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Measuring the Coupling Coordination between Technological Innovation and Financial Development in Anhui Province

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Abstract

Integrating technology and finance drives regional economic expansion. Using municipal data from Anhui Province (2012–2020), we construct an evaluation index via the entropy weight method and apply a coupling coordination model to track system evolution. The analysis reveals upward, albeit fluctuating, trajectories for both sectors. Notably, their relationship progressed from severe dysfunction to an advanced, technology-driven coupling. However, a pronounced spatial imbalance remains, ranking Central Anhui first, followed by the Southern and Northern regions. This study offers actionable evidence for narrowing inter-city divides and guiding targeted regional reforms.

Keywords

Technological innovation; Financial development; Coupling model; Entropy weight method

1. Introduction

As economic paradigms shift toward innovation, regional competitiveness increasingly depends on the deep integration of technological advancements and financial systems. In Anhui—a populous, traditionally agricultural province—recent initiatives like the 14th Five-Year Plan for Technological Innovation have fostered a nascent tech-finance network. However, persistent hurdles such as severe spatial resource misallocation, sluggish financial product innovation, and structural homogenization continue to constrain growth. Unraveling the synergistic logic between technology and finance is therefore critical for overcoming these developmental bottlenecks. To this end, this study employs municipal-level panel data (2012-2020) and an entropy-weighted coupling coordination model to evaluate this dual-system integration. By rigorously charting spatiotemporal trajectories across Central, Southern, and Northern Anhui, this paper bridges existing theoretical gaps and provides targeted empirical evidence to calibrate

precise regional tech-finance policies.

2. Literature review

Current scholarship predominantly frames the tech-finance nexus as a bidirectional synergy. On one side, financial infrastructure clears funding bottlenecks and diffuses R&D risks. Concurrently, technological breakthroughs generate massive capital demand and supply frontier tools that iteratively upgrade core financial services.

2.1. Bidirectional transmission mechanisms

Considerable research highlights the catalytic impact of financial scale and structure on innovation. Integrated banking and formal financing channels stabilize real-economy R&D, dismantle capital barriers, and ignite enterprise vitality (Maudos and Guevara, 2015; Wellalage and Fernandez, 2019; Hsu et al., 2014). Domestically, localized financial expansion in Anhui significantly curtails systemic innovation costs, albeit with latent efficiency dividends (Zhu and Hong, 2015). Conversely, scientific progress acts as the foundational engine for financial evolution. Integrating IT into banking operations spurs structural optimization (Allen, 2003; Salvatore, 2014), while breakthrough technologies propel broader financial expansion by supplying high-yield targets that absorb capital and push service boundaries (Bai et al., 2020; Yuan and Chen, 2014).

2.2. Regional coupling and avenues for expansion

Macro-level measurements confirm that tech-finance coupling bolsters overall macroeconomic efficiency (Wang and Yang, 2015) and exhibits a steady, yet spatially imbalanced, national trajectory (Zhu and Yu, 2021). Specific to Anhui, while its tripartite integration of technology, finance, and industry drives local upgrading (Hua and Ding, 2021), the province’s overall coordination still trails neighboring Yangtze River Delta regions, primarily due to lagging scientific invention (He and Bei, 2019).

Critically, existing literature predominantly validates unidirectional causalities or aggregates data at national and macro-regional scales. The internal, dynamic spatiotemporal evolutionary trajectories across Anhui’s distinct sub-regions (Central, Northern, and Southern) remain glaringly underexplored. Addressing this empirical void, this paper applies a coupling coordination framework to Anhui's localized panel data, aiming to unearth nuanced spatial heterogeneities and anchor future policy interventions.

3. Data and measurement

Adhering to the principles of representativeness and operational feasibility, this study extracts 2012-2020 panel data from the Anhui Statistical Yearbook to formulate a dual-subsystem evaluation framework.The technological innovation

subsystem is mapped across input metrics (R&D personnel and expenditures) and output proxies (authorized patents across three categories, alongside technology market transaction turnover). Simultaneously,the financial development subsystem is quantified through environmental indicators (consolidated deposit and loan balances within financial institutions) and capacity metrics (premium income, aggregate equity financing, and the number of publicly listed firms). The complete structure of these indicators is delineated in **Table 1**.

