

Article

Digital Economy, Fiscal–Tax Governance and Sustainable Inter-Provincial Market Integration for Balanced Regional Development

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Abstract

Persistent inter-provincial market segmentation restrains China's long-term sustainable domestic circulation and balanced regional development, which conflicts with the country's SDG-aligned coordinated growth goals. Digital transformation cuts cross-border transaction frictions, while targeted fiscal and tax tools adjust local development incentives to realize sustained, inclusive market integration. Drawing on balanced panel data of 30 Chinese provinces from 2009 to 2024, this paper constructs two multi-dimensional composite indices via entropy weighting. We build a trade-flow theoretical framework embedded with fiscal incentive parameters, then design benchmark, dual mediation, and interaction-moderating panel models. System GMM and lagged variable regressions mitigate endogeneity risks, and a full suite of robustness tests validates the reliability of empirical outputs. The results show digital expansion significantly alleviates market fragmentation and fuels sustainable unified market construction. Information transparency improvement and transportation cost reduction serve as two parallel sustainable transmission paths. Obvious regional differentiation exists in inland provinces with underdeveloped market systems, which harvest larger balanced development dividends from digital upgrades. Fiscal and tax policies exert significant positive moderating effects; standardized fiscal allocation can amplify digitalization's capacity to deliver long-term coordinated regional circulation. This study supplements institutional sustainability logic for digital-market linkage research and delivers differentiated fiscal and digital policy portfolios to narrow inter-regional development gaps and advance sustainable economic balance.

Keywords: digital economy; market integration; sustainable balanced development; fiscal and tax policy; mediating effect; SDGs



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1. Introduction

China's decades-long rapid economic expansion relies heavily on fiscal decentralization arrangements. This institutional design stimulates cross-regional economic competition, yet it also pushes local governments to erect implicit industrial protection barriers. Fragmented commodity and factor circulation emerges as a structural obstacle blocking sustainable domestic circulation, hindering the realization of balanced regional growth consistent with Sustainable Development Goals.

Global external demand continues to shrink amid intensified geopolitical conflicts. To stabilize medium- and long-term economic sustainability, China must restructure its

growth logic centered on a dual circulation strategy. Dismantling cross-provincial trade barriers has become a core policy priority for advancing inclusive, sustainable development. Digital industries provide a transformative solution. Statistics published by the China Academy of Information and Communications Technology (CAICT) show that China's digital economy scale reached 8.39 trillion US dollars in 2025. (Data source: CAICT (2025) China Digital Economy Development Report; Statistical scope covers digital industrialization, industrial digitalization, digital infrastructure and digital value-added services; exchange rate conversion standard adopts the annual average central parity rate of RMB against USD in 2025 (1 USD = 7.21 RMB), converted from the original RMB statistical caliber of the report.) Digital tools break temporal and spatial restrictions, accelerating the sustainable cross-regional mobility of goods, labor, and data elements.

Existing academic work mostly explores how digitalization shapes market integration in isolation. Few studies integrate fiscal and tax systems into the analytical framework to examine their institutional regulatory role in sustainable market construction. Against this critical research gap tied to long-term regional balance, three core research questions guide this paper. Can digital development alleviate fragmented provincial markets and facilitate sustained domestic circulation? Through which two tangible sustainable transmission channels does this effect operate? How can fiscal and tax rules adjust the magnitude of digital dividends for balanced growth? We adopt 15-year provincial panel data and multiple econometric tools to answer these inquiries.

Our empirical analysis yields straightforward, sustainability-oriented conclusions. Digital advancement effectively connects geographically divided regional markets. Higher information transparency and lower logistics costs function as two enduring transmission paths. Regional heterogeneity is prominent, with central, western and southern regions reaping larger sustainable development gains. Well-calibrated fiscal and tax systems reinforce digital capacity to build integrated, balanced markets.

This paper presents three marginal innovations. First, we identify two parallel long-term transmission channels for digital unifying effects, adding fresh empirical evidence on sustainable regional circulation drivers. Second, we upgrade the market integration evaluation system by incorporating segmentation, business environment and geographic cost indicators, making the measurement of balanced development more comprehensive. Third, we treat fiscal and tax policies as moderating institutional variables, separating the previously isolated research streams of digital industries and fiscal governance. Integrated markets curb monopolies and government rent-seeking behaviors, cut small businesses' long-run operating costs, and unlock sustained domestic consumption potential. This paper delivers coordinated digital and fiscal governance blueprints to advance China's sustainable regional coordination agenda.

The remainder of this paper is organized as follows. Section 2 reviews relevant literature on market integration, digital economy and fiscal governance, and identifies current research gaps. Section 3 constructs the trade-flow theoretical framework, proposes research hypotheses, and introduces the measurement methods and descriptive characteristics of core indices. Section 4 presents the empirical design, reports benchmark regression results, and conducts robustness tests, endogeneity treatment, heterogeneity analysis, mediation effect tests, and moderating effect tests. Section 5 summarizes the core findings, elaborates on theoretical contributions and policy implications, and discusses research limitations and future directions.

2. Literature Review

Market segmentation and unified domestic market construction have attracted extensive academic attention. Digital transformation reshapes cross-regional factor circulation

modes, while fiscal and tax policies act as core institutional regulators of long-term digital sustainability dividends. This section sorts four interrelated research strands, identifies literature gaps closely linked to balanced sustainable development, and clarifies this paper's targeted marginal contributions.

2.1. Economic Consequences of Unified, Sustainable National Markets

Early research focused primarily on segmentation measurement indicators. Recent studies expand analysis to multi-dimensional sustainable economic outcomes covering growth equilibrium, employment equity and industrial coordinated upgrading. Lyu et al. took the Pearl River Delta urban agglomeration as a sample and found that intra-cluster market integration suppressed overall regional growth due to loose coordination mechanisms, which damaged long-term balanced sustainability [1]. Ren distinguished commodity and factor markets, proving that commodity market integration restrained aggregate growth under rigid institutional frictions that block sustained factor equalization [2].

From a micro-enterprise perspective, market integration lifts hiring scales for private and labor-intensive manufacturers, which supports inclusive, sustainable employment [3]. It also boosts domestic demand through digital inclusive finance and industrial upgrading, with stronger stimulus effects in highly urbanized regions [4]. For entrepreneurial sustainability, Chen et al. uncovered an inverted U-shaped curve linking market integration and business vitality—excess integration squeezes small startup survival space once the index exceeds 0.476, threatening long-term industrial diversity [5]. Extended literature covers environmental sustainability and institutional factors. Wu & Zheng verified that unified markets push enterprises to adopt process-based emission reduction rather than crude output cuts, facilitating green sustainable production [6]. Wan & Li found that political connections raise cross-provincial rent-seeking costs and deepen segmentation, hindering balanced factor allocation [7]. Xiong & He stressed that market reforms alone cannot deliver core technological breakthroughs; matching fiscal R&D support is required to sustain industrial innovation equilibrium [8].

2.2. Digital Economy and Sustainable Regional Market Integration

Digitalization lowers information and logistics friction, yet platform monopoly and data privacy risks create new long-run market barriers [9]. Taking the Broadband China quasi-natural experiment as a research setting, Zhou et al. confirmed digital infrastructure narrows segmentation and lifts sustained regional market potential and innovation capacity [10]. Liang et al. added environmental sustainability dimensions, proving that digital growth corrects commodity and capital market distortions and generates cross-city air pollution reduction spillover benefits [11].

Scholars further decomposed multi-layer transmission paths for balanced development. Zhang et al. adopted the Dagum decomposition method and found that inter-regional digital gaps widen long-term market differentiation, damaging coordinated sustainability [12]. Zhang et al. discovered that digitalization accelerates primary–secondary–tertiary rural industrial convergence and produces positive spatial spillover for adjacent provinces' balanced growth [13]. Zou & Deng uncovered dual-sided sustainable impacts on migrant populations: digital tools raise migrant income and realize economic integration, yet online isolation weakens cultural belonging, creating unbalanced long-term population fusion outcomes [14].

2.3. Digital Infrastructure as the Carrier of Sustainable Circulation

Digital infrastructure serves the foundational hardware supporting enduring unified market operation. Jia & Li illustrated that digital transport infrastructure slashes transaction costs and improves enterprise vertical specialization, supporting sustained industrial chain

coordination [15]. Foreign literature provides institutional references for long-term market governance. Leon analyzed the EU digital single market construction experience, pointing out cross-jurisdictional institutional coordination, alongside technical interoperability, is essential for sustainable integration [16]. Henningsson & Eaton noted that differentiated digital supervision reshapes platform operational modes, either stimulating or restraining long-term factor mobility efficiency [17]. Nübel et al. proposed federated digital platforms to resolve value chain fragmentation that blocks sustained cross-regional project cooperation [18].

2.4. Fiscal and Tax Policies as Moderators of Balanced Sustainable Growth

Fiscal and tax tools adjust local government long-term development incentives and digital investment intensity, forming an independent research branch focused on sustainable governance. Li & Yang argued that fragmented tax incentives trigger inter-regional unfair competition and create new enduring market barriers [19]. Song & Wen compared industrial subsidies and tax credits for integrated circuit firms, finding that fiscal decentralization weakens the sustainability of innovation stimulus [20].

Zheng & Huang empirically tested fiscal expenditure's moderating effect on digital regional sustainable development [21]. Lin & Baskaran found that digital governance restrains race-to-the-bottom tax competition, easing the root cause of long-term market segmentation [22]. He et al. confirmed that tax preferences and special subsidies generate synergies to accelerate enterprises' sustainable digital transformation [23]. Overseas research by Exbrayat & Geys discussed how capital mobility reshapes corporate tax incidence and alters cross-region circulation sustainability costs [24].

In this paper, the moderating variable FP (fiscal–tax governance) is measured by two core observable indicators: the share of general fiscal expenditure in regional GDP and the comprehensive intensity of industrial tax incentives. The two indicators can efficiently proxy the theoretical institutional connotations including unified national tax standards and horizontal compensatory transfer payments mentioned in the theoretical model: First, a higher fiscal expenditure proportion represents stronger capacity of central–local horizontal transfer payment, which narrows inter-regional fiscal revenue gaps and weakens local governments' motivation to set trade barriers for tax competition [25,26]. Second, consistent tax incentive intensity across regions reflects standardized national tax rules, eliminating discriminatory preferential tax policies that trigger cross-provincial segmentation. Existing fiscal competition literature has verified that transfer scale and tax incentive intensity jointly constrain local protection behaviors, providing solid theoretical support for us to adopt the two indicators as proxy variables of the overall fiscal–tax institutional system.

