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How New Quality Productive Forces Interact with High-Quality Economic Development: Spatiotemporal Evidence from China

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Abstract: Promoting high-quality economic development has become one of the key factors of China's economic transformation. In this context, the concept of new quality productive forces has been proposed to characterize a development paradigm driven by innovation, digital transformation, industrial upgrading, and ecological sustainability. Understanding the interaction between new quality productive forces and high-quality economic development is therefore crucial for assessing structural transformation and regional development performance. This study investigates the coupling and coordination relationship between new quality productive forces and high-quality economic development in China from spatiotemporal and dynamic perspectives. Using panel data for 30 provincial-level regions from 2013 to 2022, comprehensive evaluation index systems are constructed for both systems. The entropy-weighted TOPSIS method is employed to measure their overall development levels, and a coupling coordination degree model is applied to evaluate their interactive relationship. Regional disparities are further decomposed using the Dagum Gini coefficient, while kernel density estimation and spatial Markov chain analysis are used to examine distributional dynamics, state transitions, and spatial spillover effects. The results show that the overall coupling coordination level in China has increased steadily over the study period, although it remains relatively low. Significant regional heterogeneity is observed, with eastern regions consistently exhibiting higher coordination levels than central and western regions. Subsystem analysis indicates that new quality labor is more closely aligned with high-quality economic development, whereas new quality means of production represents the main constraint, particularly in less developed regions. Further analysis reveals that interregional disparities are the primary source of spatial inequality in coupling coordination. Moreover, spatial Markov chain results identify strong path dependence and significant neighborhood effects, suggesting the existence of club convergence driven by spatial spillovers. Overall, the findings indicate that the coordinated evolution of new quality productive forces and high-quality economic development is jointly shaped by internal structural conditions and external spatial interactions, providing empirical insights for promoting more balanced and sustainable regional development in transitional economies.

Keywords: New quality productive forces; High-quality economic development; Coupling coordination degree; Spatial heterogeneity; Dynamic evolution

1. Introduction

Against the backdrop of profound transformations in the global economy, promoting high-quality economic development has become a central objective for many economies undergoing structural transition (Chen &

Xing, 2025). In recent years, China has increasingly emphasized a shift away from extensive growth driven by factor inputs toward a development model characterized by efficiency improvement, innovation, sustainability, and structural upgrading (Glawe, 2025). Within this context, the concept of new quality productive forces has been proposed as a development paradigm aimed at fostering innovation-driven productivity growth, industrial transformation, and green development (Zheng et al., 2025).

New quality productive forces represent an evolution of traditional productive forces, placing greater emphasis on qualitative improvement rather than simple quantitative expansion. They are commonly associated with breakthroughs in advanced technologies, more efficient allocation of production factors, digital transformation, and the cultivation of emerging and future industries (Shi et al., 2025). By enhancing total factor productivity and reshaping industrial structures, new quality productive forces are widely regarded as a key driving force of high-quality economic development (Dai & Zheng, 2025). At the same time, high-quality economic development requires productive forces that are compatible with new institutional arrangements, technological conditions, and sustainability objectives (Geels et al., 2023; Schmidt-Scheele and Mattes, 2025). This implies that new quality productive forces and high-quality economic development are not independent processes, but rather two interrelated systems that interact and co-evolve over time (Liu et al. ,2025c). Existing studies have explored new quality productive forces from both qualitative and quantitative perspectives. Qualitative research has primarily focused on conceptual definitions, theoretical foundations, and development pathways, highlighting the roles of technological innovation, green transformation, and digitalization in enhancing productivity (Yang et al., 2025; Liang & Huang, 2025). Quantitative studies, in contrast, have sought to measure the development level of new quality productive forces by constructing comprehensive indicator systems, although considerable variation remains in terms of dimensional frameworks and indicator selection. Common approaches include frameworks based on labour, means of production, and labour objects (Hu and Jia, 2025; Lei et al., 2025; Liu et al., 2025a), as well as alternative classifications that emphasize technological, digital, or ecological dimensions (Jiang, 2025; Lu, 2025).

An expanding body of literature has increasingly recognized the close relationship between productivity upgrading and high-quality economic development. Innovation driven improvements in productivity are widely regarded as a core determinant of high-quality growth (Nguyen et al., 2025), while appropriate institutional arrangements can reduce transaction costs and enhance the efficiency of resource allocation (Kafouros et al., 2024). From this perspective, new quality productive forces not only contribute to high-quality economic development but are also shaped by it. high-quality economic development provides the institutional and structural conditions under which the emission-reduction, efficiency enhancing, and sustainability effects of new quality productive forces can be effectively realized (Li & Wang, 2025).

Despite these advances, several research gaps remain. First, although existing studies have separately measured the development level of new quality productive forces or high-quality economic development, relatively limited attention has been paid to their interaction from a system coupling perspective. Second, most empirical analyses focus on static cross regional comparisons, while the dynamic evolution of the coupling relationship and the associated state transitions over time have received insufficient consideration. Third, although spatial disparities are frequently documented, the mechanisms through which neighboring regions influence the evolution of coupling coordination, particularly from dynamic and probabilistic perspectives have not been adequately explored.

This study examines the coupling coordination relationship between new quality productive forces and high-quality Economic development in China from spatiotemporal and dynamic perspectives. Using panel data for 30 provincial-level regions over the period 2013–2022, comprehensive evaluation index systems are first constructed for both new quality productive forces and high-quality economic development. The entropy weighted TOPSIS method is then employed to assess the overall development level of each system, followed by the application of a coupling coordination degree model to quantify their interactive relationship. Subsequently, the Dagum Gini coefficient is used to decompose regional disparities and identify the sources of spatial inequality. Finally, kernel density estimation and spatial Markov chain analysis are adopted to investigate distributional dynamics, state transitions, and spatial spillover effects.

This study makes three main contributions. First, by conceptualizing new quality productive forces and high-quality economic development as two interdependent systems, this paper provides a systematic framework for evaluating their coupling coordination and evolutionary patterns. Second, the study offers a comprehensive empirical assessment of spatiotemporal disparities and dynamic transitions across regions, thereby enriching the literature with evidence from a large transitional economy. Third, by incorporating spatial Markov chain analysis, the study highlights the role of neighborhood effects in shaping the evolution of coupling coordination, offering insights into regional development patterns and policy coordination. Overall, the findings are expected to deepen the understanding of how productivity upgrading interacts with high-quality economic development and to provide empirical support for the formulation of regionally differentiated development strategies in transitional economies.

2. Theoretical analysis

The interaction between new quality productive forces and high-quality economic development can be conceptualized as a multidimensional coupling process, in which productivity upgrading and development quality mutually shape and reinforce each other (Xiao et al., 2025). To clarify this relationship, it is necessary to first examine the internal structure of each system and then elucidate the mechanisms through which they interact.

From the perspective of productivity theory, new quality productive forces represent a qualitative transformation of traditional productive forces. This transformation is not confined to technological progress alone, but also involves comprehensive changes in labor quality, production facilities, industrial structure, and ecological conditions (Lin et al., 2024). Accordingly, new quality productive forces can be decomposed into three interrelated dimensions: new quality labor, new quality means of production, and new quality labor objects.

New quality labor reflects the human capital foundation of production activities, encompassing labor skills, productivity, employment structure, and entrepreneurial capacity (Hosseinioun et al., 2025). Improvements in educational attainment, innovation-related employment, and labor productivity enhance the ability of the workforce to absorb new technologies and participate in advanced production processes (Shin et al., 2025). These changes provide essential support for innovation driven growth and structural upgrading, which constitute core components of high-quality economic development (He et al., 2025).

New quality means of production form the material and technological basis of production activities. This dimension covers traditional infrastructure, digital infrastructure, and investment in technological innovation (Wan et al., 2024). Upgraded transportation networks, enhanced digital connectivity, and sustained investment in research and development improve production efficiency, facilitate knowledge diffusion, and reduce transaction costs (Amankwah-Amoah et al., 2025). By strengthening the technological and infrastructural foundations of the economy, new quality means of production promote a transition toward more efficient, intelligent, and low-carbon production modes (Sharma et al., 2024).

New quality labor objects reflect changes in the content of production and in the ways production activities interact with the natural environment. The development of strategic emerging industries and future industries signals a shift in production patterns toward higher value-added and technology-intensive activities (Chen et al., 2024), while improvements in environmental quality and ecological regulation highlight the growing importance of sustainability constraints (Jin et al., 2025). Taking together, these changes indicate a reorientation of production activities toward long-term development objectives, rather than a narrow focus on short-term output expansion. High-quality economic development is a comprehensive concept that extends beyond economic growth to encompass structural optimization, sustainability, openness, and inclusive welfare improvement (Hou, 2025). Consistent with this perspective, high-quality economic development can be understood through five key dimensions: Innovation, Coordination, Green development, Openness, and Sharing (Huang et al., 2022; Zhou et al., 2022). The Innovation dimension emphasizes the role of technological progress and innovative output in driving sustainable growth. The Coordination dimension focuses on the rationalization and upgrading of industrial structure, reflecting the alignment between sectoral development and overall economic efficiency. The Green development dimension highlights resource-use efficiency and environmental performance, addressing constraints arising from energy consumption and pollution. The Openness dimension captures the integration of the domestic economy into global markets through trade and investment, while the Sharing dimension reflects the inclusiveness of development outcomes in terms of consumption, public services, and income distribution.

