2017) proposed a maturity-based three-tier framework that conceptualizes innovation capability as a progressively developing continuum, this framework encompasses the following hierarchical levels: the descriptive model, which defines fundamental components; the comparative model, which establishes assessment criteria to measure relative capability levels; and the prescriptive model, which provides developmental roadmaps and best practices. Its core contribution lies in shifting the perspective from the static element view to the dynamic evolutionary view, offering a coherent theoretical pathway for subsequent research—from identification and evaluation to the systematic enhancement of innovation capability.

Scholars have conducted extensive research on methods to enhance corporate innovation capabilities. Regarding the driving mechanisms and methodological innovations of corporate innovation, Porter and Kramer (2011) point out that if companies redefine their objectives as creating "shared value" and re-integrate business with society, they can achieve a win-win situation for corporate success and social progress through three approaches: re-imagining products and markets, redefining productivity in the value chain, and establishing supportive industrial clusters in their locations. The driving approaches to corporate innovation capability extend beyond internal organizational optimization; they also require alignment with external collaboration and sustainable value orientation. In the context of cross-border

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cooperation, Wang et al. (2023) identified two practical pathways through which innovation capability delivers its value: green technology-oriented innovation investment, and collaboration-driven enhancement of innovation efficiency. This finding suggests that integrating internal R&D with cross-border resource linkage can more effectively transform innovation capability into a driving force for sustainable development. From the perspective of digital transformation, Xu et al.(2024) have empirically verified through research on 476 Chinese manufacturing enterprises that digital transformation is a key driver of corporate innovation performance, primarily through a dual-mediator pathway: first, by strengthening corporate capabilities in data collection; second, by promoting organizational flattening. Demir and Lux (2025) examined the practices of 11 enterprises engaging with co-working spaces, using them as the case studies.They argued that businesses can bolster their innovation capabilities via differentiated collaboration pathways. Functioning as open innovation platforms, co-working spaces facilitate resource integration; through activities like scanning, scouting, and community building, they also enable enterprises to access external innovation components and translate their own innovation awareness and capture capacities into actionable outcomes.

In terms of the components of innovation capability, Lianto et al.(2023), through systematic screening, identified 14 key elements in intellectual capital that drive innovation. The conclusion points out that companies must transcend reliance on a single dimension and enhance innovation capability systematically through the synergy of human, organizational, and relational capital. Suarez-Barraza et al.(2024) systematically analyzed innovation data from 135 countries using the Bayesian model averaging method. To address the fragmentation of factor frameworks, they screened out 27 robust core factors from 62 candidate elements. They found that the composition of innovation capability is a dynamic collaborative system, with "public-private R&D collaboration" and "high-skilled talent" as internal engines, and "intellectual property protection" and "industrial clusters" as external foundations.. The components of corporate innovation capability include seven aspects: vision and strategy, integration of capability foundations, organizational intelligence, creativity and creative management, organizational structure and systems, culture and atmosphere, and technology management, all of which collectively underpin the implementation and improvement of corporate innovation activities (Zhang et al.,2025).

In the field of enterprise management and development research, financial core competitiveness, as a key component of corporate financial management systems, has long attracted academic interest. In the 1990s, Hamel first introduced the concept of corporate core competitiveness. Core

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competitiveness, he argued, enables enterprises to integrate resources effectively and represents the collective learning capacity of an organization, which can significantly enhance production efficiency. Given that core competitiveness delivers strong market value and is difficult to replicate, related research has expanded significantly. Regarding its theoretical foundation, Chikan (2008) defines corporate competitiveness as the sustainable ability to achieve dual objectives: meeting customer needs while ensuring profitability. Sun et al. (2021) have verified the transmission mechanism of "from core competence to financial strength and then to corporate behavior". This provides a theoretical basis for conceptualizing financial core competence as not an isolated element, but a critical link connecting an enterprise's overall core competence with its financial performance and strategic objectives. This approach directly establishes "profitability" as the core baseline of competitiveness, highlighting financial performance as the fundamental attribute of competitive advantage (Chikan et al.,2022).

Regarding the components of corporate financial core competitiveness, a critical element of corporate financial core competitiveness is maintaining financial flexibility and robust internal financing capacity. Companies that adhere to priority financing principles and avoid value dilution inherently possess competitive advantages through their financial practices (Myers & Majluf, 1984). Chen (2009) proposed incorporating financial competitiveness analysis into evaluation systems. He developed an indicator framework for assessing listed companies' financial core competitiveness, using data from 15 steel enterprises on the Shenzhen Stock Exchange to conduct comprehensive analysis. The study ultimately proposed actionable recommendations for enhancing financial core competitiveness. Agazu & Kero (2024) integrated the conclusions of multiple empirical studies. They confirm that innovation strategy serves as the core driving force of financial competitiveness, and this driving effect must be realized through specific financial performance indicators, indicating that the performance-based components of financial competitiveness, specifically include profitability sustainability, financial security and solvency, and capital allocation efficiency. This perspective reveals that financial core competitiveness encompasses not only value creation but also risk management abilities.

The dynamic interplay between enterprise innovation capability and financial core competitiveness constitutes a pivotal research stream in contemporary management studies. Existing literature primarily elucidates this relationship through three interconnected lenses: driving effects, enabling conditions, and reciprocal reinforcement. From the perspective of innovation driving finance, scholars posit that sustained innovation activities serve as a critical engine for enhancing financial competitiveness. Yet this positive

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correlation is not linear but subject to a threshold effect—only when the intensity of R&D investment exceeds a certain critical value can technological achievements be effectively transformed into profit growth and market premium, whereas insufficient innovation input may even exert a crowding-out effect on short-term corporate performance (Zhang et al.,2025). From the perspective of finance enabling innovation, Brown et al.(2012) utilized global corporate data to demonstrate that financing constraints significantly inhibit firms' R&D investment, particularly in high-tech enterprises. Meanwhile, the efficient allocation of resources to high-potential projects supports this argument.Stein (1997) discussed the reallocation of capital from low-growth departments to high-growth, high-potential sectors or projects (often including innovation initiatives), thereby enhancing overall firm value. Furthermore, recent scholarship conceptualizes their interaction as a mutually reinforcing, co-evolutionary coupling. A higher level of innovation capability can optimize a firm's cost structure and create premium value, thereby strengthening its financial foundation and market position. In turn, superior financial health and strategic resource allocation empower more ambitious and sustained innovation investment, forming a virtuous cycle (Sempere-Ripoll et al.,2020).