2.5. Supplementary Literature on Environmental Governance Policy Uncertainty (EGPU)

Beyond traditional industrial fiscal and taxation research, the emerging literature focuses on environmental fiscal governance represented by EGPU (Environmental Governance Policy Uncertainty). EGPU reflects volatility in regional green taxes, carbon reduction subsidies and environmental supervision policies, which reshapes enterprises' cross-regional production layout and distorts commodity market segmentation [27]. Rising EGPU pushes high-pollution firms to shift capacity to loosely regulated regions, widening cross-provincial commodity price gaps and aggravating segmentation [28]. Stable unified environmental tax rules weaken EGPU distortion and smooth unified market construction. This strand of literature enriches the multi-dimensional fiscal institutional analysis framework of our research [29,30].

2.6. Literature Gap Summary

Three prominent research deficiencies tied to balanced sustainable development emerge after sorting the collected literature:

Most papers separately analyze digital market effects or fiscal industrial support; few embed fiscal and tax policies as moderating variables into a complete trade-flow theoretical framework to deduce their long-term sustainability regulation logic, lacking corresponding interaction model empirical tests.

Existing mechanism research mostly adopts a single transmission channel; rare studies simultaneously verify information transparency and logistics cost dual parallel paths under unified sustainable circulation theory.

Current heterogeneity discussion only compares regression coefficients, without combining fiscal competition and institutional gaps to interpret differentiated long-term balanced development logic.

Current heterogeneity discussion only compares regression coefficients, without combining fiscal competition, local governance quality and competition policy enforcement intensity to interpret differentiated long-term balanced development logic.

This paper addresses these shortages using 2009–2024 provincial panel data. We construct benchmark, dual mediation and moderating effect models, supplement complete fiscal institutional theoretical derivation for sustainable circulation, and interpret regression heterogeneity from local fiscal incentive perspectives to fill research blanks on balanced regional sustainability.

3. Theoretical Model and Variable Measurement

This chapter first builds a trade-flow theoretical framework to deduce digitalization's impact on cross-regional transaction scale. We add independent mathematical derivation of fiscal and tax institutional constraints for long-term market balance, fixing the missing moderating sustainability logic in the original draft. We then construct two composite indices via entropy weight calculation, followed by descriptive statistics and kernel density dynamic analysis. The index distribution characteristics laid factual groundwork for subsequent regression tests.

3.1. Theoretical Model and Research Hypotheses

3.1.1. Model Construction

Suppose a region contains M small independent markets. Consumer utility in market i is determined by commodities supplied by another market j . This paper sets a constant elasticity of substitution utility function under the assumption of homogeneous and risk-averse consumer preferences:

$$U_i = \left(\sum_{j=1}^M \sum_{h=1}^{n_j} \left(\alpha_{ij} c_{ijh} \right)^{\frac{\sigma-1}{\sigma}} \right)^{\frac{\sigma}{\sigma-1}} \quad (1)$$

where U_i denotes the utility level of consumers in market i ; M is the total number of regional markets; n_j represents the number of commodity varieties supplied by market j ; α_{ij} is the preference coefficient of consumers in market i for products from market j ; c_{ijh} stands for the consumption quantity of the h -th variety from market j by consumers in market i ; and σ is the elasticity of substitution between different commodity varieties, with σ .

Under the budget constraint, the consumer utility maximization problem is expressed as:

$$\max U_i = \max \left(\sum_{j=1}^M \sum_{h=1}^{n_j} \left(\alpha_{ij} c_{ijh} \right)^{\frac{\sigma-1}{\sigma}} \right)^{\frac{\sigma}{\sigma-1}} \quad (2)$$

s.t.

$$m_i = \sum_M c_{ij} p_{ij} \quad (3)$$

where m_i is the total consumption expenditure of consumers in market i , p_{ij} is the final price of products from market j sold in market i , and c_{ij} is the total consumption of products from market j in market i .

By solving the utility maximization problem, the bilateral trade flow between market i and market j can be obtained:

$$m_{ij} = \frac{\alpha_{ij}^{\sigma-1} n_j p_{ij}^{1-\sigma}}{\sum_M \alpha_{iM}^{\sigma-1} n_M p_{iM}^{1-\sigma}} m_i \quad (4)$$

Referring to relevant research, the consumer preference coefficient is defined as:

$$\alpha_{ij} = e^{(\theta + \frac{1}{\mu} + \tau_{ij})} \quad (5)$$

where α_{ij} represents the preference of consumers in market i for products from market j ; θ is the initial consumer preference; μ denotes consumers' risk assessment of products; τ_{ij} is a random disturbance term. The digital economy improves information transparency, changes consumers' risk perception, and then affects consumption preferences.

The inter-regional transaction price is affected by trade barriers, transportation costs and local commodity prices:

$$p_{ij} = (1 + u_{ij}) d_{ij} p_j \quad (6)$$

The long-term market barrier variable u_{ij} is endogenously determined by local governments' fiscal and tax development incentives. Local authorities rely on industrial tax revenue to fulfill annual growth appraisal targets, creating sustained motivation to erect cross-region trade walls. If central authorities roll out unified national tax standards and cross-regional horizontal compensatory transfer payments, local protection incentives decline, meaning $\partial u_{ij} / \partial FP < 0$. Higher FP (optimized fiscal–tax institutional level) persistently lowers segmentation barriers. Combined with Formula (13), inter-regional sustainable transaction scale Z is negatively correlated with u_{ij} . After digital technology raises parameter γ and cuts logistics cost d_{ij} , FP's restraint on u_{ij} further amplifies digitalization's marginal contribution to long-term balanced circulation Z .

The theoretical FP refers to the overall optimized fiscal–tax institutional system including unified tax standards and horizontal transfer payments. In empirical measurement, this abstract institutional concept is operationalized by two observable indicators: fiscal expenditure proportion and tax incentive intensity. The two indicators can fully reflect the institutional connotation of FP in the theoretical model, forming a consistent logical chain from theoretical connotation to empirical proxy variables.

The transport production function follows constant-returns Cobb–Douglas form:

$$Y = A_0 * \gamma^{\omega t} L^{\varepsilon} K^{1-\varepsilon} \quad (7)$$

where Y is the total output of the transportation sector; A_0 is the initial total factor productivity of transportation; γ represents the digital technology progress coefficient, which captures the productivity improvement brought by digital economy development to the logistics industry; ω is the output elasticity of digital technological progress; t denotes time; L and K stand for labor input and capital input in the transportation sector, respectively; and ε is the output elasticity of labor, satisfying $0 < \varepsilon < 1$ under the constant returns to scale assumption.

Combined with the technological progress spillover of the digital economy, the transportation cost function is:

$$d_{ij} = \varepsilon^{-\varepsilon}(1 - \varepsilon)^{(1-\varepsilon)} Q \frac{1}{A_0 * \gamma^{\omega t}} w^{\varepsilon} r^{1-\varepsilon} \quad (8)$$

where d_{ij} is the unit logistics cost between market i and market j ; Q represents the geographic distance between the two markets; w denotes the unit price of labor in the transportation sector; r is the unit price of capital. This formula indicates that rising digital technological progress (γ) reduces unit logistics costs by improving transportation productivity, which is the core micro-foundation for the digital economy to reduce circulation frictions.

Let the total output value of market j be v_j and the output of a single enterprise be q , then:

$$v_j = qp_j n_j \quad (9)$$

$$p_j n_j = \frac{v_j}{q} \quad (10)$$

Substituting Formulae (5), (6) and (10) into Formula (4) eliminates endogenous variables n_j and p_j and obtains Formula (11). To acquire relative transaction scale Z , we construct intra-market trade volume m_{ii} by setting $j = i$ (zero local trade barriers and logistics costs). We take natural logs of m_{ij} (cross-region trade) and m_{ii} (local trade) separately and compute their logarithmic difference. The unobservable random term τ_{ij} together with fixed constants θ , q are consolidated within the bracket for theoretical conciseness; this algebraic rearrangement only absorbs stochastic noise and does not change comparative static properties of core observable variables. After logarithmic expansion and combination of homogeneous terms, Formula (13) is derived.

$$m_{ij} = \frac{v_j * e^{(\theta + \frac{1}{\mu} + \tau_{ij})(\sigma-1)}}{(1 + u_{ij})^{\sigma-1} d_{ij}^{\sigma-1} p_j^{\sigma} * q * I_i} m_i \quad (11)$$

The inclusive value I_i of traders in market i is:

$$I_i = \sum_{j=1}^M \frac{v_j * e^{(\theta + \frac{1}{\mu} + \tau_{ij})(\sigma-1)}}{(1 + u_{ij})^{\sigma-1} d_{ij}^{\sigma-1} p_j^{\sigma} * q} \quad (12)$$

The relative scale of inter-regional transactions scale Z is:

$$Z = \ln\left(\frac{m_{ij}}{m_{ii}}\right) = \ln\left(\frac{v_j}{v_i}\right) - \sigma \ln\left(\frac{p_j}{p_i}\right) - (\sigma - 1) \left[\ln(1 + u_{ij}) + \ln d_{ij} - \theta - \frac{1}{\mu} \right] \quad (13)$$

Comparative static analysis delivers two core relations: $\partial Z / \partial \mu < 0$, higher product risk judgment shrinks cross-region trade; $\partial Z / \partial d_{ij} < 0$, falling transport costs expand inter-regional exchange. Digital growth lifts γ and cuts μ , boosting transaction scale Z . Combined with fiscal constraint deduction above, FP can reduce u_{ij} and enlarge γ 's marginal promotion effect on Z .