The coupling mechanism between new quality productive forces and high-quality economic development operates through multiple channels. On the one hand, productivity upgrading promotes high-quality economic development by enhancing innovation capacity, optimizing industrial structure, alleviating environmental pressure, and expanding development opportunities (Okolo et al., 2025). Improvements in labor quality, production facilities, and industrial positioning directly contribute to innovation performance, structural coordination, and green transformation (Degirmenci et al., 2025). On the other hand, high-quality economic development reshapes the institutional and market environment for productivity upgrading. Innovation-oriented policies, environmental regulations, openness to global markets, and inclusive development objectives influence the direction, intensity, and effectiveness of the evolution of new quality productive forces (Benatti et al., 2024).

When the internal structures and development rhythms of the two systems are well aligned, a coordinated state emerges in which productivity upgrade and development quality mutually reinforce each other. By contrast, mismatches between productivity transformation and development objectives may lead to inefficiencies, structural imbalances, or increased environmental pressure, thereby weakening the level of coordination between the two systems (Lah, 2025). Importantly, this coupling process is dynamic and characterized by spatial heterogeneity (Feng et al., 2024). The evolution of both systems exhibits path dependence, shaped by accumulated technological capabilities, institutional adaptation, and adjustments in industrial structure over time (Wolf, 2025). Moreover, spatial interactions—such as factor mobility, industrial linkages, knowledge spillovers, and policy diffusion—connect the development trajectories of neighboring regions. These spatial linkages may generate positive spillover effects that facilitate upward transitions in coupling coordination, or conversely, reinforce low-level equilibrium traps in less developed regions (Tsangaris et al., 2024).

The coupling between new quality productive forces and high-quality economic development operates through identifiable transmission channels and feedback mechanisms. On the one hand, new quality productive forces promote high-quality development by enhancing innovation capacity, improving factor allocation efficiency, and accelerating industrial upgrading. High-level human capital, advanced production technologies, and digital infrastructure increase total factor productivity and facilitate the transition toward innovation-driven and green development patterns. On the other hand, high-quality economic development provides institutional, financial, and market support for the accumulation and upgrading of new quality productive forces. Regions with stronger economic quality typically possess better innovation ecosystems, higher fiscal capacity, and stronger absorptive capability, which in turn reinforce the growth of advanced production factors. Therefore, the relationship between the two systems is not unidirectional but forms a dynamic feedback loop, in which mutual reinforcement may generate cumulative advantages and spatial divergence over time. This interaction mechanism provides the theoretical foundation for the subsequent coupling coordination analysis.

Based on the above analysis, the coupling coordination between new quality productive forces and high-quality economic development can be understood as the outcome of multidimensional interactions between the two systems, operating through channels such as innovation, structural adjustment, environmental constraints, and spatial spillovers. This theoretical framework provides the conceptual foundation for the construction of evaluation index systems and the subsequent empirical analysis of coupling coordination. The overall coupling mechanism between the two systems is illustrated in Figure 1.

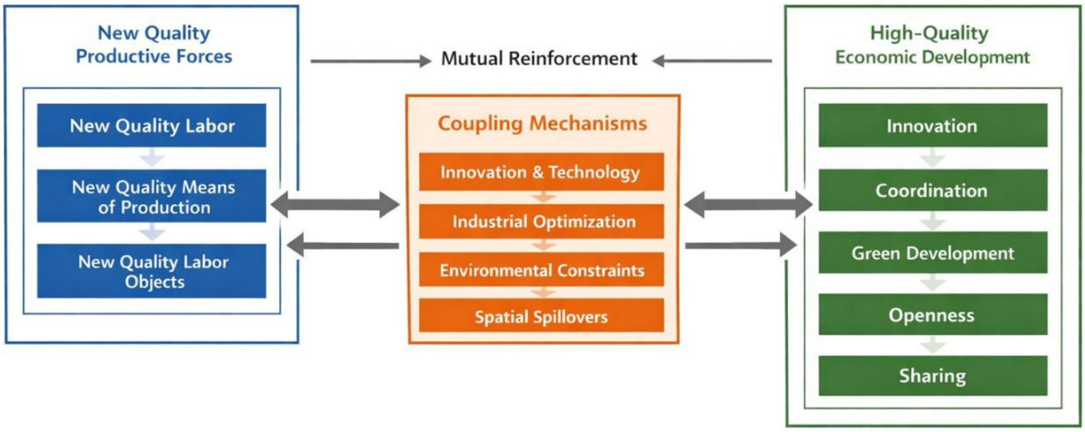


Figure 1. Coupling mechanism between new quality productive forces and high-quality economic development

3. Research Design

3.1 Construction of the Evaluation Index Systems

To examine the coupling coordination between new quality productive forces and high-quality economic development, this study constructs two comprehensive evaluation index systems. Adopting a systems-theoretic perspective, new quality productive forces and high-quality economic development are treated as two interrelated subsystems whose interactions and coordinated evolution can be quantitatively assessed.

3.1.1 Evaluation Index System for New Quality Productive Forces

In classical economic theory, productive forces consist of labor, means of production, and labor objects (Chu et al., 2025). Building on this framework, new quality productive forces emphasize innovation-driven development, modern industrial systems, digital transformation, and ecological sustainability (Zhang & Liu, 2025). Accordingly, this study constructs the evaluation index system for new quality productive forces along three dimensions: new quality labor, new quality means of production, and new quality labor objects.

The first dimension, new quality labor, is designed to capture the overall quality of the workforce, production efficiency, employment conditions, and entrepreneurial capacity. Indicators are selected from four aspects: labor skills, labor productivity, employment conditions, and entrepreneurial activity. Specifically, labor skills are measured by average years of education, human capital stock, and the share of education expenditure in fiscal spending. Labor productivity is represented by GDP per capita and the average wage of employed workers. Employment conditions are captured by the number of full-time equivalent R&D personnel per capita and the registered urban unemployment rate. Entrepreneurial activity is measured by the number of newly registered enterprises per 100 persons.

The second dimension, new quality means of production, reflects the material foundation and technological conditions that support production activities. This dimension covers traditional infrastructure, digital development, and technological innovation. Traditional infrastructure is measured by transportation network density, while digital development is captured by the number of broadband access ports, optical fiber density, and the scale of e-commerce sales. With respect to technological innovation, and in order to distinguish this subsystem from the measurement of innovation inputs and outputs within the high-quality economic development system, this study primarily selects indicators that reflect the upgrading of production modes. These include the intensity of fiscal science and technology expenditure, R&D investment, technological transformation investment, the number of patent authorizations per capita, and the level of intellectual property protection.

The third dimension, new quality labor objects, reflects the transformation of production targets toward emerging industries and ecological sustainability. This dimension is characterized by the development of strategic emerging industries and future-oriented industries. Indicators such as the ratio of transaction value of strategic emerging industry projects to GDP and industrial robot installation density are used to capture the level of industrial upgrading. In addition, environmental indicators—including forest coverage rate, the intensity of environmental protection expenditure, and the strength of environmental regulation—are incorporated to comprehensively reflect the ecological attributes of production activities.

Taken together, these indicators constitute a multidimensional evaluation system that captures both the structural composition of productive forces and the qualitative upgrading of production. The detailed indicator system is reported in Table 1.

Table 1. Indicator system of new quality productive forces

Subsystems	Primary Indicators	Secondary Indicators	Attribute
New quality labor	Labor Force Skills	Average Years of Education Per Person	+
		Total Human Capital	+
		Ratio of Education Expenditure to Total Fiscal Expenditure	+
	Labor Productivity	GDP per capita	+
		Average Wage per Employee: Average wage of active employees	+
	Labor Force Employment	R&D Personnel Intensity: Full-time equivalent R&D personnel/total population	+
		Employment Willingness: Urban registered unemployment rate	−
	Labor Force Entrepreneurship	Number of newly registered enterprises per 100 people	+
New quality means of production	Traditional Infrastructure	Transportation network density: (Highway mileage + Railway mileage) / Administrative area	+
	Digital Development	Internet broadband access ports	+
		Optical Cable Line Length/Regional Area	+
		E-commerce sales	+
	Technological Innovation	Science and Technology Expenditures as a Percentage of Fiscal Expenditures	+
		Expenditures on new product development in high-tech industries	+
		Expenditure on technological transformation of high-tech industries	+
		Patents granted per capita	+
		Intellectual Property Protection Index	+
New quality labor objects	New Quality Industries	Transaction Value of Strategic Emerging Industries Projects / GDP	+
		Industrial Robot Installation Density	+

	Ecological Environment	Forest Coverage Rate	+
		Environmental Protection Intensity: Energy Conservation and Environmental Protection Expenditures / General Public Budget Expenditures	+
		Environmental regulation intensity: Industrial pollution control completed investment / Industrial added value	+

3.1.2 Evaluation Index System for High-Quality Economic Development

High-quality economic development in China is commonly conceptualized within the framework of the five development principles: Innovation, Coordination, Green development, Openness, and Sharing (Gao et al., 2024). Based on this framework, this study constructs an evaluation index system to capture the multidimensional nature of high-quality economic development. The detailed set of indicators is presented in Table 2.

Table 2. Indicator system of high-quality economic development

Subsystems	Primary Indicators	Secondary Indicators	Attribute
Innovation	Economic growth	GDP growth rate	+
	Innovation output	Ratio of technology market transaction value to GDP	+
Coordination	Rationalization of industrial Structure	Thiel index	−
	Upgrading of industrial Structure	Tertiary industry GDP / Secondary industry GDP	+
Green development	Energy consumption	Energy consumption per unit of GDP	−
	Environmental protection	Harmless treatment rate of domestic garbage	+
		Carbon emission emissions per unit of GDP	−
Openness	External capital dependence	Inward foreign direct investment (FDI) as a percentage of GDP	+
	Dependence on foreign trade	Total import and export as % of GDP	+
	Outward Foreign Direct Investment	Outward foreign direct investment (OFDI) as a percentage of GDP	+
Sharing	Consumption upgrade	Consumption per capita	+
	Healthcare sharing	Number of beds in medical institutions per capita	+
	Urban-rural development gap	Urban-rural income ratio: disposable income per capita of urban residents / disposable income per capita of rural residents	−

The Innovation dimension primarily reflects the endogenous driving forces of economic growth and the level of innovative output. Indicators are selected from two aspects—economic growth vitality and technological innovation outcomes, including the GDP growth rate and the ratio of technology market transaction value to GDP.

