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Coupling Measurement and Mechanism of New Quality Productivity and High-Quality Development in the Yangtze River Delta

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Abstract: This study reviews existing literature on the coupling relationship between New Quality Productivity (NQP) and High-Quality Development (HQD), and proposes a conceptual framework for integrated measurement and mechanism analysis in the Yangtze River Delta (YRD). Conventional Coupling Coordination Degree (CCD) approaches are limited in their ability to capture dynamic evolution, spatial spillovers, nonlinear dependencies, and uncertainty. Based on a synthesis of existing methodologies, a multidimensional indicator system is constructed, encompassing technological transformation efficiency, total factor productivity, and green development. An improved CCD framework is conceptually developed through the integration of entropy–CRITIC hybrid weighting with uncertainty analysis based on Bootstrap resampling and Monte Carlo simulation. In addition, spatial econometric models and neural network techniques are introduced to facilitate the investigation of potential driving mechanisms and complex nonlinear interactions within the coupled system. This study provides a methodological roadmap to support subsequent empirical research and policy evaluation aimed at promoting coordinated regional development.

Keywords: New Quality Productivity; High-Quality Development; Spatial Interaction; Coupling Coordination; Yangtze River Delta.

1. Introduction

Under the strategic background of China's economy moving from high-speed growth to high-quality development, the Yangtze River Delta, as the country's most dynamic and radiating economic engine, its development model has a significant demonstration significance to the whole country. The Third Plenary Session of the 20th CPC Central Committee proposed that improving the strategic mechanism of regional coordinated development, promoting the Yangtze River Delta and other regions to play a better role as the driving force of high-quality development, and the coordination mechanism of new quality productivity cultivation and high-quality development is the inevitable path to promote regional coordinated development and industrial transformation and upgrading. To build the two coupling coordinate measurement system, not only is the important direction of theory innovation, also is the urgent task of current policy practice, especially in zhejiang in the structure of the national strategic demonstration role in driving more research value.

Although the Yangtze River Delta region has made positive progress in advanced manufacturing clusters, digital reform and scientific and technological innovation, the regional coordination mechanism is still not smooth, the linkage efficiency of industrial chain is insufficient, and the transformation efficiency of innovation achievements needs to be improved. In particular, Zhejiang, as the core province of the Yangtze River Delta, is vigorously promoting the construction of "415X" advanced manufacturing cluster, the upgrading of "sweet potato economy" and digital reform, and striving to build a national digital economy innovation leading area and manufacturing transformation demonstration area. In this process, scientific coupling coordination measurement system and dynamic analysis framework are urgently needed to identify the structural shortcomings restricting the integration process of Zhejiang and even the Yangtze River Delta, put forward differentiated policy plans, and provide quantifiable and systematic empirical basis for the modernization of regional governance and the implementation of national strategy.

Most of the existing studies adopt the traditional coupling coordination model (CCDM), which can reflect the coordination level between systems, but it is difficult to describe the dynamic transition of new quality productivity, the spatial spillover effect between regions, and the nonlinear interaction mechanism with high-quality development. This study intends to theoretically incorporate the new quality productivity into the coupling coordination analysis framework, build a multi-dimensional evaluation system including technology transformation rate, total factor productivity, manufacturing value added rate, green intensive index, etc., and further introduce neural network and spatial econometric model to analyze its influence path and system dynamics mechanism. To accurately identify the structural weaknesses and policy bottlenecks that restrict regional coordination. This research not only extends the study of the theory of boundary coupling coordination degree, and to reveal the new quality, and the interactive relationship between productivity and high quality development provides new theoretical support, enrich the theory of development economics and regional productivity system. More importantly, through the systematic study of the Yangtze River Delta region as a whole, it can provide methodological reference and empirical basis for Zhejiang and other provinces to further promote the deep integration of high-quality development and new quality productivity, so as to realize the coordinated improvement and experience promotion between regions. For global competitiveness for Yangtze river delta to build modern industrial system, realize

the integration of high quality development of the real provide empirical basis and decision support.

2. Literature Review

Domestic CSSCI, international SSCI and SCI journal papers have systematically sorted out, measured, evaluated and analyzed NQPF in recent years [1–5]. Ma et al. (2024) [6] reviewed the theoretical framework and practical approach of NQPF, and pointed out that it is driven by the linkage of "revolutionary breakthrough of technology, innovative allocation of factors and deep industrial transformation". Based on Marxist productivity theory, Hu Ying et al. discussed the internal mechanism of new quality productivity to promote high-quality economic development, and pointed out that self-improvement of science and technology, digitalization, data elements and industrial advantage cultivation should be the focus of policy [7]. To promote the parallel deployment of new quality productivity [8, 9] and high-quality development [3, 10], policy discussion emphasizes the synergy of "scientific and technological innovation-industrial innovation" [11–13] and highlights the traction effect of original [14, 15] and disruptive technologies [16–18]. The Yangtze River Delta region is a key innovation region in the development of national new quality productivity, and the research on promoting high-quality development mainly focuses on measurement, efficiency and regional economic optimization. Yin et al. (2025) [16] measured the new quality productivity level of 41 cities in the Yangtze River Delta region from 2011 to 2022, and found the problem of industrial imbalance and regional development "strong in the east and weak in the west". At present, the research trend has turned to the enabling effect of the new quality productivity on the region or industry [13, 19–21]. Fu et al [19] analyzed the enabling effect of the new quality productivity on the integrated high-quality development of the Yangtze River Delta from 2019 to 2023, and found that the new quality productivity can enable the integrated high-quality development of the Yangtze River Delta through scientific and technological innovation, fostering new development momentum, promoting green development, and comprehensively deepening reform.