Table 1. Evaluation index system for the coupling coordination degree between technological innovation and technology finance

Subsystem	Primary Indicator	Secondary Indicator
Technological Innovation	Technological Input	R&D Personnel (X1)
		R&D Expenditure (X2)
	Technological Output	Number of Authorized Patents (X3)
		Transaction Value in Technology Market (X4)
Financial Development	Financial Environment	Consolidated Balance of Domestic and Foreign Currency Deposits in Financial Institutions (X5)
		Consolidated Balance of Domestic and Foreign Currency Loans in Financial Institutions (X6)
	Financial Capability	Premium Income (X7)
		Total Equity Financing Raised (X8)
		number of publicly listed companies(X9)

4. Empirical methodology and results:

4.1. Evaluation of technological innovation and financial development based on the entropy method

(1). Construction of the initial data matrix

Given the significant disparities in measurement units and magnitudes among the raw data, it is imperative to eliminate dimensional discrepancies prior to analysis to prevent analytical biases. Assuming the evaluation framework comprises m indicators across n observational units (years), the initial raw data matrix is defined as $X = (x_{ij})m*n$ ：

$$X=\begin{bmatrix} x_{11} & x_{12} & \cdots & x_{1n} \\ x_{21} & x_{22} & \cdots & x_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ x_{m1} & x_{m2} & \cdots & x_{mn} \end{bmatrix}$$

(2). Data standardization

Where zij denotes the standardized value of indicator j in year i, xij represents the original data observation, and max(x_{ij}) and min(x_{ij}) refer to the maximum and minimum values of indicator j across the entire sample period, respectively.

$$X_{min} = \min(X_{1j}, X_{2j}, \ldots, X_{ij}) - 0.0001 \quad (1)$$

$$X_{max} = \max(X_{1j}, X_{2j}, \ldots, X_{ij}) + 0.0001 \quad (2)$$

$$z_{ij} = (X_{ij} - X_{min}) / (X_{max} - X_{min}) \quad (3)$$

(3). Calculation of indicator weights

① Calculate the weights of each indicator x_{ij} separately for both the technological innovation system and the financial development system:

$$p_{ij} = \frac{z_{ij}}{\sum_{i=1}^{n} z_{ij}} \quad (4)$$

② Calculate the entropy value ej for the j-th indicator:

$$e_j = \frac{-1}{\ln n} \sum_{i=1}^{n} p_{ij} \ln p_{ij} \quad (5)$$

③ Calculate the coefficient of variation gj for the j-th indicator:

$$g_i = (1 - e_{ij}) \quad (6)$$

④ Calculate the weight wj for the j-th indicator:

$$w_j = g_j / \sum_{j=1}^{m} g_j \quad (7)$$

Table 2. Data weights for each indicator under the entropy-weighting method for secondary indicators of Anhui's scientific and technological innovation and financial development

Subsystem	Primary Indicator	Secondary Indicator	weight
Technological Innovation	Technological Input	R&D Personnel (X1)	0.156
		R&D Expenditure (X2)	0.223
	Technological Output	Number of Authorized Patents (X3)	0.316
		Transaction Value in Technology Market (X4)	0.305
Financial Development	Financial Environment	Consolidated Balance of Domestic and Foreign Currency Deposits in Financial Institutions (X5)	0.157
		Consolidated Balance of Domestic and Foreign Currency Loans in Financial Institutions (X6)	0.17
	Financial Capability	Premium Income (X7)	0.223
		Total Equity Financing Raised (X8)	0.25
		number of publicly listed companies(X9)	0.200

(4). Calculate the weights of evaluation indicators

The comprehensive utility levels of the two subsystems in Anhui Province for each year were calculated using a linear weighted summation method, with U1 and U2 representing the total contributions of technological innovation and financial development to the stable, coordinated development of the coupled system. λ_{ij} represents the corresponding weight, w_j as calculated in the previous section. Through the aforementioned series of calculations, the combined impact of the Science and Technology Innovation subsystem and the Financial Development subsystem in Anhui Province from 2012 to 2020 was determined.The utility function is defined as follows:

$$U_i=\Sigma_{j=1}^{n}\lambda_{ij}z_{ij}\ \Sigma_{j=1}^{n}\lambda_{ij}=1 \tag{8}$$