Although innovation-related indicators also appear in the new quality productive forces system, their roles differ: in that system, innovation represents the configuration of advanced production factors, whereas here it captures the realized economic performance and output effects of innovation activities. This distinction helps maintain the conceptual independence of the two systems.

The Coordination dimension focuses on the degree of industrial structure optimization and is measured from two perspectives: industrial structure rationalization and industrial structure upgrading. Specifically, industrial structure rationalization is characterized by using the Theil index, while industrial structure upgrading is captured by the ratio of value added in the tertiary sector to that in the secondary sector.

The Green development dimension emphasizes resource-use efficiency and environmental performance. Relevant indicators include energy consumption per unit of GDP, the harmless treatment rate of domestic waste, and carbon emission intensity, which jointly reflect resource constraints and environmental impacts in the process of economic development.

The Openness dimension reflects the degree of integration with the global economy and is measured using indicators such as dependence on foreign direct investment, trade openness, and the intensity of outward foreign direct investment.

The Sharing dimension highlights the inclusiveness of development outcomes and incorporates indicators related to consumption levels, availability of medical resources, and the urban–rural income gap.

Overall, this evaluation index system is designed to capture not only economic growth performance but also structural quality, sustainability, openness, and social inclusiveness.

3.2 Data Sources and Sample Description

This study employs panel data for 30 provincial-level regions in China over the period 2013–2022. Due to data availability constraints, Tibet as well as Hong Kong, Macao, and Taiwan are excluded from the analysis. Following the conventional regional classification widely used in the literature, the sample provinces are grouped into eastern, central, and western regions to facilitate spatial comparison (Xu et al., 2025; Liu et al., 2025b).

The data are collected from multiple authoritative sources, including the China Statistical Yearbook, the China Science and Technology Statistical Yearbook, the China High-Technology Industry Statistical Yearbook, the China Energy Statistical Yearbook, the China Torch Statistical Yearbook, provincial statistical yearbooks, the China Intellectual Property Development Report, and data released by the International Federation of Robotics (IFR). All monetary variables are appropriately processed to ensure comparability across regions and over time.

3.3 Methodology

3.3.1 Entropy-Weighted TOPSIS Method

To comprehensively evaluate the development levels of the new quality productive forces system and the high-quality economic development system, this study employs the entropy-weighted TOPSIS method. By determining indicator weights based on information entropy, this approach effectively reduces the bias associated with subjective weighting schemes, while the TOPSIS framework enables the aggregation and ranking of multidimensional indicator systems (Geng et al., 2024).

Specifically, the original indicator data are first standardized to eliminate differences in units of measurement and magnitude across indicators. During this process, positive and negative indicators are treated differently to ensure directional consistency. For positive indicators, higher values correspond to better development performance, whereas for negative indicators, higher values indicate poorer performance; therefore, an inverse transformation is applied to negative indicators before normalization. Subsequently, indicator weights are calculated according to the principle of information entropy, and the standardized indicators are weighted accordingly. On this basis, the Euclidean distances between each region and both the positive ideal solution and the negative ideal solution are computed. The composite development level index of each system is then

derived by comparing these distances.
Formally, the composite development level of region i can be defined as follows:

$$\begin{cases} D_i^+ = \sqrt{\sum_{j=1}^{m} (z_j^+ - z_{ij})^2}, z_j^+ = max\{z_{1j}, z_{2j}, \ldots, z_{nj}\} \\ D_i^- = \sqrt{\sum_{j=1}^{m} (z_{ij} - z_j^-)^2}, z_j^- = min\{z_{1j}, z_{2j}, \ldots, z_{nj}\} \end{cases} \quad (1)$$

$$S_i = \frac{D_i^-}{D_i^+ + D_i^-} \quad (2)$$

In Equations (1)–(2), z_{ij} represents the standardized and entropy-weighted value of indicator j for region i, while D_i^+ and D_i^- denote the Euclidean distances from region i to the positive ideal solution and the negative ideal solution, respectively. A larger value of S_i indicates a higher overall development level of the system.

2.3.2 Coupling Coordination Degree Model

To further examine the interactive relationship between new quality productive forces and high-quality economic development, this study employs a coupling coordination degree model (Norgaard, 1990). Drawing on coupling theory, this model is widely used to assess the degree of interaction and coordination between multiple subsystems and to reveal whether their development trajectories are aligned.

Let S_{nqpf} and S_{hqed} denote the composite development indices of new quality productive forces and high-quality economic development, respectively, as obtained from the entropy-weighted TOPSIS method. The coupling degree between the two systems is defined as:

$$C = \frac{2\sqrt{S_{nqpf} * S_{hqed}}}{S_{nqpf} + S_{hqed}} \quad (3)$$

The coupling degree reflects the intensity of interaction between the two systems, but it does not fully capture their coordinated development level. To address this limitation, a coordination index is further constructed by incorporating the overall development level of the two systems. Specifically, the comprehensive coordination index T is defined as a weighted sum of the two subsystem indices:

$$T = \alpha S_{nqpf} + \beta S_{hqed} \quad (4)$$

where α and β represent the contribution weights of new quality productive forces and high-quality economic development, respectively. Following common practice in the literature, this study assigns equal weights to the two systems, setting $\alpha = \beta = 0.5$. Based on the coupling degree and the comprehensive coordination index, the coupling coordination degree D is calculated as:

$$D = \sqrt{C * T} \quad (5)$$

The coupling coordination degree integrates both the interaction intensity and the overall development level of the two systems, providing a more comprehensive measure of their coordinated evolution. A higher value of D indicates a stronger degree of coordination between new quality productive forces and high-quality economic development, whereas a lower value suggests a greater mismatch between the two systems.

3.3.3 Dagum Gini Coefficient Decomposition

To analyze the spatial disparities in the coupling coordination degree between new quality productive forces and high-quality economic development and to identify their sources, this study adopts the Dagum Gini coefficient decomposition method (Dagum, 1997). Compared with the traditional Gini coefficient, this approach allows the overall inequality to be decomposed into intra-regional disparity, inter-regional disparity, and hypervariable density, thereby effectively addressing the issue of distributional overlap across different regions. The decomposition of the overall Gini coefficient can be expressed as:

$$G=G_{\omega}+G_{nb}+G_{t} \tag{6}$$

In Equation (6), G_{ω} denotes intra-regional disparity, G_{nb} represents inter-regional disparity, and G_t refers to the contribution of hypervariable density. By comparing the relative contributions of these components, this study identifies the importance of different sources of disparity in shaping the overall spatial differentiation of coupling coordination.

3.3.4 Kernel Density Estimation

To further examine the distributional characteristics and dynamic evolution of the coupling coordination degree between new quality productive forces and high-quality economic development, this study employs kernel density estimation. As a nonparametric estimation technique, kernel density estimation allows the probability density function of a variable to be inferred directly from sample data, without imposing a specific functional form. This method is particularly suitable for identifying changes in distributional shape, polarization, and convergence or divergence trends over time. Specifically, kernel density estimation is applied to the coupling coordination degree for different years to depict its temporal evolution. The estimated density function can be expressed as:

$$f(x)=\frac{1}{n\mathrm{h}}\sum_{i=1}^{n}K\left(\frac{x\text{-}X_i}{\mathrm{h}}\right) \tag{7}$$

where $f(x)$ denotes the estimated probability density function, $f(x)$ represents the coupling coordination degree, n is the sample size, h is the bandwidth parameter controlling the smoothness of the density curve, and $K(:)$ denotes the kernel function. Following common practice in the literature, a Gaussian kernel function is adopted in this study.

By comparing kernel density curves across different time periods, this study captures shifts in the distribution of coupling coordination, including changes in central tendency, dispersion, and the presence of multimodal structures. These features provide intuitive evidence on whether the coupling coordination degree exhibits convergence, divergence, or polarization during the study period, thereby complementing the results obtained from the coupling coordination model and the Dagum Gini coefficient decomposition.

3.3.5 Spatial Markov Chain Analysis

To further investigate the dynamic evolution of the coupling coordination degree between new quality productive forces and high-quality economic development, as well as the influence of neighboring regions, this study employs spatial Markov chain analysis. Compared with the traditional Markov chain, the spatial Markov approach explicitly incorporates spatial dependence by conditioning transition probabilities on the development states of neighboring regions, thereby allowing neighborhood effects to be examined from a dynamic and probabilistic perspective.

Following common practice, the coupling coordination degree is first discretized into four ordered states—Basic, Intermediate, Advanced, and Superior—according to predefined classification criteria. Let y_{it} denote the state of region i at time t. The traditional Markov transition probability matrix describes the probability that a region shifts from state m at time t to state n at time t+1. The transition probability can be expressed as:

$$M=\begin{bmatrix} P_{11} & P_{12} & P_{13} & P_{14} \\ P_{21} & P_{22} & P_{23} & P_{24} \\ P_{31} & P_{32} & P_{33} & P_{34} \\ P_{41} & P_{42} & P_{43} & P_{44} \end{bmatrix} \tag{8}$$

In Equation (8), P_{mn} represents the probability of transitioning from state m to state n, and the transition probability matrix satisfies the standard Markov property.