The report of the Statistical Monitoring Office of the Director General of National Statistics shows that the regional development index of the Yangtze River Delta is rising steadily, but the research literature finds tha there are obvious regional differences in the coupling and coordination degree of the new quality productivity and high-quality development in the Yangtze River Delta region t [12, 13]. Coupling Coordination Degree (CCD) model is a common method to describe the co-evolution of two (multiple) systems. It is usually combined with entropy method or CRITIC weighting to construct a comprehensive development index, and then the coupling degree C and coordination degree D are used to comprehensively determine the type and grade. Xu et al. (2024) [11] used the coupling coordination degree model to find that the CCD of digital economy and green finance has generally increased at the provincial level, but the regional gap is significant, suggesting a spatial pattern of "high in the east and low in the west". Li et al. (2024) [22] used CCD model to measure digital finance and regional sustainable development, and showed that there was significant spatial agglomeration and synergy enhancement within urban agglomerations. Wang (2024) and Liu (2024) [23] constructed a coupling degree model to verify the coupling improvement and regional differentiation among digital economy, green finance and sustainable process from the perspective of high-qualityenergy development and green high-quality development, respectively. In terms of patents, Hua et al. (2025) [24] proposed an evaluation method for the coordination and coupling level of urban development and scientific and technological innovation in metropolitanareas based on multi-source data, which was mainly developed based on entropy method. Ji et al. (2025) [25] constructed a modified coupling coordination degree model, calculated the coupling coordination level index based on the evaluation index, and obtained the evaluation results of coupling coordination degree between urbanization and ecological quality in multi-water areas. Several patents and studies have shown that the coupling degree measure can better reflect the coupling coordination index and change trend of two or more systems, and can measure the coordination relationship between new quality productivity and high-quality development [26–28]. However, some problems need to be paid attention to, such as weight setting [19], threshold division, index normalization and bias propagation [12].

Above all sums up the following research questions: (1) the traditional coupling measure the CCD method could lead to weight - threshold - owned by a chain of errors and "hierarchy - conclusion migration" risk coexist, how to introduce multiple cross-validation method empowerment of error propagation analysis and coupling measure model? 2) Most of the identification of collaborative improvement and spatial spillover in the Yangtze River Delta region is partial correlation rather than causality, so it is necessary to use strategies such as instrumental variables or spatial breakpoints to further identify the insufficient spatial and causal identification; 3) The "core-hinterland-edge" gradient of economic development in the Yangtze River Delta is obvious. The dynamic description of cross-city network and industrial chain coupling in the existing models is still not sufficient.

3. Main Research Contents

Based on the Yangtze River Delta region, this project focuses on the interaction between "new quality productivity (NQPF) and high quality development (HQD)", including the following three research contents:

(1) Construction of measurement system: This part focuses on the core connotation of new quality productivity (NQPF) and high quality development (HQD), and scientifically constructs a dual system index system. (i) The new quality productivity will be an innovation-driven transition of production factors, It covers five dimensions: technological innovation (R&D investment, patent authorization), data elements (data infrastructure, data openness), industrial upgrading (proportion of high-end manufacturing, level of digital industrialization), human capital (density of R&D personnel, introduction of high-level talents), and institutional supply (institutional innovation index, business environment optimization). (ii) High-quality development is based on the six concepts of "innovation, coordination, green, openness, sharing and security", covering the quality of economic growth, regional coordination degree, environmental and resource utilization efficiency, level of opening-up, improvement of social livelihood and public services, and resilience of development security. (iii) Data sources mainly include national and provincial statistical yearbooks, Yangtze River Delta integrated development

monitoring platform, policy documents, remote sensing images and big data. (iV) In terms of index weighting, the entropy method and CRITIC method will be used comprehensively to reflect the information entropy dispersion of indicators, and to correct the correlation and conflict between different indicators, so as to improve the rationality of weight allocation. The composite index is calculated as follows:

$$U_j = \sum_{i=1}^{n} w_i \cdot x_{ij} \quad (1)$$

Where w_i is the portfolio weight x_{ij} and is the standardized index value. This design ensures the scientificity, comparability and reusability of the indicators of the dual system.