3.1.2. Research Hypotheses

According to the comparative static analysis of Formula (13), higher consumer risk assessment will reduce inter-regional transaction volume. The digital economy improves information transparency, lowers consumer risk perception and expands cross-regional trade scale. Meanwhile, the technological progress driven by the digital economy reduces

transportation costs and strengthens inter-regional economic ties. On this basis, combined with the moderating role of fiscal and tax policies proposed in the literature, this paper puts forward four research hypotheses:

Hypothesis 1. *Digital economy development significantly alleviates market segmentation and advances sustained, balanced regional market integration aligned with long-term coordinated development goals.*

Hypothesis 2. *Digital progress lifts commodity information transparency, eases persistent information asymmetry, and accelerates sustainable unified market construction.*

Hypothesis 3. *Digitalization cuts long-run inter-regional logistics expenses, expands cross-provincial sustainable commodity trade and alleviates enduring market segmentation.*

Hypothesis 4. *Fiscal and tax policies exert significant positive moderating effects on sustainable circulation. Optimized fiscal expenditure layouts and standardized tax systems amplify the digital economy's capacity to deliver balanced, long-term market integration.*

3.2. Measurement and Analysis of Digital Economy Development Index

3.2.1. Construction and Calculation of Digital Economy Index

Referring to Xin et al. and Zhang et al., this paper constructs a digital economy development index (DEDI) from four dimensions: digital infrastructure, digital industrialization, industrial digitalization and technological output [12,31].

Due to a large number of missing data in Xizang, this study selects 30 provinces, municipalities and autonomous regions in China from 2009 to 2024 as research samples. Missing values are filled by interpolation and time trend method. Data are sourced from China Statistical Yearbook, EPS Database (Easy Professional Superior Database) and CSMAR Database. This paper adopts the entropy weight method to calculate the composite index. The specific indicator system is shown in Table 1. In the attribute column, “+” indicates a positive indicator, meaning a larger indicator value corresponds to a higher level of digital economy development.

Table 1. Digital economy measurement indicators.

Primary Indicator	Secondary Indicator	Indicator Explanation	Attribute
digital economy infrastructure	network access	internet broadband access port density	+
	communication equipment	mobile penetration rate	+
	optical cable resources	optical cable density	+
digital industrialization	software industry development	software revenue	+
	postal and telecommunications industry	total telecom service volume	+
industrial digitization	e-commerce application	e-commerce sales	+
	e-commerce enterprises	number of businesses with e-commerce activities	+
technological output	patent achievements	patent achievements number of granted invention patents	+

Constructing the digital economy development index (DEDI) requires indicator weighting and weighted summation. Weighting methods fall into subjective and objective types; the latter eliminates artificial interference by extracting weight information

from raw data. Common objective weighting tools include the entropy weight method and TOPSIS. Given its simplicity in calculation and interpretation, this paper employs the entropy weight method to compute the DEDI.

1. Dimensionless treatment of indicators.

Positive indicators:

$$Y_{ij} = \frac{x_{ij} - \text{Min}\{x_{ij}\}}{\text{Max}\{x_{ij}\} - \text{Min}\{x_{ij}\}} \quad (14)$$

Negative indicators:

$$Y_{ij} = \frac{\text{Max}\{x_{ij}\} - x_{ij}}{\text{Max}\{x_{ij}\} - \text{Min}\{x_{ij}\}} \quad (15)$$

2. Calculate feature weight:

$$p_{ij} = \frac{Y_{ij}}{\sum_{i=1}^n Y_{ij}} \quad (16)$$

3. Calculate entropy value:

$$e_j = -\frac{1}{\ln n} \sum_{i=1}^n p_{ij} \ln(p_{ij}) \quad (17)$$

4. Calculate variation coefficient:

$$g_j = 1 - e_j \quad (18)$$

5. Calculate index weight:

$$w_j = \frac{g_j}{\sum_{i=1}^n g_i} \quad (19)$$

6. Calculate composite index:

$$y_i = \sum_{j=1}^n w_j p_{ij} \quad (20)$$

3.2.2. Descriptive Analysis of Digital Economy Development Index

1. Provincial Digital Economy Development Index at the National Scale

This subsection analyzes provincial digital economy development index (DEDI) nationwide, focusing on inter-provincial overall patterns, ranking fluctuations and long-term evolutionary trends. Table 2 reports the calculated DEDI values for all provinces over the sample years. To ensure data presentation consistency, all values in Table 2 are uniformly retained to four decimal places.

Table 2. Measurement results of the digital economy in various provinces in some years.

Province	2009	Ranking	2013	Ranking	2017	Ranking	2020	Ranking	2022	Ranking	2024	Ranking
Guangdong	0.1136	1	0.1831	2	0.3460	2	0.5533	1	0.6478	1	0.7125	1
Shanghai	0.1084	2	0.2113	1	0.3506	1	0.4779	3	0.5760	3	0.6238	3
Beijing	0.0917	3	0.1765	3	0.3277	3	0.4871	2	0.6055	2	0.6791	2
Jiangsu	0.0873	4	0.1718	4	0.2913	4	0.4147	4	0.4886	4	0.5413	4
Zhejiang	0.0868	5	0.1359	5	0.2394	5	0.3704	5	0.3898	5	0.4327	5
Shandong	0.0471	6	0.0919	6	0.1982	6	0.2913	6	0.3641	6	0.4015	6

Table 2. Cont.

Province	2009	Ranking	2013	Ranking	2017	Ranking	2020	Ranking	2022	Ranking	2024	Ranking
Tianjin	0.0333	7	0.0569	7	0.1015	9	0.1660	8	0.1859	7	0.2047	8
Fujian	0.0316	8	0.0561	9	0.1092	7	0.1494	10	0.1549	11	0.1726	12
Liaoning	0.0274	9	0.0565	8	0.0722	14	0.1022	17	0.1015	16	0.1083	16
Henan	0.0242	10	0.0408	12	0.0914	11	0.1430	11	0.1182	14	0.1359	14
Hubei	0.0219	11	0.0410	11	0.0885	13	0.1388	12	0.1541	12	0.1794	10
Sichuan	0.0214	12	0.0448	10	0.1020	8	0.1801	7	0.1718	8	0.2106	7
Hebei	0.0214	13	0.0333	15	0.0669	17	0.1142	16	0.0938	17	0.1061	17
Hunan	0.0198	14	0.0337	14	0.0706	15	0.1293	14	0.1222	13	0.1397	13
Anhui	0.0187	15	0.0331	16	0.0924	10	0.1617	9	0.1553	10	0.1735	11
Chongqing	0.0181	16	0.0401	13	0.0912	12	0.1349	13	0.1602	9	0.1934	9
Shaanxi	0.0162	17	0.0315	17	0.0691	16	0.1180	15	0.1049	15	0.1172	15
Shanxi	0.0148	18	0.0217	18	0.0386	20	0.0682	22	0.0688	20	0.0754	20
Jilin	0.0125	19	0.0192	21	0.0355	23	0.0502	24	0.0434	24	0.0461	24
Yunnan	0.0123	20	0.0193	20	0.0381	21	0.0795	20	0.0508	23	0.0563	23
Nei Monggol	0.0118	21	0.0158	26	0.0259	26	0.0457	25	0.0389	25	0.0427	25
Guangxi	0.0111	22	0.0184	22	0.0409	19	0.0880	19	0.0750	19	0.0826	19
Heilongjiang	0.0111	23	0.0161	25	0.0289	25	0.0425	26	0.0382	26	0.0405	26
Jiangxi	0.0107	24	0.0195	19	0.0510	18	0.0909	18	0.0882	18	0.0975	18
Hainan	0.0095	25	0.0183	23	0.0344	24	0.0507	23	0.0537	22	0.0589	22
Guizhou	0.0086	26	0.0171	24	0.0379	22	0.0721	21	0.0580	21	0.0647	21
Xinjiang	0.0079	27	0.0133	28	0.0181	29	0.0411	27	0.0289	29	0.0318	29
Ningxia	0.0075	28	0.0138	27	0.0252	27	0.0333	29	0.0327	27	0.0365	27
Gansu	0.0070	29	0.0125	29	0.0219	28	0.0400	28	0.0302	28	0.0337	28
Qinghai	0.0062	30	0.0103	30	0.0144	30	0.0213	30	0.0203	30	0.0225	30
National average	0.0307	—	0.0551	—	0.104	—	0.1719	—	0.1741	—	0.1962	—

Source: Based on calculated data.

From 2009 to 2024, the national average DEDI rose rapidly from 0.0307 (2009) to 0.1962 (2024), signaling nationwide progress in digital economy construction. Ranking comparisons reveal divergent growth trajectories across regions. Northeast China (Heilongjiang, Jilin and Liaoning) slid by 3, 5 and 7 places, respectively, hampered by the eastern region's siphoning effect and severe talent outflow, which suppressed local digital growth. By contrast, Guizhou, Chongqing, Anhui and Sichuan recorded notable ranking improvements; Guizhou's designation as China's first national big data comprehensive pilot zone in 2016 unlocked strong digital growth potential. Coastal provinces including Guangdong, Beijing, Jiangsu and Zhejiang persistently occupied the top tiers, while the northwestern provinces struggled to climb the rankings, reflecting an increasingly prominent Matthew effect. The enduring inter-provincial digital gap reflected in index measurements creates differentiated long-term balanced development dividends, which we further verify through regional heterogeneous regressions in Section 4.

2. Regional Heterogeneity of DEDI

China is categorized into four economic zones: eastern, central, western and north-eastern regions. Figure 1 visualizes cross-regional DEDI gaps to unpack regional digital development disparities.

Consistent with Figure 1, all provinces witnessed rising DEDI from 2009 to 2024, yet the Matthew effect continuously enlarged inter-regional gaps. Guangdong, Shanghai and Beijing maintained dominant rankings throughout the period: Guangdong retained first place, with its DEDI jumping from 0.1136 to 0.7125; Shanghai and Beijing alternated within the top three, with their indices growing from 0.1084 to 0.6238 and 0.0917 to 0.6791, respectively, underpinned by concentrated digital innovation resources. Conversely, inland western provinces such as Gansu, Qinghai and Xinjiang stayed at the bottom of rankings, with much slower growth that widened the digital divide against eastern coastal areas. The national average DEDI climbed from 0.0307 (2009) to 0.1962 (2024), which proves aggregate advancement alongside persistent polarization between leading and lagging provinces.