In conclusion, existing research on enterprise innovation capability and financial core competitiveness has yielded substantial insights, yet further exploration remains warranted. Particularly in emerging market contexts, the synergistic mechanism between innovation and financial competitiveness has not been thoroughly examined, and empirical studies focusing on specific industries—such as the energy sector—are still lacking. Therefore, this study aims to investigate the coupling mechanism between innovation capability and financial core competitiveness within Chinese energy enterprises. By doing so, it seeks to address the gaps in current research regarding contextual applicability and industry heterogeneity, and to provide a reference for theoretical advancement and managerial practice.

The Coupling Mechanism between Corporate Financial Core Competence and Corporate Innovation Capability

Originating from the physics concept of "coupling"—which describes the interaction, mutual influence, and energy or information exchange between different systems—Coupling Coordination Theory has been progressively developed. Its conceptual foundations and quantitative methods have evolved along key research trajectories, such as system interactions and sustainable coordination frameworks (Kikkawa, K. et al.,1999). The conceptual foundations and quantitative methods of coupling coordination analysis have evolved incrementally along research trajectories including system interactions and sustainable coordination frameworks. Costanza et al. (1997) innovatively quantified the interactive relationship between ecosystem

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services and human economic systems; the indicator system and value assessment logic they developed laid the core methodological foundation for subsequent coupling analysis in the ecological-economic domain. Building on this work, Norgaard (2001) proposed a theoretical framework for economic-ecological coordinated development from a systems theory perspective, emphasizing the dynamic equilibrium properties of multi-system synergy. The logic underlying its coordination degree measurement aligns with that of later-developed coupling coordination degree models, thereby expanding the theoretical boundaries of cross-system coordination research. Gonzalez-Benito et al.(2006), in turn, employed structural equation modeling to quantify the coupling relationship between corporate environmental management and stakeholder pressure. This application facilitated the extension of coupling coordination analysis from macro-level contexts to the micro domain of management, enabling the quantitative expansion of the method's utility.

In the field of social sciences, scholars have introduced this theory into research areas such as regional economy, industrial integration, and urban-rural development (Turner et al.,2003; Folke et.al.,2005; Seto et.al.,2012). By constructing a coupling degree model, the interaction intensity between two or more subsystems can be measured quantitatively—this approach helps reveal the co-evolution mechanism of different subsystems in the dynamic evolution process. Building on this foundation, subsequent scholars introduced the coupling coordination degree index to evaluate the quality and sustainability of coupling relationships (Fang et al.,2016; Zhang et al.,2024). The index is designed to identify the optimal development path that maximizes overall system benefits.

The coupling and coordination mechanism between corporate innovation capability and financial core competence is essentially a dynamic and in-depth interactive relationship. Regarding how innovation capability propels financial core competitiveness, da Silva et al.(2018), in their analysis of Brazilian energy enterprises, demonstrated how low-carbon energy technologies and digital-intelligent production control optimize operations: the former replaces traditional power supply and matches energy demand, reducing procurement costs and energy waste; the latter optimizes equipment parameters in real time, lowering energy consumption per unit of production by 18%-22% and reducing the proportion of energy costs. Furthermore, innovation-driven equipment intelligence upgrades and supply chain digital transformation enhance operational efficiency indicators such as fixed asset turnover and inventory turnover. The accumulation of innovative assets like technological patents and R&D outcomes also strengthens the appreciation potential of corporate assets, thereby improving the asset operation dimension of financial core competitiveness (Zhang et al.,2025). Conversely, financial core competitiveness exerts a significant feedback effect on innovation

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capability. Brown et al.(2009) argued that internal cash flow—particularly the stable cash flow of firms with strong financial strength—is a key funding source for R&D investment. The R&D expansion of young high-tech firms is highly dependent on internal cash flow and retained earnings; the funding stability derived from financial core competence directly alleviates innovation's financial constraints. Ample and efficient capital supply ensures the continuous advancement of R&D projects, precise financial resource allocation prioritizes funding for high-potential innovative areas, and mature risk hedging mechanisms increase corporate confidence in pursuing disruptive innovations (Illmeyer et al.,2017).

When the coupling between a firm's innovation capability and financial core competence exceeds a critical threshold, it generates systemic synergy. For Chinese energy enterprises, this threshold is even industry-specific, Yang & Zhang (2020) found that energy firms only achieve positive innovation-to-financial performance conversion when their R&D investment intensity crosses a critical value, otherwise redundant innovation input may erode profit margins. This synergy not only enables lower-cost resource acquisition and higher-efficiency value realization but also establishes a self-reinforcing cycle where innovation and finance mutually drive upgrades. (Guo, Z et al.,2022) Ultimately, this process constructs a unique market barrier centered on this synergistic advantage, forming a sustainable and hard-to-replicate competitive position. (Ren, Y & Li, B., 2023; Chen, J.et al.,2024).

Existing research on the coupling between innovation capability and financial competitiveness in China's energy enterprises exhibits significant gaps. Theoretically, it lacks a framework that integrates policy-driven dynamics and industry-specific traits, and fails to apply coupling coordination theory specifically to the innovation-finance interplay. Empirically, studies overlook the unique context of energy firms, such as their cost structures and long-cycle green innovation value logic. Methodologically, there is a mismatch in evaluation indicators and a reliance on static approaches, unable to capture the long-term, dynamic evolution of this relationship.