To account for spatial interactions, a spatial Markov transition framework is further constructed by conditioning state transitions on the spatial lag of the coupling coordination degree. Specifically, the spatial lag of region i at time t is defined based on a spatial weight matrix W, as follows:

$$W=\begin{bmatrix} P_{11|1} & P_{12|1} & P_{13|1} & P_{14|1} \\ P_{21|1} & P_{22|1} & P_{23|1} & P_{24|1} \\ P_{31|1} & P_{32|1} & P_{33|1} & P_{34|1} \\ \&P_{41|1} & \&P_{42|1} & \&P_{43|1} & \&P_{44|1} \\ \&P_{11|2} & \&P_{12|2} & \&P_{13|2} & \&P_{14|2} \\ \&\vdots & \&\vdots & \&\vdots & \&\vdots \\ \&P_{41|3} & \&P_{42|3} & \&P_{43|3} & \&P_{44|3} \\ \&P_{11|4} & \&P_{12|4} & \&P_{13|4} & \&P_{14|4} \\ \&P_{21|4} & \&P_{22|4} & \&P_{23|4} & \&P_{24|4} \\ \&P_{31|4} & \&P_{32|4} & \&P_{33|4} & \&P_{34|4} \\ \&P_{41|4} & \&P_{42|4} & \&P_{43|4} & \&P_{44|4} \end{bmatrix} \tag{9}$$

In equation (9), $P_{mn|k}$ denotes the probability that a province with initial state type m transitions to type n in the following year under neighborhood type k. When considering spatial spillover effects, this paper defines adjacency based on contiguity: regions in the spatial weight matrix are set to 1 if adjacent and 0 otherwise.

After prolonged state transitions, the coupling coordination degree between each province's new quality productive forces system and high-quality economic development system eventually reaches a stable state unaffected by temporal variations. Equations (10)-(11) compute this steady state, derived from the initial state and the Markov transition probability matrix.

$$\lim_{k\to\infty}\pi(k+1)=\lim_{k\to\infty}\pi(k)M \tag{10}$$

In Equation (10), π denotes the steady-state matrix of the Markov process, subject to the condition:

$$\sum_{i=1}^{n}\pi_i=1, 0\leq\pi\leq1 \tag{11}$$

By comparing the traditional Markov transition matrix and the spatial Markov transition matrices under different neighborhood contexts, this study examines whether and how neighborhood conditions affect the likelihood of upward or downward transitions in coupling coordination. A higher probability of upward transition when surrounded by high-level neighbors indicates positive spatial spillover effects, whereas a higher probability of persistence in lower states under low-level neighborhood conditions suggests spatial dependence that may reinforce low-level equilibrium traps.

Overall, spatial Markov chain analysis provides a dynamic framework for identifying path dependence, state persistence, and neighborhood effects in the evolution of coupling coordination. This method complements the results of kernel density estimation and Dagum Gini coefficient decomposition, offering deeper insights into the spatiotemporal dynamics of the coupling relationship between new quality productive forces and high-quality economic development.

4. Results

4.1 Temporal Evolution of Coupling Coordination at the National and Regional Levels

Based on the entropy-weighted TOPSIS method and the coupling coordination degree model, this study systematically calculated the coupling coordination degree between new quality productive forces and high-quality economic development for China as a whole and for each province over the period 2013–2022. The detailed results are reported in Table 3, which presents provincial values, regional averages, and national trends.

At the national level, the average coupling coordination degree during the sample period was 0.443, indicating that the overall coordination level remained relatively low but exhibited a gradual improvement. According to commonly used classifications of coupling coordination stages, this level can be classified as a low coordination stage. Despite the relatively low initial level, the coupling coordination degree showed a clear upward trend, increasing from 0.435 in 2013 to 0.470 in 2022, with an average annual growth rate of approximately 0.87%. This pattern suggests that the interaction between new quality productive forces and high-quality economic development strengthened steadily over time.

In addition to the coupling coordination degree, this study further examines the relative development degree between the new quality productive forces system and the high-quality economic development system, which is defined as the ratio of their composite development levels. A value greater than one indicates that the development level of new quality productive forces exceeds that of high-quality economic development, whereas a value below one suggests the opposite. The results show that the national average relative development degree during the study period was 0.905. Moreover, the average relative development degree in the eastern, central, and western regions was consistently below one.

These findings indicate that, over the sample period, the development level of the high-quality economic development system generally exceeded that of the new quality productive forces system in China. This imbalance suggests that, in the short run, enhancing the overall development level of the new quality productive forces system would be conducive to improving the coupling coordination between the two systems.

At the provincial level, notable heterogeneity is observed. Provinces such as Jiangsu, Zhejiang, Fujian, Shandong, and Guangdong exhibited relative development degree values greater than one, indicating that the development of new quality productive forces in these regions progressed more rapidly than high-quality economic development. In contrast, most other provinces recorded relative development degree values below one, reflecting a lag in the development of new quality productive forces relative to economic development quality.

Table 3. Degree of coupling coordination between new quality productive forces and high-quality economic development in China

Region	Province	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	Mean	Relative Development Level
Eastern China	Beijing	0.780	0.698	0.784	0.711	0.777	0.755	0.783	0.769	0.750	0.747	0.755	0.571
	Tianjin	0.612	0.517	0.580	0.562	0.551	0.550	0.585	0.560	0.579	0.583	0.568	0.646
	Hebei	0.344	0.324	0.358	0.334	0.373	0.432	0.406	0.410	0.411	0.408	0.380	0.982
	Liaoning	0.426	0.394	0.391	0.369	0.397	0.403	0.388	0.378	0.409	0.402	0.396	0.598
	Shanghai	0.634	0.599	0.697	0.643	0.671	0.700	0.695	0.682	0.707	0.743	0.677	0.716
	Jiangsu	0.590	0.512	0.583	0.545	0.578	0.573	0.566	0.580	0.618	0.604	0.575	1.662
	Zhejiang	0.541	0.492	0.568	0.524	0.563	0.577	0.572	0.593	0.610	0.632	0.567	1.101
	Fujian	0.454	0.572	0.458	0.478	0.495	0.488	0.468	0.471	0.496	0.501	0.488	1.340
	Shan dong	0.461	0.412	0.461	0.443	0.488	0.489	0.491	0.498	0.514	0.511	0.477	1.309
	Guang dong	0.646	0.571	0.654	0.609	0.659	0.675	0.682	0.708	0.702	0.699	0.660	1.771
	Hainan	0.424	0.377	0.415	0.392	0.493	0.456	0.453	0.435	0.483	0.507	0.443	0.340
	Mean	0.537	0.497	0.541	0.510	0.550	0.554	0.553	0.553	0.571	0.576	0.544	0.907
Central China	Shanxi	0.325	0.283	0.362	0.311	0.370	0.375	0.356	0.346	0.381	0.348	0.346	1.143
	Jilin	0.352	0.317	0.347	0.321	0.346	0.345	0.369	0.380	0.435	0.353	0.356	0.679
	Heilong jiang	0.362	0.320	0.420	0.355	0.403	0.402	0.454	0.407	0.492	0.457	0.407	0.810
	Anhui	0.386	0.343	0.415	0.401	0.441	0.458	0.471	0.488	0.507	0.497	0.441	0.959
	Jiangxi	0.367	0.310	0.372	0.357	0.406	0.431	0.455	0.466	0.474	0.455	0.409	0.706
	Henan	0.366	0.339	0.378	0.367	0.404	0.414	0.419	0.420	0.431	0.457	0.400	0.896

	Hubei	0.406	0.372	0.437	0.406	0.466	0.488	0.478	0.444	0.513	0.480	0.449	0.991
	Hunan	0.381	0.344	0.387	0.391	0.428	0.413	0.427	0.454	0.490	0.494	0.421	0.692
	Mean	0.368	0.329	0.390	0.364	0.408	0.416	0.429	0.426	0.465	0.443	0.404	0.846
Western China	Guangxi	0.337	0.289	0.343	0.316	0.350	0.356	0.351	0.350	0.408	0.379	0.348	0.871
	Inner Mongolia	0.358	0.342	0.366	0.322	0.389	0.384	0.337	0.324	0.381	0.358	0.356	0.909
	Chong qing	0.405	0.366	0.420	0.381	0.426	0.416	0.411	0.415	0.443	0.441	0.412	0.817
	Sichuan	0.435	0.397	0.399	0.364	0.426	0.431	0.415	0.442	0.472	0.452	0.423	1.171
	Guizhou	0.358	0.292	0.325	0.304	0.354	0.351	0.344	0.345	0.373	0.407	0.345	0.974
	Yunnan	0.361	0.296	0.343	0.306	0.347	0.348	0.342	0.341	0.352	0.359	0.339	0.812
	Shaanxi	0.538	0.486	0.464	0.545	0.443	0.504	0.451	0.434	0.449	0.450	0.477	1.137
	Gansu	0.330	0.285	0.318	0.326	0.341	0.337	0.314	0.306	0.337	0.387	0.328	0.626
	Qinghai	0.375	0.345	0.407	0.372	0.390	0.377	0.356	0.310	0.330	0.316	0.358	1.227
	Ningxia	0.349	0.370	0.428	0.356	0.362	0.376	0.368	0.335	0.361	0.339	0.364	1.162
	Xinjiang	0.333	0.303	0.327	0.302	0.333	0.336	0.340	0.305	0.346	0.324	0.325	0.702
	Mean	0.380	0.343	0.376	0.354	0.378	0.383	0.366	0.355	0.386	0.383	0.371	0.954
Nationwide Mean		0.435	0.396	0.440	0.414	0.449	0.455	0.451	0.447	0.475	0.470	0.443	0.905

In terms of growth dynamics, the central region recorded the highest average annual increase in the coupling coordination degree, indicating a tendency toward partial convergence with the eastern region. By contrast, the western region experienced only modest improvement, suggesting that the gap between western provinces and more developed regions continued to widen during the sample period.