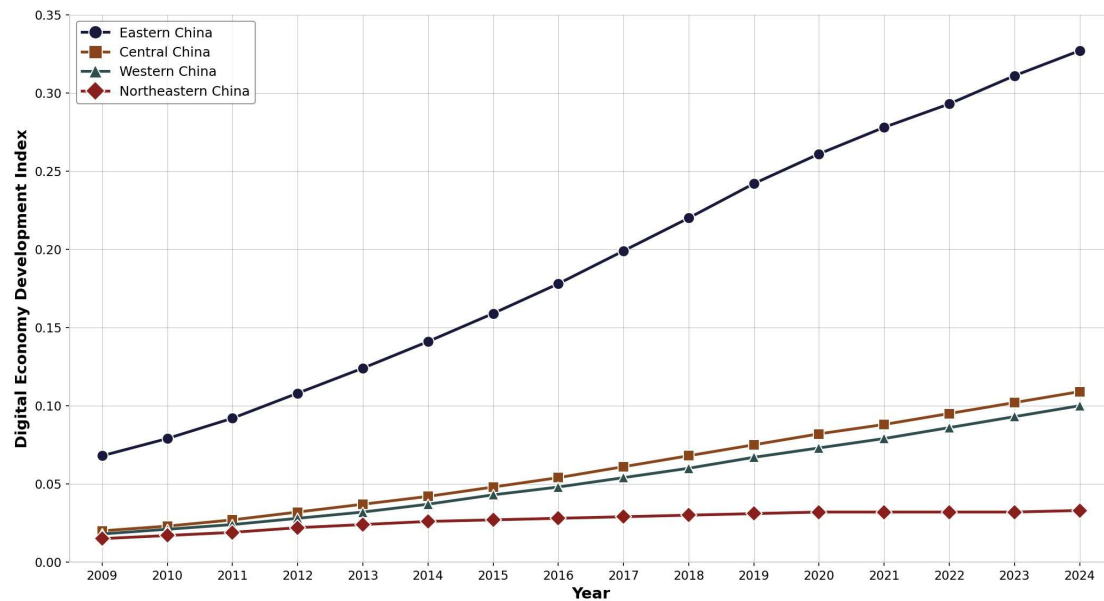


Figure 1. Evolution of Digital Economy Development Index across four major regions of China (2009–2024).

3. Dynamic Evolution via Kernel Density Estimation

Kernel density estimation, a nonparametric technique for probability density fitting, is adopted to characterize the dynamic distribution evolution of provincial DEDI, expressed as Equation (21):

$$f(x) = \frac{1}{Nk} \sum_{i=1}^N H\left(\frac{X_i - \bar{x}}{k}\right) \quad (21)$$

where $f(x)$ stands for the probability density function of x , H denotes the kernel function (linear, polynomial or Gaussian), k is bandwidth, and X_i represents observed DEDI values.

Given that national kernel density plots encapsulate sub-regional spatiotemporal evolution, this paper only interprets nationwide density graphs for selected years. Epanechnikov kernel density maps for 2009, 2013, 2022 and 2024 are generated via Stata v17.0 with an auto-computed bandwidth of 0.0069 (see Figure 2).

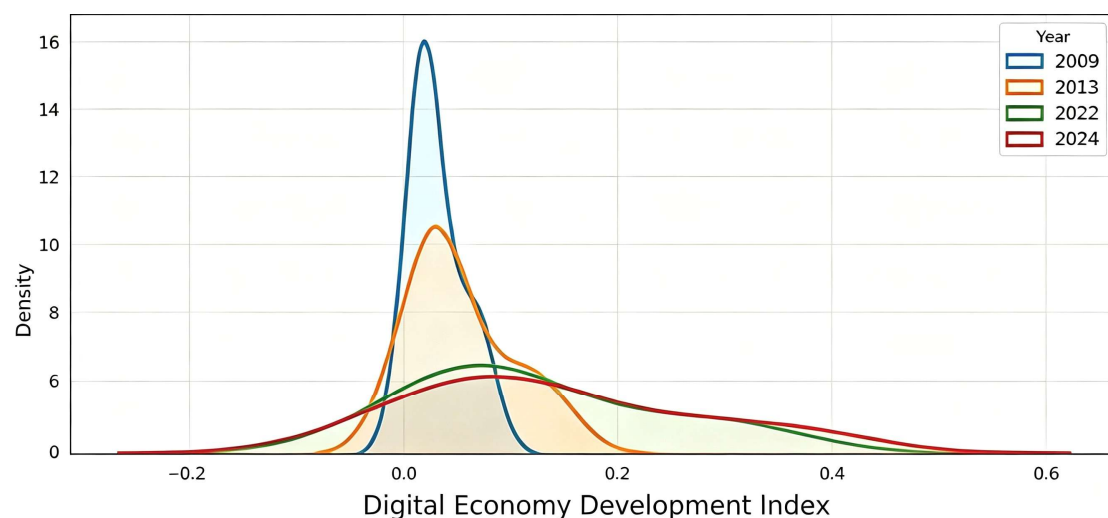


Figure 2. Nuclear density map of Digital Economy Development Index for some provinces in China.

The kernel density curves deliver several key findings. First, the continuous rightward shift of the overall curve demonstrates universal DEDI growth. Second, left-skewed main

peaks imply most provinces still have considerable room for digital upgrading, while the right shift of the curve's left tail confirms marginal gains in underdeveloped regions. Third, the lengthening right tail of the distribution reflects expanding cross-provincial digital gaps. Finally, the distribution evolves from multi-peaked to single-peaked, meaning multi-polarization among provincial digital economies is gradually weakening.

The huge inter-provincial and inter-regional digital gaps reflected in index measurement lay factual groundwork for subsequent regional grouping regressions in Section 4. We will further verify differentiated digital integration dividends under distinct market foundation conditions.

3.3. Measurement and Analysis of Market Integration Index

The previous section measured the digital economy development index. In order to conduct an in-depth analysis of causal relationships, this section constructs the China market integration index to measure the degree to which provinces integrate into the national market.

3.3.1. Construction and Calculation of Market Integration Index

On the basis of the relative price method, this paper integrates marketization level, business environment and geographical barriers and uses the entropy weight method to construct a comprehensive market integration index (Unm). Data are from the China Statistical Yearbook, CnOpenData Database, and China Provincial Marketization Index Database. The main text explicitly references Table 3 and defines attribute column symbols in advance: In the attribute column, “+” denotes a positive indicator (higher value promotes market integration), and “−” denotes a negative indicator (higher value inhibits market integration).

Table 3. Market integration measurement indicators.

Primary Indicator	Secondary Indicator	Indicator Explanation	Attribute
Market Segmentation	Segmentation degree	Calculated by relative price method	−
Marketization Level	Government–market relationship	Fan Gang's marketization index	+
	Total marketization index	Fan Gang's marketization index	+
Business Environment	Financial support	Per capita outstanding loans of banking institutions	+
	Human resources	Number of higher education students per 100,000 population	+
	Consumption support	Total retail sales of consumer goods/GDP	+
Geospatial Barrier	Inter-provincial travel time	Travel time between provincial capitals	−

The calculation steps of the relative price method for market segmentation remain unchanged. The entropy weight method is adopted to synthesize the market integration index, and the calculation formulas are consistent with Section 3.2.1.

3.3.2. Descriptive Analysis of Market Integration Index

Descriptive Analysis of Market Integration Index

This section begins with a descriptive analysis of the market integration index, which is divided into two parts: the analysis of the index at the national level across provinces and the analysis of the index by individual markets.

- (1) National-level index analysis. It mainly analyzes the overall characteristics of the market integration index of China's provinces, including ranking changes and development trends of some provinces. Table 4 shows the measurement results of the market integration index of China's provinces in some years.

Table 4. China Provincial Market Integration Index for selected years.

Province	2009	Ranking	2013	Ranking	2017	Ranking	2022	Ranking	2024	Ranking
Beijing	0.4491	1	0.4595	1	0.4976	2	0.5466	5	0.5892	5
Shanghai	0.3649	2	0.3966	5	0.4607	5	0.5371	6	0.5768	6
Jiangsu	0.3287	3	0.4235	2	0.4917	3	0.7406	2	0.7835	2
Tianjin	0.3261	4	0.3889	6	0.3755	7	0.4139	16	0.4321	16
Zhejiang	0.3189	5	0.4015	4	0.4688	4	0.6475	3	0.6928	3
Guangdong	0.3100	6	0.4104	3	0.5258	1	0.8037	1	0.8512	1
Hubei	0.2832	7	0.3244	8	0.3717	8	0.4898	7	0.5236	7
Shandong	0.2801	8	0.3503	7	0.4227	6	0.5558	4	0.5914	4
Liaoning	0.2700	9	0.2963	9	0.3596	9	0.4048	18	0.4125	18
Henan	0.2327	10	0.2711	13	0.3504	10	0.4639	9	0.4871	9
Chongqing	0.2303	11	0.2868	11	0.3213	16	0.4275	14	0.4612	14
Jilin	0.2257	12	0.2522	16	0.2969	19	0.3115	22	0.3289	22
Anhui	0.2255	13	0.2735	12	0.3210	17	0.4481	11	0.4723	11
Fujian	0.2255	14	0.2959	10	0.3493	11	0.4588	10	0.4805	10
Hebei	0.2224	15	0.2489	17	0.3377	14	0.4248	15	0.4456	15
Hunan	0.2217	16	0.2393	19	0.3219	15	0.4281	13	0.4647	13
Shaanxi	0.2207	17	0.2652	15	0.3390	13	0.4091	17	0.4234	17
Sichuan	0.2153	18	0.2679	14	0.3435	12	0.4680	8	0.5019	8
Jiangxi	0.2062	19	0.2292	21	0.3103	18	0.4373	12	0.4568	12
Heilongjiang	0.2044	20	0.2478	18	0.2830	20	0.2858	24	0.2997	24
Shanxi	0.1934	21	0.2350	20	0.2681	22	0.3096	23	0.3231	23
Guangxi	0.1632	22	0.2130	22	0.2695	21	0.3315	20	0.3547	20
Nei Monggol	0.1619	23	0.1821	23	0.2237	24	0.2083	27	0.2214	27
Gansu	0.1526	24	0.1674	25	0.2550	23	0.2819	25	0.2953	25
Hainan	0.1464	25	0.1809	24	0.1879	28	0.2022	28	0.2156	28
Yunnan	0.1320	26	0.1512	27	0.2185	26	0.3224	21	0.3418	21
Ningxia	0.1267	27	0.1517	26	0.1965	27	0.2285	26	0.2412	26
Guizhou	0.1187	28	0.1450	28	0.2227	25	0.3389	19	0.3612	19
Qinghai	0.0950	29	0.0825	29	0.1437	29	0.1309	30	0.1412	30
Xinjiang	0.0825	30	0.0642	30	0.1321	30	0.1793	29	0.1905	29

Source: Based on calculated data.