Research Methods

To systematically examine the coupling and coordinated development mechanism between innovation capability and financial core competitiveness of Chinese energy enterprises under the Belt and Road Initiative, this study establishes a structured research framework progressing through "indicator weighting-system evaluation-coupling analysis-driver identification." First, the entropy method is adopted to objectively assign weights to evaluation indicators within the innovation and financial subsystems, thereby mitigating subjective bias and clarifying the relative importance of each indicator in the integrated assessment. Second, the TOPSIS method is applied to compute the

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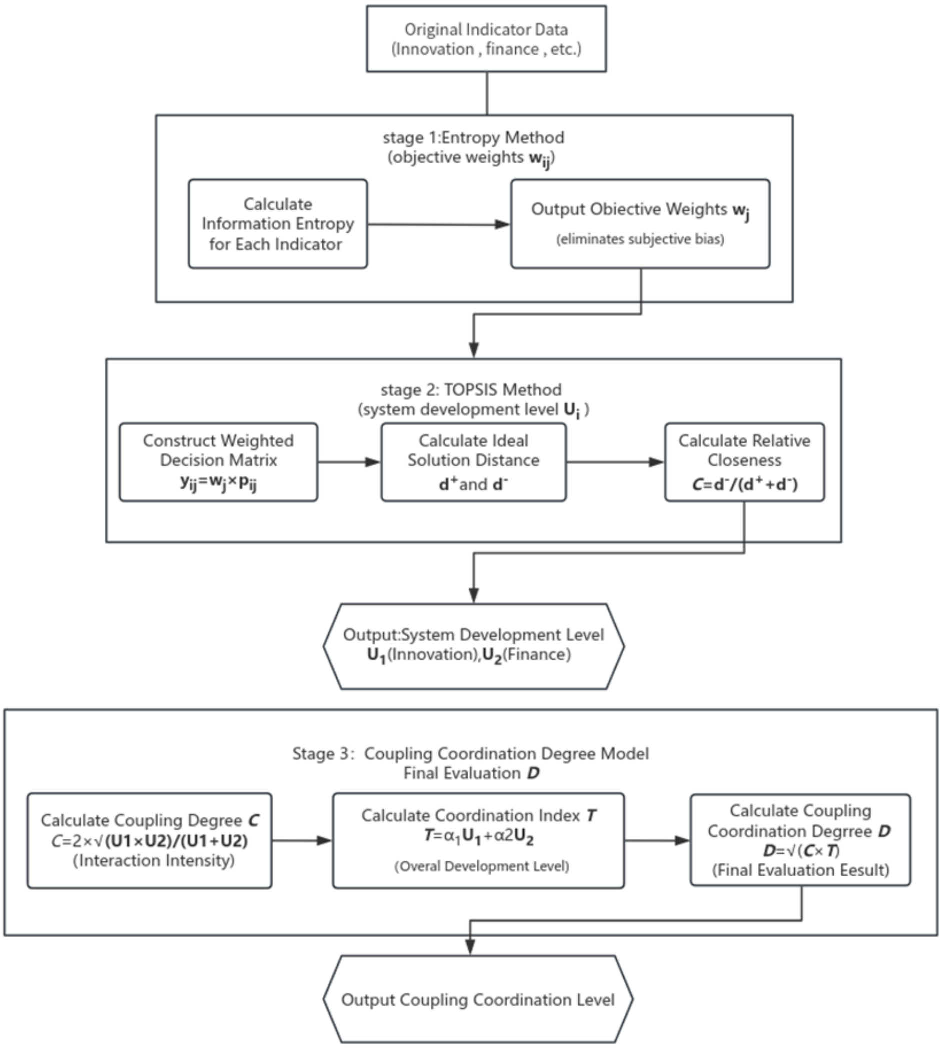
annual comprehensive development levels of the two subsystems, which quantifies their relative developmental status by measuring proximity to the ideal solution. Subsequently, a coupling coordination degree model is employed to assess the interaction strength (coupling degree) between the two systems and their synergistic development level (coordination degree), thus elucidating the quality and phased characteristics of their dynamic interaction. Finally, gray relational analysis is used to identify key determinants affecting system coordination, thereby informing evidence-based policy recommendations.

Figure 1: Three-Stage Modeling Flowchart for Evaluating the Coupling Coordination of Innovation and Financial Systems



Note: Author's own work.

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Entropy Method

The entropy method constitutes a cardinal step in research on inter-system coupling and coordination, where it is utilized to objectively derive weights for the constituent evaluation indicators (Shannon, 1948). This objective weighting establishes the basis for aggregating indicators into a composite measure of development for each system.

First, since the units of each index are different, it is necessary to standardize the index.

$$X_{ij} = \{\frac{A_{ij} - min(A_{ij})}{max(A_{ij}) - min(A_{ij})} \quad A_{ij}\ is\ positive\ indicator \quad \frac{max(A_{ij}) - A_{ij}}{max(A_{ij}) - min(A_{ij})} \quad A_{ij}\ is\ negative\ indicator$$

Suppose there are i sample observations, with the maximum value being g, and j evaluation indicators, with the maximum value being h. A_{ij} represents the original measure indicator sequence, X_{ij}represents the standardized measure indicator sequence, and $min(A_{ij})$and $max(A_{ij})$ are the minimum and maximum value, A_{ij} respectively.