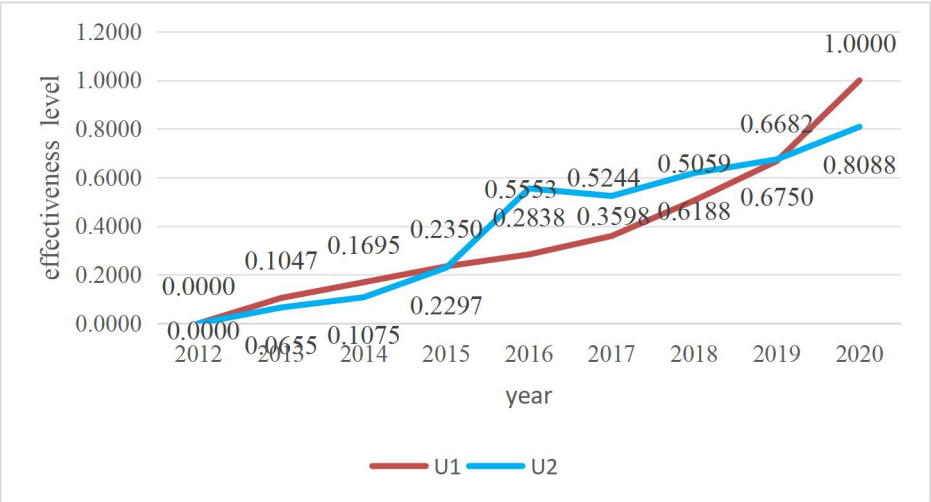


Figure 1. The overall effectiveness level of technological innovation and financial development in Anhui Province

As depicted in **Figure 1**, the comprehensive utility of technological innovation in Anhui Province exhibited a steady upward trajectory, whereas the performance of financial development was characterized by a fluctuating evolutionary pattern — reaching a preliminary peak in 2016, followed by a transient retraction and subsequent recovery. Across the observed temporal span, the interactive dynamics between the two subsystems underwent three distinct shifts in dominance. During the initial phase 2012-2015, both utilities lingered at subdued levels yet harbored substantial developmental latency; within this context, technological innovation maintained a relatively higher proportional contribution, dictating a tech-led structural pattern. In the ensuing period (2015-2019), catalyzed by the implementation of provincial financial incentive policies and a pronounced expansion in equity financing, financial kinetic energy was rapidly unleashed, propelling this subsystem to eclipse technological innovation and transition the paradigm to a finance-led model. Ultimately, between 2019 and 2020, the

technological innovation sector experienced a robust, explosive resurgence, allowing its utility level to once again overtake that of financial development and steering the systemic coupling mechanism back into a technology-dominant configuration.

4.2. Coupling degree and coupling coordination degree models

By generalizing the formulas used in relevant models of physics:

$$C_m=m\sqrt{\{(u_1\cdot u_2\cdots u_m)/[\Pi(u_i+u_j)]\}} \tag{9}$$

Based on the measurement methodology presented in Chen Weizhong and Zhou Chunying's (2021) study, since there are two subsystems, n is set to 2. Thus, the coupling degree measurement model formula is as follows:

$$C=2\sqrt{\{(U_1\cdot U_2)/[(U_1+U_2)\cdot(U_1+U_2)]\}} \tag{10}$$

The coupling coefficient C ranges from [0, 1]: higher values indicate stronger coupling and coordinated, orderly system development; lower values suggest disorder and uncoordinated development. As the value approaches 1, complete coupling is achieved, with both systems mutually reinforcing each other's growth; when approaching 0, they operate independently with their development being balanced against each other.The coupling model provides a clear temporal reflection of the development status of coupled systems, but struggles to capture regional variations; thus, the aforementioned coupling degree model was further refined. The resulting coupling coordination evaluation model is presented below:

$$\begin{cases} D=\sqrt{C\times H} \\ H=\alpha U_1+\beta U_2 \end{cases} \tag{11}$$

D represents the coupling coordination degree, while H denotes the comprehensive harmony index, which reflects the overall synergistic effect between the systems of technological innovation and financial development. α and β denote the weight coefficients of these two systems respectively, with α + β = 1. Based on prior research and the actual conditions in Anhui Province, technological innovation and financial development are equally important to the coupled system; therefore, this study adopts a value of 0.5 for both. The coupling process between technological innovation and financial development is categorized into the following types according to Wang et al. (2014), as detailed in **Table 3**.