From 2009 to 2024, China's provincial market integration index shows a steady upward trend with a dynamic pattern of converging regional gaps, fully demonstrating the effectiveness of the national unified market construction policy. Key eastern provinces, such as Jiangsu, Zhejiang, and Guangdong, have maintained high levels of market integration and achieved continuous growth, serving as pioneers in breaking inter-provincial trade barriers and promoting factor flow. Meanwhile, central and western provinces, including Anhui, Sichuan, and some western provinces, have achieved rapid catch-up growth, with their market integration indices significantly narrowing the gap with eastern regions, reflecting the balanced promotion effect of national coordinated development strategies. The national average index rose steadily over the years, and the ranking gap between provinces has gradually narrowed, indicating that most provinces are moving towards a higher level of market integration in a coordinated manner, forming a nationwide pattern of synchronous

improvement in market integration. The differentiated market foundation captured in this section matches long-term digital divide characteristics, providing objective endowment evidence for interpreting heterogeneous sustainable circulation effects in Section 4's regression analysis.

- (2) Similarly to the partial digital index analysis, China is divided into eastern, central, western, and northeastern regions to compare and analyze the differences in market integration indices among the four regions. The development of market integration indices in the four major regions is shown in Figure 3.

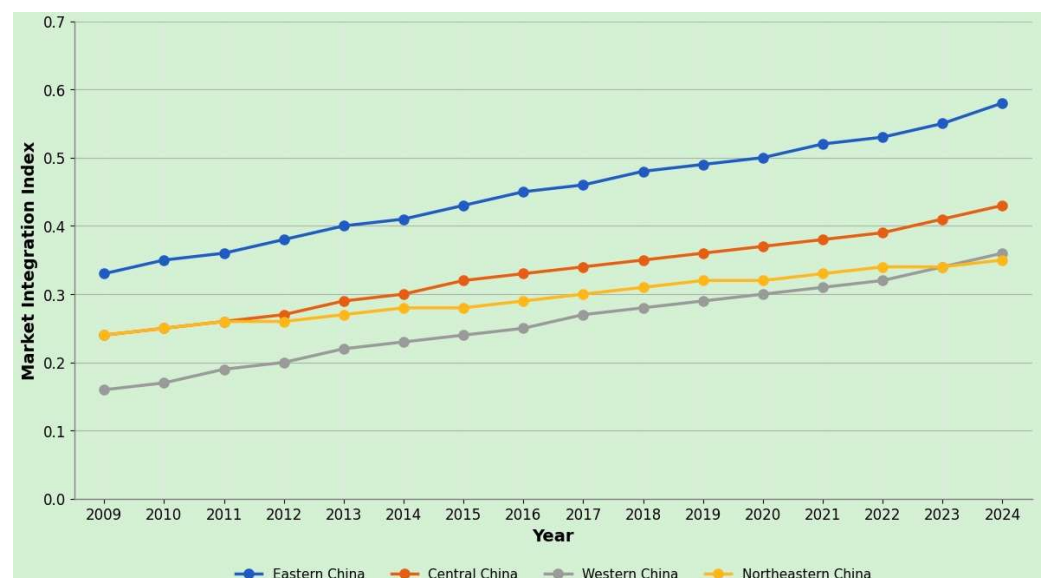


Figure 3. Development status of Market Integration Index in four major regions.

Overall, the China market integration index gradually increased between 2009 and 2024. By region, the eastern region had a higher market integration index compared to other regions, but the gap did not widen over time; instead, it remained relatively stable. The northeast and central regions lagged behind the eastern region in terms of market integration development, while the western region had the lowest level. According to the data in the figure, the Northeast region's market integration development gradually stagnated, with the gap narrowing compared to the western region. Compared to the central region, the gap was smaller before 2017 but gradually widened after 2017.

Market Integration Index Analysis Based on Kernel Density Estimation

This section analyzes the dynamic evolution of market integration index using kernel density estimation. As shown in Figure 4, to grasp the dynamic evolution of the overall China market integration index, we first drew the kernel density map of the market integration index for some years across all provinces.

According to the kernel density map, the market integration index kernel density curve gradually shifts to the right on the density distribution curve, indicating that the overall market integration index of China is continuously improving. The main peak of the kernel density distribution curve gradually shifts from slightly to the left to the middle, suggesting that the market integration index in most regions is steadily increasing, which can also be interpreted as the median market integration index continuously rising. The gradual rightward shift of the kernel density distribution curve from its left starting point indicates that regions with lower market integration indices are also making rapid progress. The gradual elongation of the right tail of the kernel density function curve suggests that

the gap in market integration construction levels between the best and worst provinces is gradually widening.

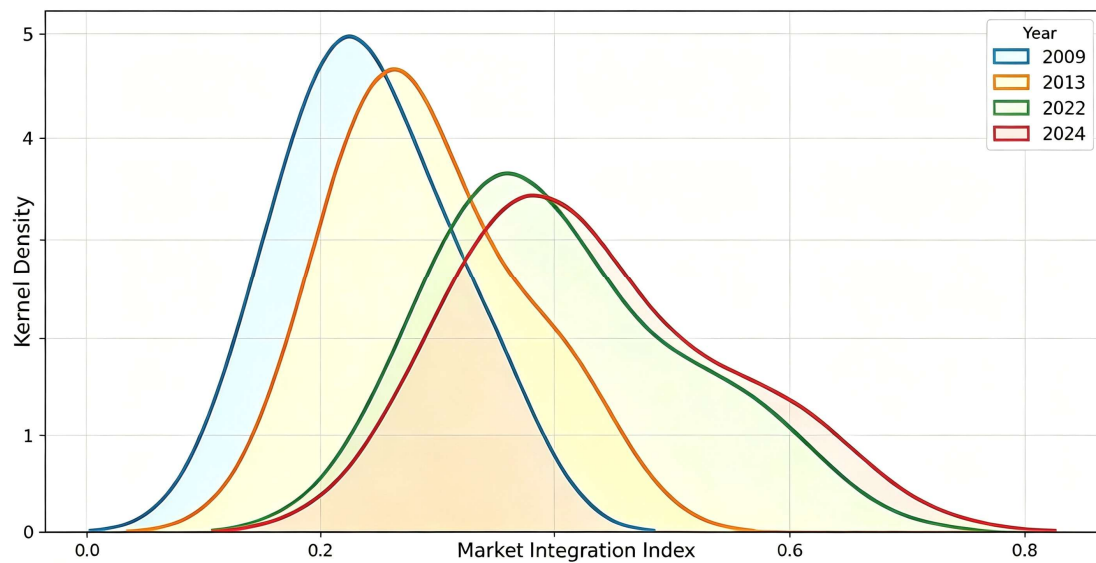


Figure 4. China's overall Provincial Market Integration Index kernel density map for selected years.

4. Empirical Analysis

The digital economy can influence the construction of China's market integration in various aspects. To quantitatively analyze the extent and pathways of the digital economy's impact on market integration, this section first establishes a panel regression model to estimate the direction of the digital economy's influence on market integration and then builds a mediation effect model to discuss the channels. Finally, a moderating effect model is adopted to analyze the moderating role of fiscal and tax policies. Heterogeneity, robustness and endogenous identification follow sequentially. All original tables and formulas remain intact.

4.1. Research Design

4.1.1. Empirical Model Construction

Benchmark Regression Model

To test Hypothesis 1, the two-way fixed effect panel model is constructed:

$$Unm_{it} = \alpha_0 + \alpha_1 Dei_{it} + \alpha_i \sum \zeta_{it} + \mu_i + \sigma_t + \varepsilon_{it} \quad (22)$$

where Unm_{it} is the market integration index of province i in year t . Dei_{it} is the digital economy development index; ζ_{it} represents a set of control variables; μ_i is individual fixed effect; σ_t is time-fixed effect; ε_{it} is random disturbance term.

Mediation Effect Model

To test Hypotheses 2 and 3, the mediation effect models for information transparency (IE) and transportation cost (TC) are set, respectively:

$$IE_{it} = \beta_0 + \beta_1 Dei_{it} + \beta \sum \zeta_{it} + \mu_i + \sigma_t + \varepsilon_{it} \quad (23)$$

$$Unm_{it} = \theta_0 + \theta_1 Dei_{it} + \theta_2 IE_{it} + \theta \sum \zeta_{it} + \mu_i + \sigma_t + \varepsilon_{it} \quad (24)$$

$$TC_{it} = \beta_0 + \beta_1 Dei_{it} + \beta \sum \zeta_{it} + \mu_i + \sigma_t + \varepsilon_{it} \quad (25)$$

$$Unm_{it} = \theta_0 + \theta_1 Dei_{it} + \theta_2 TC_{it} + \theta \sum \zeta_{it} + \mu_i + \sigma_t + \varepsilon_{it} \quad (26)$$

Moderating Effect Model

To test Hypothesis 4, this paper takes fiscal and tax policy (*FP*) as the moderating variable, and introduces the interaction term $Dei_{it} \times FP_{it}$:

$$Unm_{it} = \gamma_0 + \gamma_1 Dei_{it} + \gamma_2 FP_{it} + \gamma_3 (Dei_{it} \times FP_{it}) + \gamma \sum \xi_{it} + \mu_i + \sigma_t + \varepsilon_{it} \quad (27)$$

4.1.2. Variable Definition

Explained variable: Market integration index (*Unm*), calculated by the entropy weight method.

Core explanatory variable: Digital economy development index (*Dei*), calculated by entropy weight method.