Calculate the proportion of the feature for the nth sample value under the nth indicator: Second, calculate the proportion of the i_{th} year under the j_{th} indicator.

$$p_{ij} = \frac{X_{ij}}{\sum_{i=1}^{g} X_{ij}}$$

Calculate the information e_{ij}entropy of the first indicator using the entropy calculation formula (in which $0 \leq e_j \leq 1$):

$$e_j = \frac{1}{ln\ ln\ n} \sum_{i=1}^{g} P_{ij} ln P_{ij}$$

Calculate the coefficient of variation D_j for the j_{th} indicator based on e_j.

$$D_j = 1 - e_j$$

Calculate the weight w_j of the g_{th} indicator using D_j.

$$w_j = \frac{D_j}{\sum_{j=1}^{h} D_j}$$

TOPSIS Method

The TOPSIS method is used in coupling coordination studies to compute a “comprehensive closeness score” for each subsystem, based on its distance from ideal reference points (Li, Y et al., 2025). This score objectively reflects each subsystem’s development level and provides a clearly interpretable, standardized measure for calculating the coupling coordination index. Thus, the index evaluates both the strength of system interactions and their joint advancement toward an ideal state.

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First, based on the calculated weight w_j and the proportion p_{ij} of the g_{th} indicator, a weighted decision matrix y_{ij} is established.

$$y_{ij} = w_j \times p_{ij}$$

Secondly, the positive ideal solution is determined according to the maximum value of the matrix index, and the corresponding ideal solution vector is constructed.

$$Y^+ = (y_1^+, y_2^+, \dots \dots y_n^+)$$

The maximum y_{ij}value in the range y_j^+.

$$y_j^+ = \{(max_i y_{ij} | j \in positive\ indicator), (min_i y_{ij} | j \in negative\ indicator)\}$$

$$y_j^- = \{(min_i y_{ij} | j \in positive\ indicator), (max_i y_{ij} | j \in negative\ indicator)\}$$

Third, calculate the Euclidean distance, with the positive and negative ideal solutions of each indicator serving as evaluation criteria, and compute the Euclidean distances between the indicators of each evaluation scheme and the positive/negative ideal solutions.:

$$d_i^- = \sqrt{\sum_{j=1}^{m} (y_{ij} - y_j^-)^2}, i = 1,2, \dots \dots, n$$

$$d_i^+ = \sqrt{\sum_{j=1}^{m} (y_{ij} - y_j^+)^2}, i = 1,2, \dots \dots, n$$

Finally, the degree of closeness between the evaluation b_i object and the optimal value is calculated as the comprehensive level score, and the order is made.

$$b_i = \frac{d_i^-}{d_i^+ + d_i^-}, 0 \leq b_i \leq 1$$

Coupling Coordination Degree Model

The Coupling Coordination Degree Model operationalizes the abstract concept of “synergistic development” into a quantifiable, comparable single index with clear policy implications (Zhao, X., & Chen, B., 2008). Its core contribution lies not merely in measuring the intensity of interaction between systems, but more critically in evaluating whether such interaction leads to an upward developmental trajectory for the system as a whole.

To assess the coupling coordination development stage between innovation and financial core competitiveness for the industry leader, the coupling degree and coupling coordination degree models were constructed and applied.

This subsystem has two components, so the calculation formula is:

$$C_{12} = \frac{2\sqrt{U_1 U_2}}{U_1 + U_2}$$

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C reflecting the coupling degree between systems, the value ranges from 0 to 1. The magnitude of the value only indicates the mutual coupling degree between corporate innovation and financial core competitiveness or their respective internal elements. A higher value suggests better coupling, while a lower value indicates poorer coupling. However, high coupling does not equate to high coordination; it must be comprehensively evaluated in conjunction with the coordination index *T*.

The coupling degree reflects the degree of interaction between the enterprise innovation system and the financial core competitiveness or the internal elements. In order to accurately determine the relationship between the subsystems, the following coordination model is established:

$$T_{12} = \alpha_1 U_1 + \alpha_2 U_2$$

$$D_{12} = \sqrt{C_{12} \times T_{12}}$$

In the formula: D_{12} represents the coupling coordination degree between corporate innovation capability and financial core competitiveness, ranging from 0 to 1; T_{12} is the comprehensive evaluation index of the innovation capability of selected pipeline energy enterprises; α_1 and$\alpha_1$are respectively undetermined weight coefficients, and $\alpha_1 + \alpha_2$=1.

Gray Relational Analysis (GRA)

This study adopts the Gray Relational Analysis method in order to identify the key factors influencing the "innovation-finance" coupling coordination system of energy enterprises and to evaluate the convergence in the temporal trajectories of their element sequences (Kuo, Y.et al., 2008). Suitable for uncertain systems characterized by "small samples and poor information", this method does not require data to follow a typical distribution and can effectively measure the order of strength of correlations between various factors in the system. It is highly compatible with the characteristics of this study, such as limited sample size and complex system relationships.

The specific procedures are as follows:

$$\xi_i(K) = \frac{min_i min_k |y(k) - x_i(k)| + \rho max_i max_k |y(k) - x_i(k)|}{|y(k) - x_i(k)| + \rho max_i max_k |y(k) - x_i(k)|}$$

$$S_i = \frac{1}{n} \xi_i(K)$$

Where：$\xi_i(K)$denotes the relational coefficient of the i_{th} comparison series at the k_{th} point. $|y(k) - x_i(k)|$denotes the absolute value of the difference between the evaluated indicator and the reference indicator, ρ is the distinguishing coefficient， with a value of 0.5.

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Data Sources and Standardization

Through research, enterprises engaged in energy cooperation with countries along the Belt and Road Initiative from 2018 to 2024 were selected. In the traditional oil and gas sector, three companies—China Petroleum, China Petrochemical, and China National Offshore Oil Corporation (CNOOC)—were chosen, their overseas oil and gas resource cooperation projects have an extensive presence along the Belt and Road Initiative. In the new energy sector, five state-owned enterprises, including China Energy Engineering Corporation, Power China, China General Nuclear Power Group, Guanghui Energy, and Jinko Solar, were selected, these enterprises serve as key players in new energy investment, engineering construction, and technology transfer within Belt and Road cooperation. The selection of these enterprises was primarily based on the following criteria:

Participation in the "Belt and Road" Initiative

First, the proportion of overseas business revenue. In 2023, the sample companies had an average overseas business revenue share of 32.6%, significantly higher than the overall level of Chinese energy enterprises (about 15%). Among them, China Energy Engineering Corporation had an overseas business share of 38.2%, and Jinko Energy had over 60% of its business overseas, covering more than 40 countries and regions along the "Belt and Road." This indicator ensures that the operating activities of the sample companies are truly profoundly influenced by the practice of the "Belt and Road."