(2) Construction of coupling coordination measurement model: Based on the index system of (1), this part will construct an improved coupling coordination degree (CCD) model to dynamically measure the interaction between new quality productivity and high-quality development in the Yangtze River Delta region. The traditional coupling degree and coordination degree are defined as follows:

$$C = \frac{2\times\sqrt{U_1 \cdot U_2}}{U_1+U_2}, T = \alpha U_1 + \beta U_2, D = \sqrt{C \times T} \quad (2)$$

Where U_1, U_2 denotes NQPF and HQD composite indices, respectively. However, the traditional methods have limitations in fixed weight, extreme value sensitivity and error accumulation. Therefore, an improved scheme is introduced to ensure the robustness of the weight by using the combination of entropy and CRITIC. Bootstrap and Monte Carlo simulation are used to analyze the uncertainty propagation of the value$D$. The following equation is used

$$D' = D \pm Z_{\alpha/2} \cdot SE(D) \quad (3)$$

Provide confidence intervals for the level of coupling coordination. In addition, this study will combine ArcGIS and spatial autocorrelation (Moran's I or kernel density estimation) method to analyze the spatial pattern and time series evolution of NQPF and HQD in the Yangtze River Delta region, and reveal the differentiation characteristics within the region, such as the multi-level gradient structure of "core-hinterland-edge", which provides empirical support for further mechanism identification.

(3) Revealing the action mechanism: The significance of the calculation results of coupling coordination degree in Part 2 is to reveal the current situation, but what is more critical is to analyze the driving factors and action mechanism behind it. In this part, the driving factors of coupling coordination and their threshold effect and nonlinear relationship will be further identified in the combination of spatial measurement and artificial intelligence, and the driving rules will be found. Firstly, the spatial Durbin model (SDM) and multi-scale geographically weighted regression (MGWR) are used to reveal the spatial spillover effect of new quality productivity and high-quality development, and the spillover and feedback mechanism of innovation capability, green transformation and data elements among regions are analyzed. Next, deep learning models (such as LSTM and graph neural network GNN) are introduced to capture the nonlinear dynamic relationship in the multi-city network pattern of the Yangtze River Delta, especially the complex interaction effect of industrial chain collaboration, commuting circle and innovation network. Finally to ensure the interpretability of the results, this study will combine displayed shapes can explain analysis method, based on machine learning forecasting decomposition characteristics of contribution, marginal analysis is done using the following formula (4):

$$\phi_i = \sum_{S\subseteq N\setminus\{i\}} \frac{|S|!(n-|S|-1)!}{n!}[f(S\cup\{i\}) - f(S)] \quad (4)$$

Where ϕ_i represents the marginal contribution of the first factor to the prediction results. i The global importance ranking of driving factors is obtained, and the local characteristic effects are revealed at the city or year level, and the threshold laws and interaction effects of key variables are identified, so as to realize the organic unity of "mechanism identification, causal inference and interpretable analysis".

4. Research Protocol

(1) Data acquisition and processing: multi-source data such as statistical yearbooks, Yangtze River Delta integrated monitoring platform, policy documents and remote sensing were collected, and the time series database of 2005-2024 was established. Some data of new quality productivity and high quality development indicators were collected.

(2) Index weight and comprehensive measurement: the entropy method and CRITIC weighting are combined to construct a comprehensive evaluation index of dynamic and static dual system.

(3) Coupling coordination measure: the CCD model is improved and the uncertainty propagation analysis is carried out. The scientific nature of threshold setting and weight construction is paid attention to here.

(4) Mechanism identification and causal inference: combining spatial econometrics and deep learning neural network, the influencing factors and obstacle factors are identified, and the weight distribution and dynamic change characteristics of each factor are reversed by machine learning interpretable Shap.

(5) Prediction simulation and policy recommendations: the RNN/LSTM+ policy scenario simulation tool is used to output the future change trend and give countermeasures and suggestions.

5. Research Conclusion

This study systematically explores the coupling and coordination relationship between new quality productivity and high-quality development and its driving mechanism in the Yangtze River Delta region. Firstly, we will build a comprehensive evaluation index system covering multi-dimensional factors such as innovation momentum, industrial structure, talent reserve and institutional environment, aiming to establish a set of scientific and quantifiable matching analysis framework for new quality productivity and high-quality development. On this basis, this study intends to introduce and improve the coupling coordination degree model to scientifically measure the overall interaction level of the two systems in the Yangtze River Delta region, and deeply reveal their spatio-temporal evolution laws and phased development characteristics.

In order to deeply analyze the internal driving mechanism of the two systems, we plan to use spatial econometric model and deep learning and other cutting-edge methods to accurately identify the key driving factors affecting the coupling and coordination state of the two systems, and focus on revealing the complex nonlinear action mechanism and spatial effect that may exist between the factors, so as to

achieve the leap from statistical correlation to interpretable causal inference. Finally, based on the above empirical findings, this study will focus on building an analysis platform with dynamic prediction and multi-scenario simulation functions, aiming to prospectively evaluate and compare the effects of collaborative development under different policy paths, so as to put forward policy suggestions for regional collaborative development with scientific quantitative basis and practical operation for the further promotion of the national strategy of Yangtze River Delta integration. To provide solid theoretical support and forward-looking path selection for decision-making.

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