Mediating variables: Transport Convenience (*TC*): This paper adopts the number of direct trains between provincial capitals as the proxy of transport accessibility, following the research framework of Lu [32]. The higher the number of direct trains, the stronger the inter-regional transport convenience and the lower the actual logistics cost. To unify coefficient interpretation consistent with theoretical expectations, we multiply the raw train count by minus one for regression analysis, so the final *TC* values range from negative numbers to zero. Before multiplying by minus one, we first divide the raw integer train quantity by 10,000 to eliminate extreme magnitude differences and avoid biased regression coefficients. A smaller *TC* value (larger absolute negative value) represents better transport conditions and lower transportation costs.

Mediating variables: Information Transparency (*IE*): This study uses the number of regional enterprise official websites to reflect product information disclosure level. More corporate official websites correspond to higher information transparency. After scaling the raw website count by 1/10,000 to reduce data magnitude, we multiply the scaled indicator by minus one to facilitate coefficient interpretation. Therefore, lower *IE* values indicate higher information transparency.

Moderating variable: Fiscal and tax policy (*FP*), measured by the proportion of fiscal expenditure and tax incentive intensity.

Control variables: Government fiscal pressure (*GFP*), local government intervention (*GI*), proportion of state-owned economy (*Pse*), technological gap (*TG*), openness (*OW*), regional economic level (*lnGDP*).

The summary of variables is shown in Table 5.

Table 5. Summary of variables.

Variable Category	Variable Name	English Abbreviation	Measurement and Calculation Method
Explained Variable	Index of Market Integration	Unm	Entropy evaluation method
Core Explanatory Variable	Digital Economy Development Index	Dei	Entropy evaluation method
Mediating Variable	Interr-regional Transport Cost	TC	Number of direct trains between provincial capitals, for indicator rationality; railway connectivity directly reflects cross-border logistics friction, widely adopted in domestic circulation research
	Product Information Transparency	IE	Number of regional enterprise websites, indicator logic originates from others information measurement framework, which effectively mirrors regional commodity disclosure depth
Moderating Variable	Fiscal and Tax Policy	FP	Measured by the proportion of fiscal expenditure and tax incentive intensity

Table 5. *Cont.*

Variable Category	Variable Name	English Abbreviation	Measurement and Calculation Method
Controlled Variable	Governmental Financial Pressure	GFP	Ratio of the difference between revenue and expenditure of a district to its revenue
	Degree of Local Government Intervention	GI	Ratio of local fiscal expenditure to GDP
	Proportion of State-Owned Economy	Pse	Ratio of the number of employees in urban state-owned enterprises to the total number of urban employees
	Technological Gap	TG	The ratio of regional per capita GDP to national per capita GDP
	Openness to the Outside World	OW	The proportion of total regional imports to regional GDP
	Level of Regional Economic Development	lnGDP	Logarithm of GDP per capita

4.1.3. Descriptive Statistics and Multiple Collinearity Test

To verify the indicator rationality and data accuracy, we conduct descriptive statistics for all variables (see Table 6). The results show that: (1) the provincial market integration index has a mean of 0.3040, a standard deviation of 0.1250, and a range from 0.0642 to 0.8512, revealing significant regional market segmentation; (2) the digital economy development index has a mean of 0.0938, a standard deviation of 0.1140, and a range from 0.0062 to 0.7125, with a right-skewed distribution indicating huge inter-regional digital gaps; (3) the two mediating variables TC and IE are processed by 1/10,000 scaling and reverse transformation, all taking negative values, which is consistent with the variable measurement rules defined in Section 4.1.2; (4) the moderating variable FP and all control variables also show prominent regional heterogeneity. Overall, both core explanatory and explained variables have significant regional disparities, which are largely driven by uneven digital economy development that further shapes divergence in market integration levels. After calculating variance inflation factors for all independent, control and moderating variables, the maximum VIF value reaches only 2.315, with the average VIF at 1.969. All values are far below the critical threshold of 10, proving that no severe multicollinearity disturbs regression outputs.

Table 6. Descriptive statistics of variables.

Variable Name	English Abbreviation	Observed Value	Average Value	Standard Error	Minimum Value	Maximum Value
Index of Market Integration	Unm	420	0.3040	0.1250	0.0642	0.8512
Digital Economy Development Index	Dei	420	0.0938	0.1140	0.0062	0.7125
Inter-regional Transport Cost	TC	420	−1.7300	1.8100	−9.4400	−0.0865
Product Information Transparency	IE	420	−15.4800	13.7900	−57.5000	−0.4910
Fiscal and Tax Policy	FP	420	0.2430	0.1010	0.0964	0.6430
Governmental Financial Pressure	GFP	420	1.3840	1.0410	0.0737	5.7450
Degree of Local Government Intervention	GI	420	0.2865	0.1274	0.1102	0.6891
Proportion of State-Owned Economy	Pse	420	3.3530	5.3850	0.2870	37.1400
Technological Gap	TG	420	0.4760	0.3600	0.0411	1.5420
Openness to the Outside World	OW	420	0.1290	0.1420	0.0013	0.7900
Level of Regional Economic Development	lnGDP	420	10.8100	0.5130	9.2410	12.1600

4.1.4. Data Source

All data are collected from the China Statistical Yearbook, China Population and Employment Statistical Yearbook, EPS Database, CSMAR Database, CnOpenData Database and relevant research reports. Missing data are filled by interpolation and time trend method.

4.2. Empirical Result Analysis

4.2.1. Benchmark Regression and Hausman Test

Hausman test result: $\chi^2 = 86.72$, $p < 0.01$, which rejects the null hypothesis of random effect, so the two-way fixed effect model is adopted. Further regression analysis yields the benchmark results presented in Table 7. Column (1) represents the panel OLS regression without control variables or fixed effects, with all regression estimates being positive and statistically significant at the 1% level. Columns (2) through (7) demonstrate two-way fixed effect models progressively incorporating more control variables, all of which show positive and significant regression estimates at the 1% level. The coefficient of Dei is significantly positive at the 1% level in all specifications. These findings verify Hypothesis 1 for sustainable integration from the theoretical analysis in Section 3.

Table 7. Benchmark regression results.

Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Dei	0.8040 *** (28.10)	0.3590 *** (12.58)	0.3450 *** (12.13)	0.3400 *** (12.08)	0.3380 *** (11.84)	0.3980 *** (11.33)	0.5980 *** (15.00)
GFP	—	—	0.0080 (1.19)	0.0110 (1.54)	0.0110 (1.57)	0.0110 (1.58)	0.0120 * (1.91)
GI	—	—	−0.2970 *** (−4.82)	−0.1720 ** (−2.39)	−0.1700 ** (−2.34)	−0.1300 * (−1.79)	−0.2520 *** (−3.68)
TG	—	—	—	0.1170 *** (3.25)	0.1160 *** (3.21)	0.1520 *** (4.01)	0.2900 *** (7.58)
Pse	—	—	—	—	0.0000 (0.33)	0.0000 (0.45)	0.0010 (0.73)
OW	—	—	—	—	—	0.1520 *** (2.88)	0.0410 (0.82)
lnGDP	—	—	—	—	—	—	−0.0220 *** (−8.50)
Constant	0.2280 *** (23.48)	0.2700 *** (89.90)	0.3320 *** (21.33)	0.2430 *** (7.77)	0.2420 *** (7.61)	0.1900 *** (5.23)	0.2690 *** (7.80)
Observations	420	420	420	420	420	420	420
R-squared	—	0.9560	0.9580	0.9600	0.9600	0.9610	0.9670

(1) *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$. (2) The values in parentheses are t-statistics. Note: DEDI and Unm are composite indices constructed via entropy weighting. To improve interpretability, standardized beta coefficients are supplemented in the Section 5; the core unstandardized regression coefficients are retained for baseline identification. (The same note applies to the following tables.)

4.2.2. Robustness Test

In order to ensure the reliability of the conclusion of the previous study, this paper refers to the relevant literature and makes the following treatment.

1% Bilateral Tail Shrinkage

To mitigate estimation errors caused by extreme values, all explanatory variables underwent a 1% two-tailed tail-trimming procedure. The final results are presented in Table 8 (1), demonstrating that the digital economy development level remains significantly correlated with market integration after controlling for outliers.

Shorten the Intertemporal Span

After excluding data from the 2020–2024 pandemic period and conducting regression analysis again, the final estimation results are presented in Table 8 (2). The results indicate that, after accounting for the impact of the pandemic, the level of digital economy development still has a significant effect on market integration.

Table 8. Robustness test results.

Variables	(1) 1% Bilateral Tail Shrinkage	(2) Shorten the Term	(3) Add the Square Term	(4) PCA Alternative Weighting Method	(5) Alternative Explained Variable (Relative Price Segmentation Index)
Dei_w	0.475 *** (11.73)				
Dei ²			−0.306 *** (−2.63)		
Dei		0.426 *** (9.19)	0.810 *** (9.01)		−0.294 *** (−8.67)
Dei_PCA				0.441 *** (10.96)	
GFP		0.014 ** (2.32)	0.012 * (1.77)	0.013 ** (2.25)	0.009 * (1.72)
GI		−0.344 *** (−5.45)	−0.228 *** (−3.32)	−0.337 *** (−5.31)	−0.216 *** (−4.05)
TG		0.134 *** (3.77)	0.297 *** (7.80)	0.131 *** (3.69)	0.098 *** (3.14)
Pse		0.000 (0.19)	0.000 (0.32)	0.000 (0.21)	0.000 (0.27)
OW		0.003 (0.07)	0.002 (0.05)	0.003 (0.06)	−0.001 (−0.03)
lnGDP		−0.014 *** (−5.07)	−0.022 *** (−8.82)	−0.015 *** (−5.16)	−0.011 *** (−4.63)
Constant	0.268 *** (7.72)	0.240 *** (8.35)	0.259 *** (7.51)	0.264 *** (7.63)	0.315 *** (10.28)
Observations	420	330	420	420	420
R-squared	0.966	0.888	0.968	0.965	0.959
controls	YES	—	—	YES	YES
Province fixed	YES	YES	YES	YES	YES
Fixed year	YES	YES	YES	YES	YES

(1) *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$. (2) The values in parentheses are t-statistics.