At the provincial level, Beijing, Shanghai, Guangdong, Zhejiang, and Jiangsu consistently ranked among the top provinces in terms of coupling coordination. These provinces are characterized by relatively advanced innovation systems, higher levels of industrial upgrading, and stronger institutional support for high-quality economic development. In contrast, several western provinces remained at comparatively low coordination levels for most of the study period, reflecting persistent structural constraints and limited accumulation of new quality productive forces.

4.2 Coupling Coordination between Subsystems of New Quality Productive Forces and High-Quality Economic Development

To further explore the internal structure of coupling coordination, this study examines the interactions between the subsystems of new quality productive forces—new quality labor, new quality means of production, and new quality labor objects—and high-quality economic development. The results are summarized in Table 4, which reports the coupling coordination degree between each subsystem and high-quality economic development at the national level as well as across eastern, central, and western regions.

Table 4. Degree of coupling coordination between new quality productive forces subsystem and high-quality economic development in China

Year	Labor - Economy				Means of Production - Economy				Labor Objects - Economy			
	Overall	East	Central	West	Overall	East	Central	West	Overall	East	Central	West
2013	0.481	0.593	0.396	0.406	0.439	0.567	0.361	0.321	0.448	0.519	0.364	0.421
2014	0.484	0.601	0.397	0.405	0.440	0.570	0.361	0.324	0.374	0.452	0.282	0.341
2015	0.472	0.586	0.384	0.396	0.436	0.561	0.364	0.323	0.480	0.546	0.435	0.428
2016	0.483	0.595	0.406	0.401	0.437	0.566	0.374	0.310	0.395	0.437	0.338	0.371
2017	0.495	0.600	0.424	0.421	0.450	0.573	0.391	0.330	0.460	0.536	0.429	0.393
2018	0.500	0.604	0.435	0.422	0.450	0.571	0.392	0.329	0.480	0.560	0.445	0.410
2019	0.506	0.615	0.445	0.419	0.452	0.574	0.397	0.330	0.474	0.559	0.462	0.378

2020	0.508	0.623	0.454	0.406	0.453	0.578	0.408	0.320	0.460	0.537	0.442	0.380
2021	0.526	0.635	0.484	0.425	0.466	0.587	0.425	0.334	0.505	0.564	0.507	0.430
2022	0.522	0.637	0.470	0.419	0.468	0.592	0.422	0.337	0.493	0.580	0.458	0.414
Mean	0.498	0.609	0.429	0.412	0.449	0.574	0.390	0.326	0.457	0.529	0.416	0.397

At the national level, the coupling coordination degree between new quality labor and high-quality economic development remained relatively stable during the study period, with values generally fluctuating between 0.47 and 0.50. This subsystem consistently exhibited the highest coordination level among the three subsystems, indicating a comparatively stronger alignment between labor-related improvements and the overall quality of economic development.

The coupling coordination degree between new quality means of production and high-quality economic development was slightly lower, with national average values mostly ranging from 0.43 to 0.45. Although this subsystem showed a gradual upward trend over time, its coordination level remained below that of new quality labor, suggesting a relatively slower alignment between production conditions and high-quality development outcomes.

By contrast, the coupling coordination degree between new quality labor objects and high-quality economic development displayed greater volatility and a generally lower level. National-level values varied more substantially over the sample period, reflecting uneven progress in the transformation of production targets toward emerging industries and environmentally sustainable activities.

Marked regional disparities are also evident across all three subsystems. As shown in Table 4, the eastern region consistently recorded the highest coupling coordination degrees for each subsystem, followed by the central region, while the western region lagged behind. This regional ranking remained stable throughout the study period, indicating persistent spatial heterogeneity in subsystem-level coordination patterns.

In terms of relative performance across subsystems, new quality labor exhibited the highest coordination level with high-quality economic development in all three regions, whereas new quality labor objects generally showed the weakest coordination, particularly in the central and western regions. These results suggest that, during the sample period, improvements in labor quality were more closely aligned with high-quality economic development than transformations in production means and labor objects.

4.3 Spatial Inequality and Sources of Regional Disparities

To examine spatial inequality in the coupling coordination degree between new quality productive forces and high-quality economic development, this study employed the Dagum Gini coefficient and its decomposition. The overall disparity G, intra-regional disparity G_{ω}, inter-regional disparity G_{nb}, and their corresponding contribution rates G_z were calculated, with the results reported in Table 5. In addition, Figure 2(a)–Figure 2(c) provide a visual illustration of the temporal evolution and structural composition of spatial inequality.

At the national level, the overall Gini coefficient exhibited a slight but persistent upward trend from 2013 to 2022, indicating a gradual widening of spatial disparities in coupling coordination. As shown in Table 5, the mean value of the overall Gini coefficient during the sample period was 0.161, suggesting a moderate level of inequality that did not substantially decline over time. This trend is visually reflected in Figure 2(a), which shows an increasing dispersion in the distribution of coupling coordination across provinces.

Decomposition results indicate that inter-regional disparity was the dominant source of overall spatial inequality throughout the study period. On average, inter-regional disparity accounted for approximately 68.87% of total inequality, highlighting pronounced differences among the eastern, central, and western regions. As illustrated in Figure 2(b), the contribution of inter-regional disparity consistently exceeded that of intra-regional disparity and hypervariable density, underscoring the persistent role of regional gaps in shaping spatial inequality.

Table 5. Dagum Gini coefficients and contribution rates

Year	G	G_ω			G_{nb}			G_z（%）		
		East	Central	West	East-Central	East-West	Central-West	intra-regional	inter-regional	hypervariable density
2013	0.134	0.127	0.074	0.034	0.187	0.192	0.059	23.81	66.77	9.42
2014	0.144	0.121	0.089	0.042	0.197	0.207	0.073	23.17	67.83	9.00
2015	0.132	0.136	0.042	0.070	0.172	0.189	0.063	25.05	65.42	9.53
2016	0.139	0.128	0.051	0.086	0.178	0.197	0.077	24.55	62.79	12.66
2017	0.125	0.116	0.049	0.054	0.159	0.190	0.063	22.71	70.77	6.52
2018	0.126	0.112	0.057	0.065	0.150	0.188	0.074	23.43	69.63	6.94
2019	0.133	0.123	0.055	0.058	0.143	0.207	0.091	22.76	72.34	4.90
2020	0.143	0.126	0.058	0.073	0.148	0.222	0.105	22.89	71.89	5.22
2021	0.127	0.113	0.050	0.068	0.125	0.197	0.103	22.88	70.87	6.25
2022	0.136	0.115	0.064	0.070	0.149	0.206	0.096	22.81	70.41	6.78
Mean	0.134	0.122	0.059	0.062	0.161	0.200	0.080	23.41	68.87	7.72

By contrast, intra-regional disparity contributed a smaller but non-negligible share to overall inequality. As reported in Table 5, the average contribution of intra-regional disparity was 23.41%, indicating the presence of heterogeneity among provinces within the same region. This pattern is also evident in Figure 2(b), where intra-regional disparity remained secondary relative to inter-regional disparity throughout the study period.

The contribution of hypervariable density, which captures distributional overlap across regions, was relatively limited. The average contribution of hypervariable density was 7.72%, suggesting that overlapping distributions played a minor role in shaping overall spatial inequality. This finding is further confirmed by Figure 2(c), which shows that the hypervariable density component remained consistently low compared with the other two sources of disparity.

Further disaggregation reveals that disparities between the eastern and western regions contributed most to inter-regional inequality, followed by differences between the eastern and central regions, while disparities between the central and western regions were comparatively smaller. Taken together, the combined evidence from Table 5 and Figure 2(a)–(c) indicates that spatial inequality in the coupling coordination degree was largely driven by persistent inter-regional disparities, with limited convergence observed during the study period.