Second, participation in landmark projects. The eight companies collectively participated in over 200 "Belt and Road" energy projects, covering landmark projects such as the Central Asian natural gas pipeline, the China-Russia crude oil pipeline, and the Rabigh photovoltaic power plant in Saudi Arabia, providing rich practical scenarios for examining the interaction between innovation capability and financial performance.

Industry Leading Position

In the traditional oil and gas sector, the three central enterprises, PetroChina, Sinopec, and CNOOC, occupy more than 90% of the domestic oil and gas exploration and development market and have undertaken most oil and gas resource cooperation projects along the "Belt and Road." By the end of 2023, the three major oil companies operated over 100 oil and gas cooperation projects along the "Belt and Road," forming five major oil and gas cooperation zones. These companies have accumulated extensive experience in technological innovation and financial management, and their "innovation-financial" coupling characteristics can represent the highest level of internationalization of Chinese energy enterprises.

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In the new energy sector, China Energy Engineering Corporation and China Power Construction are the world's largest power engineering general contractors, constructing over 60% of coal, hydro, and renewable energy projects along the "Belt and Road" route; CGN is the world's third-largest nuclear power operator; Guanghui Energy is the only domestic private enterprise that owns coal, oil, and gas resources simultaneously; and Jinko Energy is one of the world's largest photovoltaic module manufacturers, ranking first in global photovoltaic module shipments for five consecutive years. This combination ensures that the sample can reflect the differentiated characteristics of various types of energy enterprises in the "innovation-financial" coupling mechanism.

Industry Specificity

Energy enterprises are characterized by significant asset-intensive and technology-intensive features, which imposes higher requirements on sample selection:

The asset-intensive feature requires that sample companies must have large-scale fixed assets and operating capital to examine the core role of operational capacity in financial core competitiveness. By the end of 2023, the total assets of all eight companies exceeded 100 billion yuan, exhibiting typical characteristics of asset-intensive enterprises. The technology-intensive feature requires that sample companies have sustained and representative R&D investment and technological innovation. In 2023, the average R&D intensity of the eight companies reached 3.2%, higher than the average level of Chinese industrial enterprises (about 1.5%).

The relevant data mainly came from the National Bureau of Statistics website, annual financial statements of various companies, CNNIC, and Guotai An database. For missing data, the mean method was used for valuation. Due to the diversity of data sources and the existence of differentiated data units in the indicator system, indicators were categorized into positive indicators and moderate indicators, with the latter undergoing moderation treatment.

Empirical Result

Evaluation Index System and Weight of Enterprise Innovation Capability

The construction of the innovation capability index system in this study is based on Cohen & Levinthal (2015)'s theory of "absorptive capacity" and Lawson & Samson's (2001) framework of "dynamic innovation capability." Cohen & Levinthal (1990) pointed out that a company's innovation capability depends on its ability to identify and utilize external knowledge, which needs to be cultivated through continuous R&D investment and talent accumulation. Based on this, this study decomposes innovation

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capability into two dimensions: "innovation input capability" and "innovation output capability." Among them, innovation input capability covers three aspects: capital investment, talent input (proportion of R&D personnel, proportion of personnel with a master's degree or above), and platform support , so as to comprehensively reflect the intensity and structural quality of enterprises' allocation of innovation resources. Innovation output capability focuses on patent achievements, distinguishing between the number of patent applications and the number of authorized patents to reflect differences in the quantity and quality of innovation achievements. This index system takes into account the "input-output" logical chain of the innovation process while responding to the theoretical proposition of Narcizo et al. (2017) to shift from a static element perspective to a dynamic evolutionary perspective. The weights of each index are obtained by entropy weight method, as shown in Table 1.

Table 1: Weight of the indicators of innovation ability

primary indicator	index weight	secondary indicator	Indicator selection	index weight
Innovation investment capacity	60.4014%	R&D funding input	Total R&D investment	15.1152%
			R&D investment increased year-on-year	14.9825%
		R&D human input	Proportion of R&D personnel	4.5817%
			Proportion of individuals with a master's degree or higher	13.3590%
			Number of national R&D platforms	12.3630%
Innovation output capacity	39.5985%	Patent development capabilities	Number of patent applications	18.8829%
			Number of granted patents	20.7156%

Based on the indicator weights shown in the tables, innovation resource input is the core support for state-owned energy enterprises' innovation capability. Among these inputs, financial input accounts for the highest weight, followed by talent input and R&D platforms—this reflects that "finance + talent + platforms" are the core elements of innovation input. In terms of output, patent quality (rather than quantity) is the core evaluation dimension for innovation output.

Evaluation Index System and Weight of Enterprise Financial Core Competitiveness

The construction of the core financial competitiveness indicator system mainly refers to Rappaport (1986)'s value driver framework and

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Chikán et al. (2022)'s enterprise competitiveness model. Rappaport (1986) pointed out that the creation of enterprise value originates from the synergy of profitability, operational efficiency, and growth capability; Chikán et al. (2022) further emphasized that financial competitiveness is the sustainable ability of an enterprise to achieve profitability while meeting customer needs, and its core components include value creation ability and risk management ability.

The evaluation system comprises four primary indicators and 15 quantifiable metrics, covering four key financial dimensions: profitability, operational efficiency, growth potential, and solvency. These metrics comprehensively capture the essential financial indicators for listed energy companies, as detailed in the table below. The weight of each indicator is determined using the entropy weight method, as shown in Table 2.