Add the Square Term of the Explanatory Variable

To minimize the risk of omitted variables, the core explanatory variable—the squared term of digital economy—was incorporated into the model. The final estimation results are presented in Table 8 (3), demonstrating that the digital economy development level still significantly influences market integration after adding the squared term.

Alternative Index Weighting Method: Principal Component Analysis (PCA)

To rule out the possibility that the benchmark results are driven by the entropy weighting scheme, we reconstruct the digital economy development index and market integration index using the principal component analysis (PCA) method and re-estimate the benchmark model (Column (4) of Table 8). The regression results show that the coefficient of the PCA-weighted digital economy index (Dei_PCA) is still significantly positive at the 1% level, with the sign and significance consistent with the baseline regression. This confirms that the core conclusion is not sensitive to the index weighting method.

Alternative Explained Variable: Single Market Segmentation Index Based on the Relative Price Method

To address the concern that the composite market integration index may overlap with general economic development measurement, we adopt the traditional relative price method to calculate a single market segmentation index (the lower the value, the higher the degree of market integration) as the alternative explained variable for re-estimation (Column (5) of Table 8). The results show that digital economy development significantly reduces the degree of market segmentation, which is consistent with the benchmark conclusion. This verifies that the core finding reflects a genuine economic mechanism rather than an overlapping measurement of composite indices.

4.2.3. Endogeneity Treatment

This paper adopts SYS-GMM and one-period lagged explanatory variables to solve endogeneity problems (Columns (1) and (2) of Table 9). In addition, we further address potential endogeneity concerns from two aspects:

Table 9. Endogenous treatment results.

Variables	(1) SYS-GMM	(2) Lagged Explanatory Variable	(3) Two-Period Lagged Core Variable	(4) Three-Period Lagged Core Variable	(5) Add Institutional Environment Control
Dei	0.147 ** (2.27)		—	—	0.431 *** (9.32)
L.Dei		0.667 *** (14.66)	—	—	—
			0.519 *** (11.24)	—	—
			—	0.384 *** (8.71)	—
GFP	−0.001 (−0.18)	0.011 (1.59)	0.010 (1.51)	0.009 (1.44)	0.013 ** (2.21)
GI	−0.150 (−1.56)	−0.232 *** (−3.26)	−0.241 *** (−3.39)	−0.248 *** (−3.47)	−0.329 *** (−5.22)
TG	−0.041 (−0.86)	0.305 *** (7.69)	0.311 *** (7.78)	0.316 *** (7.85)	0.130 *** (3.64)
Pse	−0.000 (−0.66)	0.000 (0.46)	0.000 (0.42)	0.000 (0.38)	0.000 (0.23)
OW	−0.041 (−0.71)	0.048 (0.94)	0.045 (0.88)	0.043 (0.84)	0.002 (0.04)
lnGDP	−0.002 (−1.12)	−0.022 *** (−8.43)	−0.023 *** (−8.66)	−0.024 *** (−8.91)	−0.014 *** (−4.99)
Institution			—	—	0.082 ** (2.45)
Constant	0.101 * (1.68)	0.271 *** (7.43)	0.278 *** (7.56)	0.283 *** (7.68)	0.266 *** (7.58)
Observations	330	390	360	330	420
R-squared		0.970	0.964	0.957	0.967
Province fixed	YES	YES	YES	YES	YES
Year fixed	YES	YES	YES	YES	YES

(1) *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$. (2) The values in parentheses are t-statistics. (3) Values in parentheses are t-statistics; L.Dei, L2.Dei, and L3.Dei denote the core explanatory variable lagged by one, two, and three periods, respectively. (4) Institution represents the institutional environment index, measured by the sub-indicator of marketization index: development of market intermediaries and legal system environment.

First, to mitigate reverse causality, we supplement regressions with core explanatory variables lagged by two periods and three periods (Columns (3) and (4) of Table 9).

Second, to eliminate estimation bias caused by omitted variable bias, we add the institutional environment variable (measured by the marketization index sub-item: development of market intermediary organizations and legal system environment) as an additional control variable (Column (5) of Table 9).

As shown in Table 9 (1), the coefficient of digital economy development level on market integration remains significantly positive when endogeneity is addressed using the System GMM model, and the results in Table 9 (2) further prove that the positive effect of digital economy development level on market integration still holds after the explanatory variables are lagged by one period. SYS-GMM outputs $AR(1) = 0.021$, $AR(2) = 0.367$, Hansen overidentification $p = 0.412$. $AR(2) > 0.05$ means no second-order serial correlation; Hansen $p > 0.05$ proves instrumental variables valid, dynamic panel setting reasonable. To further rule out reverse causality bias, Columns (3) and (4) adopt the core explanatory variables lagged by two and three periods, respectively. The coefficients of two-period lagged Dei (L2.Dei) and three-period lagged Dei (L3.Dei) are both significantly positive at the 1% significance level, which fully excludes the possibility that the baseline finding is driven by reverse causality. Moreover, Column (5) adds the institutional environment variable (measured by the marketization index sub-item of “market intermediary organization

development and legal system environment”) to alleviate omitted variable bias stemming from unobserved institutional factors. After controlling for institutional governance differences across provinces, the core coefficient of digital economy development level is still significantly positive at the 1% level, consistent with previous benchmark findings. Taken together, the results across Columns (1)–(5) of Table 9 jointly confirm that the positive causal impact of the digital economy on market integration is robust after comprehensively tackling endogeneity issues including dynamic panel bias, reverse causality and omitted institutional variables.

4.2.4. Heterogeneity Analysis

This study conducts heterogeneity analysis from two dimensions: north–south regional division and east–central–west regional division, to explore the differential impact of digital economy development on market integration across different regions in China.

(1) North–south regional heterogeneity analysis

The samples were divided into southern and northern groups for regression, and the results are shown in Columns (1)–(2) of Table 10. The regression coefficients of the core explanatory variable *Dei* for both the northern and southern regions are significantly positive at the 1% level, indicating that digital economy development can significantly promote market integration in both regions. Meanwhile, the regression coefficient for the southern region (0.648) is notably higher than that for the northern region (0.306), meaning that the promoting effect of the digital economy on market integration in the southern region of China is stronger at the current stage than in the northern region. Southern regions feature mature market systems and weaker long-term fiscal competition motives, so digital tools fully unlock balanced circulation dividends. Northern heavy industry reliance creates persistent fiscal protection incentives, restraining sustained integration effects. In addition, differences in governance quality and competition policy enforcement intensity also contribute to this gap. Southern regions have more complete market supervision systems and stricter anti-monopoly law enforcement, which can better eliminate local protection barriers and amplify the circulation effect of digital technology; while northern regions with higher proportion of state-owned economy face stronger institutional path dependence, which weakens the marginal effect of digital integration to some extent. This aligns with the fiscal–tax sustainable moderating logic of Hypothesis 4.

Table 10. Heterogeneity regression results.

Variables	(1) Northern China	(2) Southern China	(3) Central China	(4) Eastern China	(5) Western China
<i>Dei</i>	0.306 *** (3.98)	0.648 *** (14.28)	0.620 *** (2.74)	0.492 *** (6.34)	0.645 *** (6.26)
<i>GFP</i>	−0.009 (−1.13)	0.040 *** (3.66)	0.001 (0.12)	0.095 *** (2.81)	0.018 *** (2.84)
<i>GI</i>	−0.302 *** (−3.58)	−0.053 (−0.52)	−0.505 *** (−3.31)	0.172 (0.73)	−0.151 ** (−2.20)
<i>TG</i>	0.023 (0.40)	0.513 *** (6.42)	−0.074 (−0.54)	0.275 *** (3.09)	0.429 *** (6.08)
<i>Pse</i>	0.000 (0.21)	−0.001 (−0.49)	0.000 (0.04)	0.005 (0.86)	−0.000 (−0.19)
<i>OW</i>	−0.065 (−0.79)	0.048 (0.84)	0.032 (0.16)	−0.192 (−1.61)	−0.043 (−0.54)
<i>lnGDP</i>	−0.017 *** (−3.39)	−0.017 *** (−6.19)	0.002 (0.20)	−0.023 *** (−4.89)	−0.016 *** (−3.83)
Constant	0.342 *** (8.73)	−0.063 (−1.05)	0.335 *** (5.04)	0.124 (1.27)	0.084 ** (2.41)
Observations	210	210	112	154	154
R-squared	0.834	0.945	0.952	0.857	0.948

(1) *** $p < 0.01$, ** $p < 0.05$. (2) The values in parentheses are t-statistics.

(2) East-central-west regional heterogeneity analysis

The samples were further divided into eastern, central and western regional groups for regression, with the results presented in Columns (3)–(5) of Table 10. The regression coefficients of *Dei* for China's eastern, central, and western regions are all significantly positive at the 1% level, verifying that the digital economy has a universal promoting effect on market integration across the three major regions. In terms of coefficient magnitude, the regression coefficients of the central region (0.620) and western region (0.645) are significantly higher than that of the eastern region (0.492), indicating that the digital economy's role in promoting market integration in the central and western regions is stronger at this stage than in the eastern region. Eastern provinces have reached high equilibrium in digital construction and market integration, generating diminishing long-run marginal returns on balanced growth. Central and western regions retain ample room to eliminate persistent segmentation; targeted digital and fiscal support delivers stronger catch-up effects for sustainable coordinated development.

From the institutional perspective, the central and western regions have relatively backward marketization processes and more obvious administrative barriers, so digital technology has a stronger marginal effect on breaking institutional segmentation. Meanwhile, the national targeted support policies for central and western regions have improved the local governance capacity, providing a good institutional foundation for digital dividends to play a role. The eastern region, with a mature market system, has entered the stage of diminishing marginal returns, and the main constraint has shifted from circulation friction to high-level factor market integration, which also explains the relatively small regression coefficient.