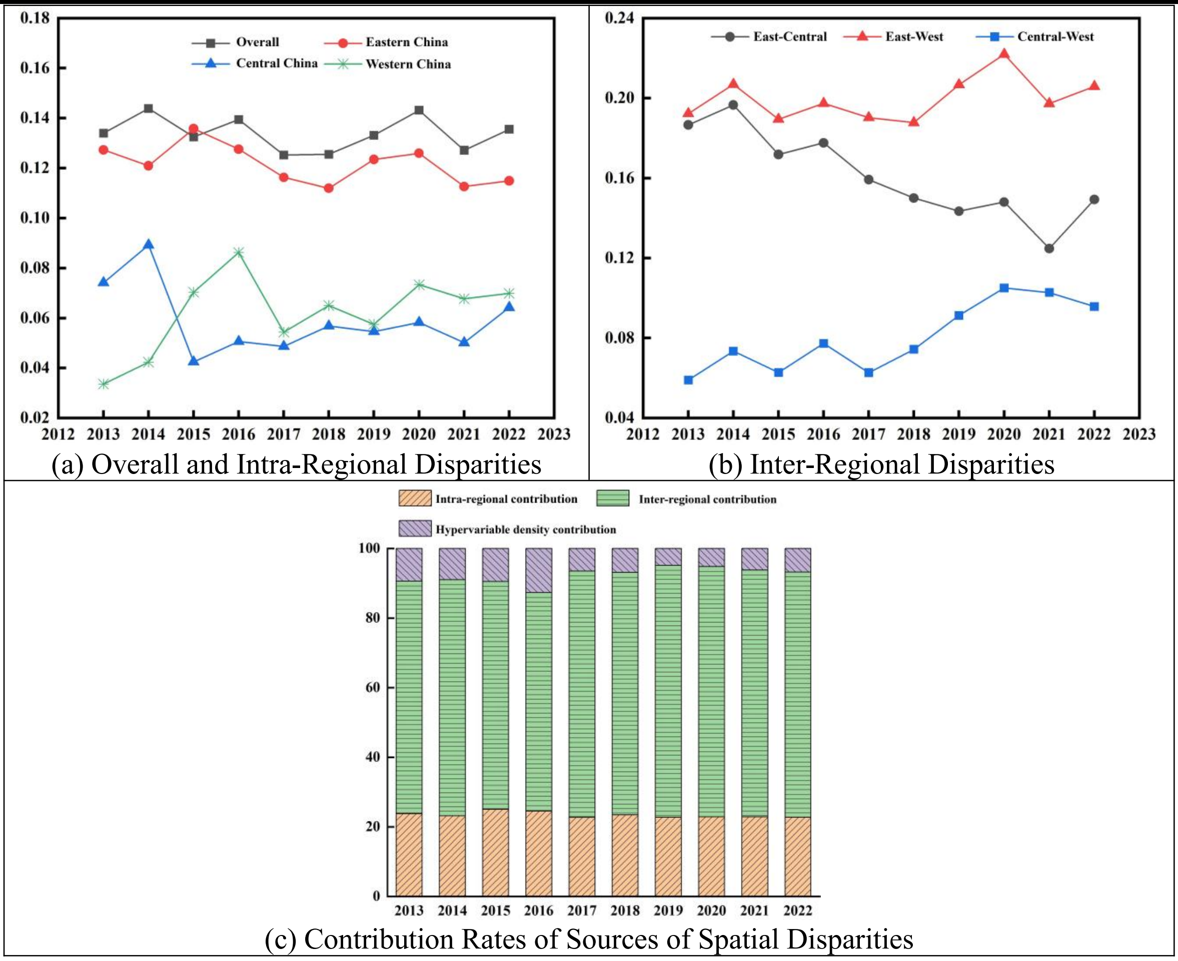


Figure 2. Temporal evolution and decomposition of the Gini coefficient

4.4 Dynamic Evolution and Spatial Transition of Coupling Coordination

4.4.1 Kernel Density Estimation

To explore the distributional dynamics of the coupling coordination degree between new quality productive forces and high-quality economic development, kernel density estimation was applied at the national level and for the eastern, central, and western regions. The results are illustrated in Figure 3(a)–Figure 3(d).

Figure 3(a) depicts the evolution of the national distribution of the coupling coordination degree. The density curves are characterized by a left-shifted peak, indicating that provinces with relatively low coordination levels accounted for a large proportion of the sample. Over time, the main peak gradually shifted to the right, suggesting an overall improvement in the coupling coordination degree, although the magnitude of this increase remained limited. Meanwhile, the height of the main peak declined and the distribution became wider, accompanied by a noticeable tailing effect. The emergence of secondary peaks further indicates the presence of polarization, reflecting increasing heterogeneity among provinces at the national level. This polarization may be associated with uneven policy support, differential factor mobility, and the agglomeration of innovation resources in leading regions, which reinforce cumulative advantages. Meanwhile, regions with weaker industrial foundations or limited access to advanced production factors may experience slower improvement, thereby widening the distributional gap.

Figure 3(b) presents the distributional dynamics for the eastern region. In contrast to the national pattern, the peak of the density curve was located closer to the middle range and exhibited no pronounced tailing effect. The main peak shifted steadily to the right, indicating that a relatively large number of provinces achieved higher levels of coupling coordination than the national average. Moreover, the height of the main peak increased over time, implying a gradual reduction in intra-regional disparities within the eastern region.

Figure 3(c) illustrates the distributional dynamics for the central region. The peak of the density curve was concentrated toward the lower range, indicating that provinces with relatively low levels of coupling coordination accounted for a large share of the region. Over time, the main peak exhibited a moderate rightward movement, suggesting an overall improvement in the coupling coordination degree. Temporary secondary peaks emerged in certain years, reflecting short-lived polarization rather than a persistent structural divide. Meanwhile, the widening of the density curve indicates an expansion of intra-regional disparities in the central region.

Figure 3(d) illustrates the kernel density estimates for the western region. Similar to the central region, the main peak was positioned on the left side of the distribution, reflecting generally low coordination levels. The gradual rightward shift of the peak indicates an overall increase in the coupling coordination degree. However, the persistent presence of secondary peaks, together with an expanding distribution width and tailing effects, reveals a growing degree of internal heterogeneity and polarization within the western region.

Figure 3. Kernel density estimation

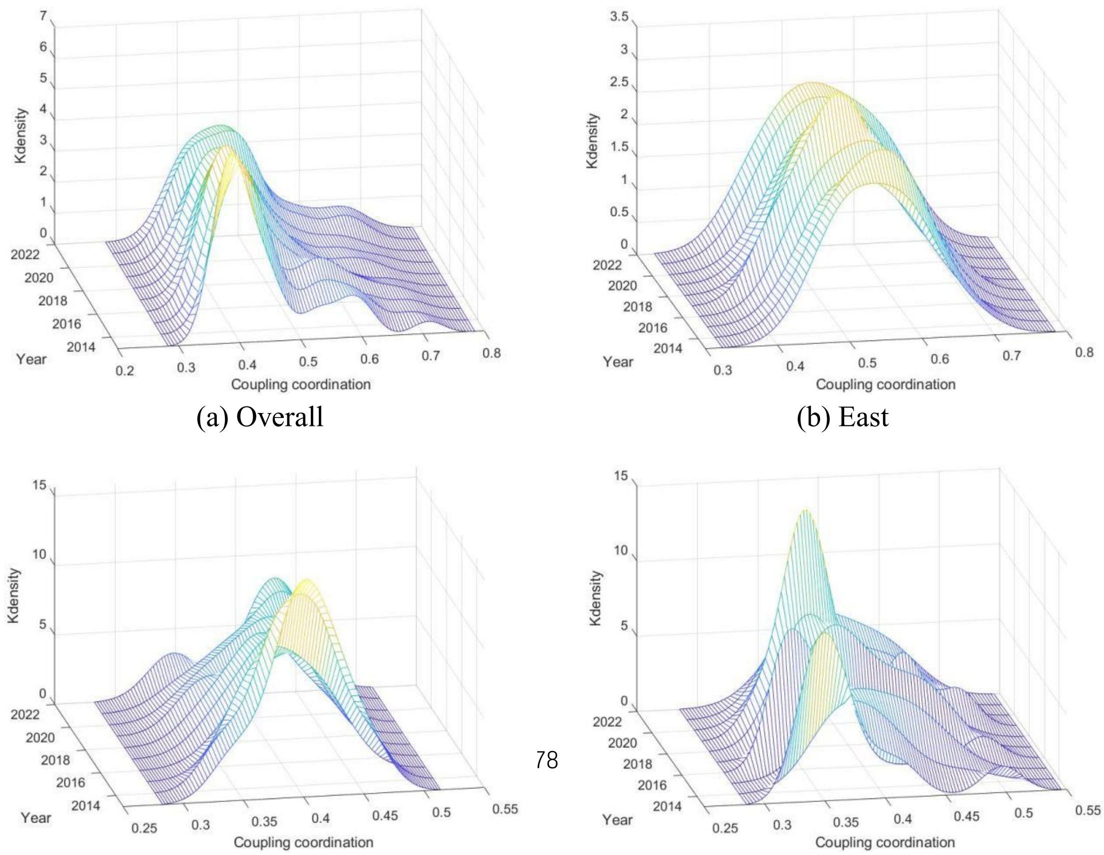
Overall, the kernel density estimates for China as a whole and for the three major regions consistently exhibit a rightward shift of the main peak, indicating a continuous increase in the coupling coordination degree over the study period. The dynamic evolution of peak positions corresponds closely to the observed changes in coupling coordination levels. At the same time, intra-regional disparities narrowed in the eastern region but expanded in the central and western regions, contributing to a widening trend in interprovincial disparities at the national level.

4.4.2 Markov Chain and Spatial Markov Analysis

To further investigate the dynamic evolution of the coupling coordination degree between new quality productive forces and high-quality economic development, both traditional Markov chain analysis and spatial Markov chain analysis were employed. Based on the estimated transition probabilities, the evolutionary tendency of coupling coordination was further examined.

(1) Traditional Markov Chain Analysis

A traditional Markov transition probability matrix was first constructed to analyze the intrinsic evolution of the coupling coordination degree without explicitly accounting for spatial interactions. The corresponding



(a) Overall (b) East

(c) Central (d) West

transition probability matrix is reported in Table 6, where the coupling coordination degree was classified into four ordered states: Basic, Intermediate, Advanced, and Superior.

Table 6. Traditional Markov transition probability matrix

t\t+1	n	Basic	Intermediate	Advanced	Superior
Basic	70	0.686	0.286	0.029	0
Intermediate	68	0.265	0.471	0.250	0.015
Advanced	68	0.029	0.176	0.632	0.162
Superior	64	0	0	0.125	0.875

As shown in Table 6, the diagonal elements of the transition matrix are consistently higher than the off-diagonal elements, indicating strong state persistence. In particular, the Superior state exhibits the highest persistence probability, with 87.5% of provinces remaining in the same state in the subsequent period. This is followed by the Basic state, which shows a persistence probability of 68.6%, suggesting pronounced stability at both low and high coordination levels.