Table 2: Weight of Financial Core Competitiveness Indicators

Primary indicator	index weight	secondary indicator	index weight
profitability	8.6018%	Operating Profit Margin (%)	4.7393%
		Return on Assets (%)	2.666%
		Return on Net Assets (%)	1.1965%
operation capacity	73.0507%	Fixed assets turnover rate (times/year)	26.4184%
		Current assets turnover (times/year)	30.6020%
		Inventory turnover rate (times/year)	10.8302%
		Accounts receivable turnover rate (times/year)	8.7850%
Growth potential	7.47%	Total assets growth rate (%)	4.8775%
		turnover of net assets (%)	2.5925%
debt paying ability	6.2496%	current ratio （%）	3.9381%
		quick ratio （%）	1.673%
		asset-liability ratio （%）	1.6385%

The results indicate that the financial core competitiveness of state-owned energy enterprises exhibits a distinct structural characteristic: operational efficiency occupies the dominant position, with current asset turnover and fixed asset turnover serving as the key driving factors, whereas the weights assigned to profitability, growth potential, and solvency are relatively low. This finding is highly consistent with the industry-specific attribute of energy enterprises as asset-intensive and capital-intensive entities. Such enterprises hold substantial volumes of fixed assets and current assets; their financial health and sustainability depend more on the efficiency of asset turnover rather than merely on profit scale or leverage level. Therefore, the high-weight structure reveals that, in advancing the Belt and Road Initiative, the financial strategy of state-owned energy enterprises tends to consolidate core competitiveness by enhancing asset operational efficiency. Meanwhile,

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the overall debt-servicing risk of the industry remains controllable, providing a financial safety margin that enables enterprises to focus on long-term asset optimization and intensive development.

Comprehensive Development Level of the Dual Systems Based on the TOPSIS Method

After determining indicator weights via the entropy method, this study applies the TOPSIS method to calculate the comprehensive development level of the two subsystems. The TOPSIS method measures the "closeness degree (C)" of each sample to the ideal solution, where a higher C indicates a better comprehensive development level of the system.

Table 3: Comprehensive evaluation levels of the dual systems

	Comprehensive evaluation level of the innovation capability system			Comprehensive evaluation level of financial core competitivene ss		
a particular year	ideal solution distance d^+	negative imaginary solution distance d^-	close degree C	ideal solution distance d^+	negative imaginary solution distance d^-	close degree C
2019	0.3252	0.1056	0.2430	0.4316	0.0760	0.1422
2020	0.3215	0.1105	0.2528	0.4317	0.0773	0.1436
2021	0.3056	0.1314	0.2958	0.4357	0.0606	0.1198
2022	0.3058	0.1359	0.3102	0.4342	0.0616	0.1231
2023	0.3081	0.1359	0.2973	0.4281	0.0789	0.1531
2024	0.3063	0.1451	0.3155	0.4059	0.1204	0.2157

The closeness degree (C) of the innovation capability system shows a steady upward trend, rising from 0.2430 to 0.3155, reflecting the gradual transformation of B&R energy enterprises' innovation inputs into improved innovation capability. In contrast, the C value of the financial core competitiveness system fluctuates more notably, it slightly declines in 2021-2022 before surging to 0.2157 in 2024. This volatility echoes the energy industry's sensitivity to external shocks such as international energy price fluctuations, while the 2024 rebound signals a recovery in financial operational efficiency.

Coupling Degree Model

This paper draws on the classification criteria for coupling degrees used by Shi,T.et et al. (2020) in their research on economic and environmental systems. As shown in the table below:

Table 4: Criteria for classifying coupling degrees

Group number	degree of coupling	coupling type
1	C=0	at arm's length

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2	0<C≤0.3	low level coupling
3	0.3<C≤0.5	antagonist
4	0.5<C≤0.8	breaking-in period
5	0.8<C≤1	high level coupling
6	C=1	good resonance type

The improvement of corporate innovation promotes the enhancement of financial core competitiveness, and the improvement of financial competitiveness drives the innovative operation of enterprises. This study assigns equal weight to the two based on the following theoretical logic ($\alpha_1 = 0.5, \alpha_2 = 0.5$):

1. Theoretical Grounding: From a systems coupling perspective, innovation capability and core financial competitiveness share a symbiotic and interdependent relationship. Innovation drives financial performance, while financial strength provides the bedrock for sustained innovation (Brown et al., 2012; Illmeyer et al., 2017). Neither is logically subordinate to the other.
2. Research Objective Alignment: This study aims to investigate the "coupling coordination mechanism"—the dynamic, mutually reinforcing evolution between the two systems. Assigning unequal weights would predetermine the superiority of one system, which contradicts the core principle of coupling coordination, which is to achieve a system-wide optimum. Equal weights ensure an unbiased assessment of their synergistic parity.
3. Methodological Convention: In the absence of strong theoretical or empirical justification for prioritizing one subsystem in dual-system coupling studies, it is standard practice to adopt an equal weighting scheme as the baseline model (Fang et al., 2016; Shi et al., 2020). This ensures model simplicity and provides a clear benchmark for robustness testing.

Table 5: Criteria for Coupling and Coordination

broad heading	coupling coordination degree	coordination level
	0.00—0.10	extreme dysregulation
	0.10—0.20	major maladjustment
phase of decline	0.20—0.30	moderate dysregulation
	0.30—0.40	mild dysregulation
	0.40—0.50	approaching deficit
transition period	0.50—0.55	coordinated coupling
	0.55—0.60	primary coupling coordination
	0.60—0.65	intermediate coupling coordination
coordinated development period	0.65—0.70	Good coupling coordination
	0.70—1.00	high quality coupling coordination

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Coupling and Coordination Relationship Analysis

The development of corporate innovation capability in China is closely linked to the enhancement of financial core competitiveness. Corporate innovation capability optimizes resource allocation and improves management efficiency, thereby driving the growth of financial core competitiveness. Meanwhile, the strengthening of financial core competitiveness provides enterprises with the necessary financial, human, and managerial support for the advancement of innovation capabilities.