Table 3. Criteria for classifying coupling types in the coupling system between technological innovation and financial development

Coordination Level	Range of D	U_2/U_1 Ratio	Developmental Paradigm
High-Quality	0.9<D≤1	U2/U1>1.1	Finance-Led
Favorable	0.8<D≤0.9	0.9≤U2/U1≤1.1	Synchronous Development
Intermediate	0.7<D≤0.8	U2/U1<0.9	Technology-Led
Primary	0.6<D≤0.7	U2/U1>1.1	Finance-Led
Marginal	0.5<D≤0.6	0.9≤U2/U1≤1.1	Synchronous Development
		U2/U1<0.9	Technology-Led

Coordination Level	Range of D	U_2/U_1 Ratio	Developmental Paradigm
Transitional Dysfunction	0.4<D≤0.5	U2/U1>1.1 0.9≤U2/U1≤1.1 U2/U1<0.9	Finance-Led Synchronous Development Technology-Led
Mild Dysfunction	0.3<D≤0.4		
Moderate Dysfunction	0.2<D≤0.3		
Severe Dysfunction	0.1<D≤0.2		
Extreme Dysfunction	0.0<D≤0.1		

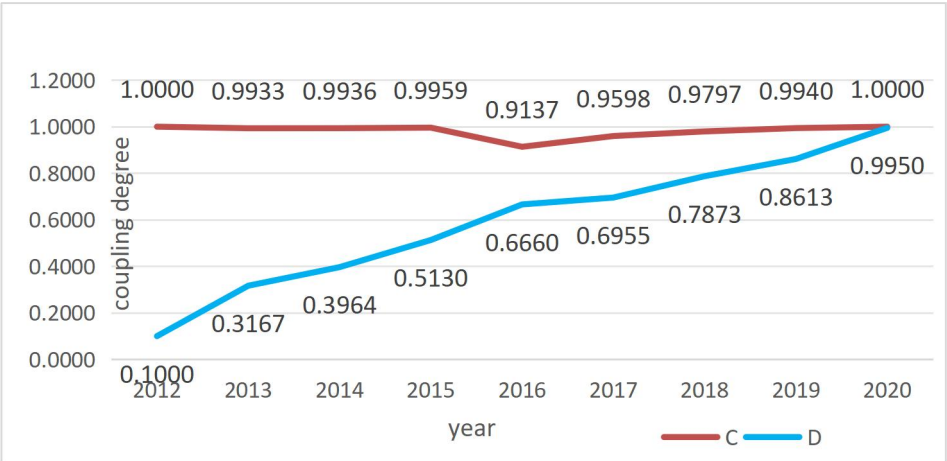


Figure 2. Variation curves of coupling degree and coupling coordination degree

As visualized in **Table 3** and **Figure 2**, the raw coupling parameter between Anhui's dual systems persistently hovered above the 0.9 threshold, tracing an evolutionary path of initial plateau, interim volatility, and ultimate stabilization. Nevertheless, because the absolute comprehensive utilities of both sectors were severely depressed between 2012 and 2015, relying exclusively on the baseline coupling metric risks masking their fragile structural foundations, thereby generating a deceptive "high coupling, low utility" paradox. To rigorously gauge their genuine synergistic multiplier effect, the subsequent coupling coordination degree evaluation was applied, uncovering a profoundly ascendant trajectory. Originating from a state of extreme dysfunction in 2012, the system's coordination capacity systematically navigated through successive transitional tiers — namely, marginal, primary, and intermediate coordination. By 2020, the index surged to 0.99, accomplishing a substantive structural leap into the high-quality coordination paradigm. This milestone definitively signals that the provincial tech-finance network has inaugurated a novel trajectory characterized by highly sophisticated, mutually reinforcing development.

4.3. Comparative analysis of coupling relationships among cities in Anhui province

Constrained by the omission of specific municipal-level indicators in the statistical yearbooks, we reconfigured the evaluation framework and recalibrated the entropy weights for sub-regional analysis. By aggregating city-level data (2012-2020) into

three distinct geographic macro-regions—Central, Southern, and Northern Anhui—we computed the respective regional coupling and coordination degrees. This cross-sectional comparative approach effectively uncovers the spatial distribution and regional heterogeneity of the tech-finance synergy across the province.