Downward transition probabilities decrease as the coordination level rises. Specifically, provinces in the Intermediate state have a 26.5% probability of transitioning downward in the next period, while this probability declines to 20.5% for the Advanced state and further to 12.5% for the Superior state. These results indicate that provinces with higher coupling coordination levels face a relatively lower risk of deterioration. Overall, the traditional Markov results suggest that the evolution of coupling coordination follows a gradual upward trajectory, characterized by strong path dependence and a stepwise transition pattern.

(2) Spatial Markov Chain Analysis

The state of neighboring regions may influence the transition path of a province's coupling coordination state in the subsequent period. To capture this effect, a binary (0–1) spatial weight matrix was adopted as the spatial weight matrix in the Markov chain framework, and the corresponding spatial transition probabilities were calculated.

The spatial Markov transition probability matrix is reported in Table 7. Compared with the traditional Markov transition matrix shown in Table 6, substantial changes in transition probabilities are observed, indicating that spatial factors play an important role in shaping state transitions. The statistical significance of spatial spillover effects can be tested using Equation (12). The null hypothesis is that state transitions across regions are mutually independent and unrelated to the states of neighboring regions:

$$Q_b = -2\,log\left\{\prod_{l=1}^{k}\prod_{i=1}^{k}\prod_{j=1}^{k}\left[\frac{p_{ij}}{p_{ij}(S)}\right]^{n_{ij}(S)}\right\} \tag{12}$$

In Equation (12), k denotes the number of states, which is set to 4 in this study; p_{ij} represents the transition probability in the traditional Markov chain; $p_{ij}(S)$ denotes the spatial Markov transition probability conditional on the neighboring state S; and $n_{ij}(S)$ refers to the number of observed transitions under neighboring state S. The test statistic Q_b follows a chi-square distribution with degrees of freedom $k(k\text{-}1)^2$. In this study, the value of Q_b is 87.992, with a corresponding p-value of 0.000. At the significance level of α=0.005, the null hypothesis of independent state transitions is rejected, providing strong evidence of spatial spillover effects.

As shown in Table 7, the coupling coordination states exhibit a clear pattern of spatial clustering. For example, when the neighboring state is Basic, the number of observations that remain in the Basic state in both the current and subsequent periods (n = 19) is substantially higher than the corresponding numbers for other states (n = 7, 3, and 1). Similarly, when the neighboring state is Superior, the number of observations remaining in the Superior state (n = 37) is markedly higher than those transitioning to other states (n = 13, 1, and 0). The spatial Markov transition results remain stable under alternative specifications of the spatial weight matrix. Using an economic distance matrix yields consistent transition probabilities, confirming robustness.

Table 7. Spatial Markov transition probability matrix

Neighborhood Type	t\t+1	n	Basic	Intermediate	Advanced	Superior
Basic	Basic	19	0.737	0.211	0.053	0
	Intermediate	7	0.143	0.714	0.143	0
	Advanced	3	0	0.667	0.333	0
	Superior	1	0	0	1.000	0
Intermediate	Basic	40	0.700	0.275	0.025	0
	Intermediate	39	0.308	0.462	0.231	0
	Advanced	16	0.063	0.250	0.563	0.125
	Superior	6	0	0	0.333	0.667
Advanced	Basic	11	0.545	0.455	0	0
	Intermediate	19	0.263	0.474	0.263	0
	Advanced	30	0.033	0.133	0.700	0.133
	Superior	19	0	0	0.158	0.842
Superior	Basic	0	0	0	0	0
	Intermediate	1	0	0	1.000	0
	Advanced	13	0	0	0.692	0.308
	Superior	37	0	0	0.027	0.973

Moreover, when a province is initially in the Basic state, the probability of upward transition increases with the coordination level of neighboring regions. Specifically, when the neighboring states are Basic, Intermediate, and Advanced, the probabilities of upward transition are 26.9%, 30.0%, and 45.5%, respectively. Notably, when the neighboring state is Superior, no observations remain in the Basic state in the subsequent period.

These results indicate that the spatial Markov transition probability matrix exhibits a pronounced club convergence pattern in the spatial dimension. Under the influence of neighboring states, regions are more likely to experience upward transitions rather than downward transitions, and the probability of upward mobility increases as the coordination level of neighboring regions rises. Overall, the spatial Markov analysis suggests that the coupling coordination degree between new quality productive forces and high-quality economic development in China follows a gradual upward evolution path shaped by significant spatial spillover effects.

(3) Evolution Trend Prediction of Coupling Coordination Degree

The long-term evolution trend of the coupling coordination degree can be effectively predicted by deriving the steady-state distribution of the Markov transition probability matrix. Table 8 reports the predicted long-run distribution of coupling coordination states for China.

Table 8. Predicted evolutionary trend of coupled coordination degree state types in China

Type		Basic	Intermediate	Advanced	Superior
No spatial spillover effects	Initial state	0.233	0.367	0.167	0.233
	Steady state	0.182	0.187	0.265	0.366

Spatial spillover effects	Steady state	Basic	0.302	0.556	0.143	0.000
		Intermediate	0.358	0.299	0.249	0.093
		Advanced	0.151	0.217	0.343	0.289
		Superior	0	0	0.081	0.919

When spatial spillover effects are not considered, the steady-state distribution obtained from the traditional Markov transition matrix shows a clear upward shift in coordination levels. Compared with the initial distribution, the numbers of provinces in the Basic, Intermediate, and Advanced states all decline, while the number of provinces in the Superior state increases markedly. This result indicates that, in the long run, the coupling coordination degree between new quality productive forces and high-quality economic development tends to evolve progressively from lower to higher states, reflecting a gradual improvement in overall coordination levels.

When spatial spillover effects are taken into account, the predicted evolution pattern of coordination states changes substantially. In the long run, provinces adjacent to regions in the Basic state are more likely to remain in relatively low coordination states, with 30.2% of observations remaining in the Basic state and 55.6% transitioning to the Intermediate state, while no provinces are expected to reach the Superior state under such neighborhood conditions. By contrast, when neighboring regions exhibit higher levels of coupling coordination, the probabilities of transitioning to the Advanced and Superior states are significantly higher than in other spatial contexts. These results suggest a pronounced Matthew effect in the coupling coordination between new quality productive forces and high-quality economic development across provinces.

Overall, based on current development trends, the long-term evolution of the coupling coordination degree in China appears relatively optimistic. The coordination between the two systems is expected to improve steadily over time, accompanied by a tendency toward high-level regional clustering. The number of provinces in higher coordination states increases progressively from lower to higher levels. Neighborhood spillover effects play a critical role in shaping this evolution: adjacency to low-level regions may constrain improvements in coordination or even induce downward transitions, whereas proximity to high-level regions facilitates upward mobility toward the Advanced and Superior states, reinforcing the overall upward trajectory of coupling coordination.

5. Discussion

From a spatiotemporal and dynamic evolutionary perspective, this study systematically examines the coupling coordination between new quality productive forces and high-quality economic development in China. The empirical findings not only characterize the overall pattern of coordinated evolution between the two systems, but also reveal substantial regional heterogeneity and structural differences in their interaction dynamics.

5.1 Staged Evolution of Overall Coupling Coordination

The results indicate that the coupling coordination degree between new quality productive forces and high-quality economic development exhibited a steady upward trend during the sample period, while the overall coordination level remained relatively low. This pattern suggests that the positive role of productivity upgrading in promoting high-quality economic development has gradually emerged, yet its comprehensive effects have not been fully realized. The cultivation of new quality productive forces involves multiple dimensions, including technological innovation, factor reallocation, and institutional adaptation. These processes are inherently gradual and often characterized by time lags, making it difficult to achieve a high level of coordination with high-quality economic development in the short run.

This finding is broadly consistent with existing studies. For example, Liu and He (2024) argue that although improvements in new quality productive forces can enhance development quality in the manufacturing sector, the early stages of transformation are frequently accompanied by structural frictions and adjustment costs, which lead to a gradual rather than immediate release of synergistic effects. In this sense, the "low-level initiation followed by steady improvement" pattern of coupling coordination identified in this study reflects the practical constraints faced by China's economic transition from scale-oriented growth toward a quality-driven development model.

5.2 Regional Heterogeneity and Differentiated Development Paths

From a spatial perspective, the coupling coordination degree between new quality productive forces and high-quality economic development exhibits pronounced regional heterogeneity. Overall, the eastern region remains in a leading position, the central region shows a clear catching-up trend, and the western region continues to lag behind. This spatial pattern largely mirrors the long-standing regional disparities observed in China's economic development trajectory.

The leading position of the eastern region can be attributed not only to its concentration of innovation resources and relatively complete industrial systems, but also to the cumulative interaction among these advantages. A denser innovation network, stronger market mechanisms, and deeper integration into global value chains enable a faster conversion of technological advances into productivity gains and industrial upgrading. This self-reinforcing process strengthens the feedback loop between new quality productive forces and high-quality economic development, thereby sustaining the region's leading status. By contrast, the central and western regions continue to face constraints related to industrial upgrading, technological foundations, and the efficiency of factor allocation, which weaken the transmission from productivity upgrading to improvements in development quality. This interpretation is consistent with the findings of Feng et al. (2024), who emphasize that disparities in technological bases and industrial structures across regions are key factors driving the differentiated development of new quality productive forces and their economic effects.