Table 6: Results of Coupling Coordination Measurement of Enterprise Innovation and Financial Core Competitiveness Development from 2018 to 2024

A particular year	The overall level of corporate innovation capability	The comprehensive level of core financial competitiveness of enterprises	C	T	D
2018	0.2362	0.1348	0.1748	0.1855	0.1819
2019	0.2614	0.1371	0.1893	0.1992	0.1924
2020	0.2770	0.1027	0.1686	0.1789	0.1789
2021	0.3396	0.1064	0.1901	0.2230	0.2058
2022	0.3628	0.1397	0.2252	0.2512	0.2378
2023	0.3445	0.2699	0.3049	0.3072	0.3060
2024	0.3551	0.1189	0.2054	0.2370	0.2207

From 2018 to 2020, the innovation capabilities of the sample enterprises showed a steady growth trend (increasing from 0.236 to 0.355), while the financial core competitiveness exhibited significant volatility, especially with a notable decline in 2020. This asymmetry in development is key to understanding the coupling relationship between the two. The steady growth in innovation capabilities is largely attributed to the policy-driven "Belt and Road Initiative" and continuous technological catch-up, which aligns with Wang et al. (2023)'s view that cross-border cooperation and green technology-oriented investment are important paths to enhance innovation capabilities. However, the sharp fluctuations in financial competitiveness reflect the inherent vulnerability of the energy industry as an asset and capital-intensive sector. This not only confirms Zhang, Y.J. et al.'s perspective that technological innovation may suppress short-term operational efficiency but also reveals at the macro level the direct impact of exogenous shocks such as geopolitics, international energy price fluctuations, and global public health events on corporate financial performance. As a result, the growth rates of the coupling degree C, coordination index T, and coupling coordination degree D were relatively slow, indicating that although the innovation level of enterprises has improved, the positive impact of innovation on financial competitiveness remains limited, and a mechanism for coordinated development has yet to be formed. This may be due to the fact that innovation investment is still in its early stages and has not yet fully translated into

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economic benefits, or that enterprises have not effectively allocated financial resources to support innovation activities. This coexistence of “policy-driven stable innovation” and “market-driven volatile finance” constitutes a unique stage-specific feature of energy enterprises along the “Belt and Road”.

Analysis of Key Influencing Factors Based on Gray Relational Degree

Table 7: Grey Correlation Degree of Various Influencing Factors

Evaluation items	Average Correlation Degree	Overall ranking
Patent authorization quantity	1.000	1
R & D personnel ratio	0.757	2
Fixed asset turnover rate	0.751	3
Total R & D investment	0.713	4
Return on Equity (ROE)	0.628	5

Grey relational analysis further reveals the intrinsic driving mechanism of coupling coordination. The number of patent authorizations (with a correlation degree of 1.00) serves as the core driving factor, confirming that the quality of innovation output is the bridge connecting technology and finance. High-quality patents not only signal a company’s technological strength but can also be directly converted into financial resources and market advantages through methods such as patent pledge financing and technology licensing (Chen, J. et al.,2024). The significance of the proportion of R&D personnel echoes the viewpoint of Liato et al. (2023) that human capital is a core element of innovation. High-level talents are crucial for achieving technological breakthroughs and efficiently absorbing external knowledge.

It is particularly worth noting that the fixed asset turnover ratio, as the indicator with the highest weight (26.42%) in the financial subsystem, also becomes a key factor driving the coupling and coordination. This profoundly reveals the special logic of energy enterprises: in asset-intensive industries, strong operational capabilities (efficiently converting huge fixed assets into revenue) are not only the cornerstone of financial competitiveness but also the cash flow that supports continuous high-intensity innovation investment. Only when assets operate efficiently can stable and abundant internal cash flow be provided for long-cycle and high-risk innovation activities, thereby alleviating financing constraints (Brown et al., 2012).

Strategic Suggestions for Improving the Innovation Ability and Financial Synergy of Enterprises

Based on an empirical analysis of the phased characteristics and existing problems in the coupled and coordinated development of corporate innovation capability and financial core competitiveness, and in the context of the new “dual circulation” development paradigm and the high-quality

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development requirements of the "Belt and Road" Initiative, this study proposes targeted strategies from three dimensions: micro-level corporate operations, meso-level regional guidance, and the macro-level refinement of research methods.

Building a Closed Loop of "Innovation-Finance" Synergy to Enhance the Internal Linkage Ability of Enterprises

Establishing an innovation-finance closed-loop system and strengthening internal corporate synergy requires focusing on three dimensions: indicator prioritization, financial innovation, and industrial chain coordination. Empirical results demonstrate that total R&D investment (15.12% weighting) and patent grants (20.72% weighting) contribute to innovation capacity, while operational capability (73.05% weighting) serves as the cornerstone of financial core competitiveness.

To address the decline in financial core competitiveness caused by sudden changes in the external environment, enterprises need to optimize R&D budget management and establish a dynamic cycle model of "innovation investment—project profitability—cash flow reinvestment". Specifically, the quality of innovation output and cash flow returns should be incorporated into the financial budget evaluation system. Through technology transfer, patent pledge financing, and other methods, the liquidity of innovation assets can be enhanced, transforming technological advantages into tangible financial benefits. To mitigate the decline in financial in 2024, financial stability can be improved through asset securitization to activate existing assets and cross-border settlement to hedge exchange rate risks. At the management level, accounting elements can also be restructured to include more intangible assets in the reporting system. Furthermore, incentive policies for innovation talent, such as innovation compensation expenditures and R&D equipment design investments, demonstrate better effects in enhancing innovation compared to traditional financing constraint mitigation approaches. Enterprises should strive to establish an "innovation partner database" and collaborate with universities and research institutions along the Belt and Road to jointly build laboratories, forming stable relationships for shared knowledge creation.