Table 4. The degree of coupling and coordination between northern Anhui, southern Anhui, and central Anhui

	Northern Anhui		Central Anhui		Southern Anhui	
year	C	D	C	D	C	D
2020	0.9865	0.9162	1	0.995	0.9988	0.9708
2019	0.998	0.7984	0.9993	0.8392	0.9848	0.8485
2018	0.9333	0.8245	1	0.7813	0.9962	0.7466
2017	0.9604	0.6236	0.9864	0.7098	0.9409	0.6556
2016	0.9729	0.5658	0.9555	0.6789	0.8337	0.7292
2015	0.9998	0.4854	0.9829	0.5725	0.9998	0.5078
2014	0.9993	0.3864	0.9976	0.4172	1	0.4133
2013	0.9908	0.3343	0.9671	0.3749	0.9858	0.3574
2012	1	0.1	1	0.1	1	0.1

Table 5. The type coupling and coordination between northern Anhui, southern Anhui, and central Anhui

	Northern Anhui	Central Anhui	Southern Anhui
year	type	type	type
2020	Technology-Led High-Quality Coordination	Synchronous Development High-Quality Coordination	Technology-Led High-Quality Coordination
2019	Synchronous Development Intermediate Coordination	Synchronous Development Favorable Coordination	Synchronous Development Favorable Coordination
2018	Finance-Led Favorable Coordination	Synchronous Development Intermediate Coordination	Technology-Led Intermediate Coordination
2017	Finance-Led Primary Coordination	Finance-Led Intermediate Coordination	Finance-Led Primary Coordination
2016	Finance-Led Marginal Coordination	Finance-Led Primary Coordination	Finance-Led Intermediate Coordination
2015	Technology-Led Transitional Dysfunction	Finance-Led Marginal Coordination	Technology-Led Marginal Coordination
2014	Synchronous Development Mild Dysfunction	Technology-Led Transitional Dysfunction	Technology-Led Transitional Dysfunction
2013	Technology-Led Mild Dysfunction	Finance-Led Mild Dysfunction	Technology-Led Mild Dysfunction
2012	Finance-Led Severe Dysfunction	Synchronous Development Severe Dysfunction	Finance-Led Severe Dysfunction

Patially, **Table 4** and **Table 5** illustrates a tiered upward leap across Anhui's three macro-regions, all successfully transitioning from severe dysfunction to high-quality coordination. Specifically, Central Anhui (anchored by Hefei) demonstrated the most robust potential, pioneering a synchronous high-quality coupling through efficient financial-driven innovation. Southern Anhui ranked second, securing a technology-led coordination paradigm that now necessitates broadened financial services to complement its robust R&D base. Conversely, constrained by geographic fundamentals, Northern Anhui's progression lagged. Despite transient mid-term

peaks, its overarching synergistic capacity remains inferior to the central and southern regions, sharply underscoring the persistent spatial heterogeneity of provincial development.

5. Conclusion

Adopting a dynamic evolutionary perspective, this study empirically delineates the synergistic trajectories of Anhui’s tech-finance nexus. The findings reveal that the provincial graduates into a technology-led, high-quality coupling paradigm characterized by asynchronous, alternating subsystem dominance over time. Furthermore, a pronounced spatial heterogeneity persists in regional synergistic potential, manifesting as a tiered developmental hierarchy wherein Central Anhui leads, Southern Anhui follows, and Northern Anhui continues to lag.

To mitigate these structural disparities, policy interventions must be synchronized across three pivotal dimensions. First, policymakers should fortify direct funding mechanisms and institutional support for R&D elements, leveraging foundational technological breakthroughs to catalyze financial sector upgrades and deepen industry-finance integration. Second, remodeling regional credit and regulatory architectures is imperative to optimize credit allocation, thereby minimizing financing frictions for tech-enterprises and ensuring that liquid capital flows precisely across diverse innovation strata. Finally, dismantling administrative boundaries is essential; by harnessing the spatial spillover effects of pioneer cities like Hefei and Wuhu, stakeholders must construct cross-municipal collaborative networks integrating government, industry, academia, and finance to neutralize regional divides and orchestrate integrated, high-quality provincial growth.

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