It is also noteworthy that the central region experienced a relatively faster improvement in coupling coordination, indicating a gradual catching-up process, whereas the western region exhibited more limited progress. This divergence suggests substantial differences across regions in their capacity to absorb industrial relocation, improve infrastructure, and optimize factor structures. More broadly, these patterns highlight the strong path-dependent nature of the coordinated evolution between new quality productive forces and high-quality economic development, whereby historical endowments and accumulated advantages continue to shape regional development trajectories.

5.3 Explaining Structural Heterogeneity across Subsystems

From a subsystem perspective, pronounced differences are observed in the coupling coordination between the internal dimensions of new quality productive forces and high-quality economic development. Among the three subsystems, new quality labor exhibits a relatively higher level of coordination with high-quality economic development. This finding indicates that, at the current stage, improvements in human capital accumulation, labor productivity, and innovation-related employment are more readily translated into tangible development outcomes.

This result is consistent with the arguments of Degirmenci et al. (2025), who emphasize that human capital promotes sustainable development and high-quality growth by facilitating technological progress and green innovation. They further note that such effects tend to be more evident in regions with relatively mature institutional and market environments. In this context, the stronger coordination between new quality labor and high-quality economic development identified in this study reflects the comparatively direct and immediate role of labor-related factors in supporting innovation-driven and efficiency-oriented growth.

By contrast, the coupling coordination between the new quality means of production subsystem and high-quality economic development remains relatively weak. This pattern suggests that infrastructure modernization, digital transformation, and technological upgrading have not yet fully exerted their supporting role in some regions. One possible explanation is that such improvements typically require large-scale capital investment, long construction cycles, and complementary institutional adjustments, which delay their effective integration into the broader development system. As a result, the upgrading of production facilities may lag behind human capital improvements, thereby becoming a structural constraint on deeper coordination.

The new quality labor objects subsystem occupies an intermediate position in terms of coordination. This indicates that the development of strategic emerging industries and the strengthening of ecological constraints are gradually gaining importance, while their contribution to overall high-quality economic development is still in an accumulation phase. Taking together, these structural differences highlight the heterogeneous and asynchronous roles played by different elements of new quality productive forces in driving high-quality economic development, with each subsystem exerting its influence at a distinct pace.

5.4 Spatial Inequality, Path Dependence, and Neighborhood Effects

The decomposition results based on the Dagum Gini coefficient indicate that inter-regional disparity constitutes the primary source of spatial inequality in the coupling coordination degree between new quality productive forces and high-quality economic development. This finding suggests that long-standing differences across regions in terms of economic foundations, industrial structures, and institutional environments tend to be persistently amplified during the process of coupled and coordinated evolution. By contrast, the contributions of intra-regional disparity and hypervariable density are relatively limited, implying that adjustments within individual regions are unlikely to substantially narrow overall spatial disparities in the short run.

Further evidence from the spatial Markov chain analysis reveals pronounced path dependence and neighborhood effects in the evolution of coupling coordination. Specifically, regions with relatively high levels of coupling coordination exhibit strong temporal stability and are more likely to generate positive spillover effects on neighboring areas, whereas regions with low coordination levels tend to maintain their existing development states within spatial interactions. This spatial clustering pattern, characterized by "high–high" and "low–low" agglomerations, indicates that regional development does not proceed in isolation but is continuously reinforced or constrained through neighborhood relationships.

These findings are highly consistent with conclusions obtained in previous studies employing different research contexts and methodological frameworks. Chen et al. (2022) and Zhu et al. (2024), using spatial Markov chain approaches, demonstrate that the development level of neighboring regions significantly affects state transition probabilities, with high-level regions being more likely to form stable convergence clubs, while low-level regions exhibit a lower probability of cross-level transitions. Similarly, Liao et al. (2024) find that regional state transitions are largely concentrated around existing levels, with leapfrogging upgrades being relatively rare, thereby giving rise to distinct patterns of club convergence in spatial terms. Together, these studies underscore the critical role of spatial linkages and neighborhood effects in shaping long-term regional development trajectories.

From a longer-term perspective, low-level regions may become trapped in persistent low-equilibrium states or even development traps if they lack effective external support or cross-regional coordination. Diemer et al. (2022), in their analysis of European regional development, argue that "regional development traps" often arise from the combined effects of structural disadvantages and spatial isolation, which prevent lagging regions from achieving breakthroughs through internal adjustments alone. Likewise, Guevara-Rosero et al. (2025) show that poverty and low development levels exhibit strong spatial spillover characteristics, whereby low-level conditions in neighboring regions mutually reinforce each other and slow down overall improvement.

In the context of China, the spatial analysis conducted in this study suggests that the coupled evolution of new quality productive forces and high-quality economic development is shaped by similar mechanisms. High-level regions tend to reinforce their advantages through positive spatial spillovers, whereas low-level regions, in the absence of effective interregional linkages and external support, may remain locked in low-coordination states under the influence of path dependence. This spatially uneven structure further implies that relying solely on improvements within individual regions is likely to yield limited effects in promoting coordinated evolution. Instead, greater emphasis should be placed on regional collaboration and spatial linkage mechanisms to facilitate the diffusion of positive spillover effects.

Overall, the discussion highlights that the coupling coordination between new quality productive forces and high-quality economic development is a dynamic process jointly shaped by structural conditions, regional contexts, and spatial interactions. While productivity upgrading provides necessary conditions for high-quality development, its realized effects depend critically on the coordination among human capital, production facilities, and industrial structures, as well as on interregional spatial linkages and spillover effects. These findings suggest that advancing the coordinated evolution of new quality productive forces and high-quality economic development requires careful consideration of regional heterogeneity and spatial contexts, thereby avoiding overly simplified policy expectations.

6. Conclusion

Based on panel data for 30 provincial-level regions in China from 2013 to 2022, this study constructed comprehensive evaluation index systems for new quality productive forces and high-quality economic development. By integrating the entropy-weighted TOPSIS method, the coupling coordination degree model, and a set of complementary analytical tools—including Dagum Gini coefficient decomposition, kernel density estimation, and spatial Markov chain analysis—this study systematically examined the coupling coordination level, regional disparities, and dynamic evolution of the two systems from a spatiotemporal perspective. The core contribution of this research lies not in reiterating differences in levels or temporal trends, but in demonstrating that the coordinated advancement of the two systems is subject to pronounced structural and spatial constraints, with evolutionary paths jointly shaped by internal factor configurations and external spatial linkages.

At the aggregate level, the findings suggest that the coordinated evolution of new quality productive forces and high-quality economic development does not occur spontaneously, but rather represents a long-term process conditioned by structural characteristics, institutional adaptation, and the efficiency of factor allocation. In a broader theoretical sense, this conclusion speaks directly to the literature on structural transformation and institutional evolution, which emphasizes that development quality depends on the alignment between technological progress, structural adjustment, and institutional environments (Wiegant et al., 2024; Grazini et al., 2024). In other words, while productivity upgrading provides a necessary foundation for high-quality development, its stable translation into development performance hinges on whether regional factor systems can achieve coordinated optimization and whether they can interact constructively with the surrounding spatial environment.

From a spatial and dynamic perspective, this study further shows that regional development is not an independent or linear process. Instead, it is characterized by path dependence, state persistence, and spatial interdependence, which may give rise to hierarchical evolution patterns and club agglomeration. This finding underscores the fundamental role of regional context in shaping long-term development trajectories and provides empirical support for the view that spatial interactions can either reinforce or inhibit regional transformation processes (Yang et al., 2024). Accordingly, differences in the coordinated evolution of new quality productive forces and high-quality economic development should not be attributed solely to short-term policy interventions or cyclical fluctuations, but rather understood as the outcome of enduring structural conditions and spatial relationships.

In terms of policy implications, the results do not support a uniform strategy aimed at improving isolated indicators. Instead, they highlight the importance of targeted coordination mechanisms and regionally differentiated interventions aligned with the structural characteristics identified in the empirical analysis. For regions trapped in low-level coordination states—particularly those exhibiting "low–low" spatial clustering—priority should be given to overcoming structural bottlenecks in the means of production subsystem, including deficiencies in advanced production facilities, digital infrastructure, and technological integration capacity. Strengthening these foundational conditions is essential for breaking path dependence and facilitating upward state transitions. For regions already at relatively high coordination levels, policy efforts should focus on preventing structural lock-in and enhancing outward spillover capacity. This can be achieved by promoting cross-regional innovation diffusion, improving interregional industrial linkages, and establishing institutional mechanisms that facilitate the transmission of productivity gains to neighboring areas. Differentiated and tiered policy frameworks—based on subsystem constraints and spatial transition characteristics—are more likely to mitigate persistent divergence and promote sustainable coordinated development across regions.

Several limitations of this study should be acknowledged. First, the measurement of new quality productive forces relies primarily on macro-level statistical indicators. While this approach captures regional-level characteristics in a comprehensive manner, it is less capable of reflecting micro-level technological breakthroughs, organizational transformations, and firm-level behavioral heterogeneity. Second, the province-level analytical framework may obscure important variations within provinces, such as differences among urban agglomerations, metropolitan areas, and industrial sectors, thereby limiting a more nuanced understanding of intra-regional heterogeneity. Third, although this study focuses on descriptive characterization and dynamic evolution of coupling coordination, the causal mechanisms underlying these relationships warrant further investigation. Future research could build on this study by employing finer-grained data and adopting empirical strategies with stronger identification power to more rigorously uncover the mechanisms linking new quality productive forces and high-quality economic development. In addition, further exploration of spatial channels—such as industrial linkages, factor mobility, and policy diffusion—would help clarify how spatial interactions shape coordinated evolution across regions, thereby providing more targeted empirical evidence to support more balanced and sustainable regional high-quality development.

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