Strengthening Regional Coordination Mechanism to Promote Efficient Allocation of Resources and Factors

To strengthen regional coordination mechanisms and promote efficient allocation of resources and factors, efforts should be made from both platform construction and factor mobility. On one hand, it is necessary to establish a transnational energy industry alliance, uniting energy enterprises and research institutions along the route to create a regular communication and coordination mechanism, thereby optimizing the sustainability and technical compatibility

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of power projects. For example, by combining expert consultations, SWOT analysis, and the analytic hierarchy process, the alliance can systematically assess the opportunities and challenges of coal, hydropower, and wind power projects, facilitating precise alignment between corporate needs and scientific research technologies, and providing decision-making support for the institutional development of energy cooperation. The ASEAN "10+5" region has established a diversified cooperation mechanism encompassing bilateral, sub-regional, intra-regional multilateral, and extra-regional multilateral frameworks, promoting the inter-connectivity of energy infrastructure such as power grids and oil and gas pipelines, breaking down transmission barriers, and enhancing resource allocation efficiency. On the other hand, it is essential to facilitate the inter-regional flow of technological, human, and financial factors. By establishing technology trading markets and improving evaluation and transfer services, technology transactions can be promoted to optimize technology allocation. In terms of financial factor allocation, efforts should focus on building a financial support system characterized by "policy guidance—market dominance—cross-border linkage". Through deepening institutional cooperation with financial institutions in countries along the Belt and Road, a comprehensive service platform integrating cross-border settlement, green credit, and energy futures should be established to provide energy enterprises with full-cycle financing solutions.

Optimizing the Evaluation Method System and Consolidating the Technical Foundation of Coupling Research

The core objective of coupling research is to elucidate the interaction mechanisms and synergistic effects among different systems, such as those involving talent, capital, and technology. It is crucial to move beyond the limitations of single-indicator evaluations and establish a systematic methodological framework. By applying complex systems theory, regional factor allocation can be conceptualized as a complex dynamic system structured around "factor flow—institutional environment—industrial demand." Building on traditional input-output indicators, spatial spillover effects, network correlations, and dynamic evolutionary features are incorporated to construct a three-dimensional evaluation framework that encompasses "static state, dynamic process, and network structure." This approach significantly enhances the dynamic assessment of inter-factor correlations. Secondly, research on factor coupling exhibits strong interdisciplinary characteristics. Future studies must transcend traditional disciplinary boundaries through profound methodological innovation, thereby overcoming the linear assumptions inherent in single-discipline approaches. Thirdly, establishing a data-driven empirical research paradigm requires the integration of multi-source heterogeneous data. Techniques such as natural

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language processing (NLP) can be employed to extract control variables from policy texts, while geographic information systems (GIS) can map the spatial distribution of factor flows. This addresses common limitations in traditional evaluations, such as unidimensional data and update lag. Furthermore, developing counterfactual assessments and policy simulations—for instance, through agent-based modeling—enables researchers to evaluate the impact of different policy combinations on factor allocation efficiency, providing a pathway for the iterative refinement of evaluation methodologies. By deeply integrating quantitative techniques with domain knowledge, this paradigm achieves both representational accuracy and theoretical generalizability. Fourthly, expanding cross-scale correlation analysis necessitates the establishment of an integrative framework that links multi-scale data. This systems perspective is essential for clarifying the transmission pathways and mutual influences of factor coupling across different spatial and organizational levels. Fifthly, the adaptability analysis of policy tools should be enhanced. Based on simulation results, tailored policy combinations should be designed for different stages of coupling development, supported by mechanisms for dynamic monitoring and adjustment to align with evolving needs. Finally, methodological innovation should be actively advanced by integrating insights and tools from complex network theory, machine learning, and econometrics. Such synthesis is key to elevating the overall scientific rigor and explanatory power of research in this field.

Conclusion

This study examines the coupling coordination mechanism between innovation capability and financial core competitiveness in eight major Chinese energy enterprises under the Belt and Road Initiative from 2018 to 2024, using entropy-weighted TOPSIS, coupling coordination degree models, and grey relational analysis.

Key Empirical Findings

The results reveal a pronounced asymmetry in subsystem development. Innovation capability demonstrated steady growth of 50.4% (from 0.236 to 0.355), while financial competitiveness exhibited significant volatility—plummeting to 0.103 in 2020 before rebounding to 0.270 in 2024. Consequently, the coupling coordination degree (D) evolved from mild imbalance (0.18) through antagonistic growth (0.23) to short-term adjustment (0.30), indicating a fragile yet progressively synergistic relationship. Grey relational analysis identifies patent grants (correlation: 1.00) and fixed asset turnover (0.75) as the primary drivers of system coordination, highlighting that innovation-finance synergy ultimately depends on quantifiable technological achievements and operational efficiency.

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Theoretical Contributions

This study makes three principal contributions. First, it extends coupling coordination theory to the micro-level context of energy enterprises, revealing how policy-driven internationalization shapes the innovation-finance nexus in emerging market multinationals. Second, it provides empirical evidence of industry-specific coupling characteristics—particularly the dominant role of operational efficiency (73.05% weighting) in financial competitiveness, reflecting the asset-intensive nature of energy firms. Third, it identifies threshold dynamics where innovation investments require sustained commitment to overcome short-term financial disruption and achieve synergistic benefits.

Limitations and Future Research

Several limitations warrant acknowledgment. The sample of eight enterprises, while representative of industry leaders, constrains statistical generalizability and precludes sectoral subgroup analyses. The seven-year observation period (2018–2024) may not fully capture long-term cyclical patterns in innovation-finance dynamics. Data availability limitations required mean imputation for missing values, potentially introducing estimation bias. Future research should expand sample coverage to include small and medium-sized energy enterprises, extend the temporal horizon, and employ advanced methods such as spatial econometrics or machine learning to capture nonlinear interactions and cross-border spillover effects.

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