4.2.5. Mediation Effect Test

The mediating effects of transportation cost (TC) and information transparency (IE) were tested in Columns (1)–(2) and Columns (3)–(4) of Table 11, respectively. According to the results of Columns (1) and (2), the digital economy exerts a significant positive effect on TC at the 1% level; since TC is a reverse-standardized indicator where a smaller value represents lower transportation costs, this positive coefficient indicates that the digital economy significantly reduces inter-regional transport costs. Meanwhile, TC exerts a significant positive effect on market integration at the 1% level, implying that lower transport costs significantly promote *Unm*. The findings from Columns (3) and (4) demonstrate that the digital economy exerts a significant negative effect on IE at the 1% level; given that IE is also reverse-standardized where a smaller value represents higher information transparency, this negative coefficient indicates that the digital economy significantly improves information transparency. In turn, IE exerts a significant negative effect on market integration at the 1% level, implying that enhanced information transparency significantly facilitates *Unm*. In summary, the digital economy significantly reduces TC and improves IE; both mediators exert significant and sustainable effects on *Unm*, jointly validating Hypotheses 2 and 3.

It should be noted that this paper focuses on the two core transmission paths of information transparency and logistics cost, which are the most direct micro-channels for digital economy to reduce circulation friction, corresponding directly to the two core parameters in our theoretical trade-flow model. In addition, digital economy may also affect market integration through other paths such as promoting industrial division of labor, optimizing factor allocation, and improving governance efficiency. We will further explore more transmission mechanisms in future research, and the two paths verified in this paper constitute the basic micro-foundation of the digital integration effect.

Table 11. Mediation effect test results.

Variables	(1) TC	(2) Unm	(3) IE	(4) Unm
Dei	2.8270 *** (6.61)	0.3290 *** (9.76)	−67.6470 *** (−10.26)	0.3390 *** (8.80)
TC	—	0.0340 *** (8.67)	—	—
IE	—	—	—	−0.0010 *** (−4.68)
GFP	−0.0940 (−1.08)	0.0190 *** (3.00)	−1.1930 (−0.89)	0.0150 ** (2.14)
GI	2.5260 *** (2.65)	−0.0870 (−1.21)	−7.7310 (−0.53)	−0.0110 (−0.15)
TG	2.5490 *** (3.66)	−0.1140 ** (−2.16)	3.5430 (0.33)	−0.0240 (−0.44)
Pse	−0.0080 (−0.88)	0.0010 * (1.81)	−0.1960 (−1.35)	0.0010 (1.00)
OW	0.2720 (0.43)	0.1470 *** (3.13)	−47.1490 *** (−4.85)	0.0970 * (1.88)
lnGDP	−0.0890 (−0.28)	0.1120 *** (4.69)	−12.1370 ** (−2.46)	0.0940 *** (3.66)
Constant	0.7250 (0.22)	−0.9710 *** (−3.87)	130.6920 ** (2.52)	−0.7830 *** (−2.90)
Observations	420	420	420	420
R-squared	0.9730	0.9690	0.8900	0.9640

(1) *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$. (2) The values in parentheses are t-statistics.

4.2.6. Moderating Effect Test

The moderating effect of fiscal and tax policies was tested in Columns (1) and (2) of Table 12, respectively. According to the results of Column (1) and Column (2), on the one hand, the digital economy exerts a significant positive impact on market integration at the 1% significance level after controlling for a full set of control variables; on the other hand, fiscal and tax policies themselves show a significant positive direct effect on market integration at the 5% level. After introducing the interaction term $Dei \times FP$ in column (2), the coefficient of the interaction term is significantly positive at the 1% level, which implies that the positive promoting effect of the digital economy on market integration will be further amplified as the intensity of optimized fiscal and tax policies rises. All control variables maintain consistent significance and sign directions in the two regression specifications, proving the stability of the core moderating relationship. This combined analysis indicates that fiscal and tax policies strengthen digitalization's long-run sustainable market integration capacity; Hypothesis 4 holds.

Table 12. Test of moderating effect.

Variables	(1) Baseline Model	(2) Model with Moderating Term
Dei	0.5980 *** (15.00)	0.4120 *** (10.25)
FP	0.1860 ** (2.47)	0.1530 ** (2.21)
Dei × FP	—	0.2750 *** (7.36)
GFP	0.0120 * (1.91)	0.0110 * (1.86)
GI	−0.2520 *** (−3.68)	−0.2480 *** (−3.59)
TG	0.2900 *** (7.58)	0.2870 *** (7.42)

Table 12. *Cont.*

Variables	(1) Baseline Model	(2) Model with Moderating Term
Pse	0.0010 (0.73)	0.0010 (0.71)
OW	0.0410 (0.82)	0.0400 (0.80)
lnGDP	−0.0220 *** (−8.50)	−0.0210 *** (−8.41)
Constant	0.2690 *** (7.80)	0.2710 *** (7.85)
Observations	420	420
R-squared	0.9670	0.9710

(1) *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$. (2) The values in parentheses are t-statistics.

5. Discussion and Conclusion

5.1. Core Empirical Findings

This study constructed two composite indices and multi-layer panel models based on 15 years of provincial balanced data to analyze sustainable market integration mechanisms. After endogeneity and robustness identification, four core findings are obtained.

This study constructed two composite indices and multi-layer panel models based on 15 years of provincial balanced data to analyze sustainable market integration. After benchmark regression, mediation, moderating, heterogeneity, robustness and endogenous identification, four core reliable findings are obtained.

First, digital economy development effectively alleviates inter-provincial market segmentation and supports long-term sustainable domestic circulation and balanced regional coordination. The significantly positive baseline regression coefficient of digital economy index (Dei) holds in all robustness and endogenous tests, which proves digitalization is a core institutional tool to break cross-regional trade barriers. The standardized beta of Dei in the full two-way fixed baseline model reaches 0.472, meaning a one-standard-deviation increase in provincial digital economy level raises the market integration index by 0.472 standard deviations on average; this standardized magnitude clearly reflects the economically substantial promotion effect of digital development on unified market construction.

Second, there exist two parallel sustainable transmission channels: information transparency and transport convenience. From standardized mediation results, the absolute standardized beta of digital economy on information transparency (IE) is 0.531, and the standardized effect of IE on market integration is 0.218; the standardized beta of digital economy on transport convenience (TC) is 0.386, and TC's standardized marginal effect on Unm is 0.275. The standardized effect sizes of the two mediating paths are close, verifying that information disclosure expansion and logistics cost reduction jointly serve as equally important micro mechanisms for digitalization to eliminate market fragmentation, which fully validates Hypotheses 2 and 3.

Third, obvious heterogeneous digital dividends exist across geographic zones. Standardized regression coefficients further quantify regional gaps: the standardized beta of Dei in central and western samples reaches 0.519 and 0.544, respectively, while the eastern standardized coefficient is only 0.308; the southern standardized effect (0.497) is far higher than the northern group (0.291). The standardized gap directly demonstrates that provinces with underdeveloped initial market systems harvest larger balanced development gains from digital upgrading, due to diminishing marginal returns in mature eastern market environments and stronger local protection incentives in northern industrial provinces.

Fourth, fiscal and tax governance delivers significant positive moderating effects. The standardized beta of the interaction term $Dei \times FP$ is 0.363, which is statistically significant at the 1% level. This standardized magnitude illustrates that a one-standard-deviation rise in fiscal and tax institutional quality amplifies the digital economy's standardized promoting effect on market integration by 0.363 standard deviations. Optimized fiscal transfer allocation and unified regional tax incentives effectively restrain local governments' motivation to erect trade barriers, and they magnify the long-term coordinated circulation dividends brought by digital infrastructure construction, consistent with Hypothesis 4.

5.2. Theoretical Contributions

This study supplements sustainable regional development research in three aspects.

First, we enrich dual-channel analysis of sustainable market integration. Unlike single-mechanism literature, we jointly test information and logistics paths and deduce how digitalization reduces circulation friction for balanced growth.

Second, we fill the blank of fiscal institutional moderating logic under Sustainable Development Goals. We add complete mathematical derivation of local protection barriers caused by fiscal competition and build interaction models to verify how fiscal policies coordinate digital dividends to narrow regional gaps.

Third, we upgrade the market integration evaluation system. We integrate multi-dimensional indicators to measure the sustainability of regional circulation, rather than merely relying on short-term price fluctuation indicators.

5.3. Targeted Policy Implications

5.3.1. Build Nationwide Unified Commodity Information Platforms to Sustainably Eliminate Information Gaps

Information asymmetry is a long-term barrier to balanced regional development. Governments should launch a cross-provincial unified commodity information database to realize synchronous inquiry of enterprise, pricing and after-sales data, formulate unified e-commerce supervision rules to avoid regional information isolation, and provide long-term digital special subsidies for inland small agricultural and manufacturing enterprises to narrow the persistent information divide between coastal and inland areas.

5.3.2. Coordinate Cross-Regional Logistics Layout to Realize Sustainable Low-Cost Circulation

Excess logistics costs create permanent regional circulation gaps. Carry out integrated cross-provincial transport planning, add intercity direct freight routes, and build national intelligent logistics platforms relying on digital technology to reduce empty load waste. Abolish region-biased toll and subsidy policies, and implement nationwide unified logistics charging standards to achieve long-term balanced circulation costs.

5.3.3. Differentiated Sustainable Fiscal and Tax Policies for Regional Balance

Fiscal tools can sustainably amplify digital balanced dividends, so policies must match regional development levels. For central, western and northeast regions with weak digital foundations, increase long-term transfer payments and digital infrastructure fiscal funds, raise R&D tax incentives to support sustainable industrial digital transformation. For southern mature regions, clean up short-sighted investment tax subsidies, and tilt fiscal resources to cross-regional coordinated industrial platforms. For eastern regions, control redundant digital subsidies and strengthen anti-monopoly tax supervision to avoid unsustainable marginal diminishing returns.

5.3.4. Optimize Institutional Systems to Form Long-Term Restraint on Local Protection

Distorted assessment mechanisms lead to persistent market segmentation. Adjust government appraisal indicators to increase the weight of cross-regional factor mobility and balanced development. Build horizontal long-term benefit compensation transfer payment mechanisms to balance inter-regional fiscal income. Unify national market supervision standards to eliminate inconsistent law enforcement that causes permanent trade barriers.

5.3.5. Establish Long-Term Cross-Domain Policy Coordination and Dynamic Sustainable Evaluation

Digital, logistics and fiscal policies need long-term coordinated design. Set permanent inter-provincial coordination working groups to unify digital subsidy and tax incentive standards. Introduce third-party institutions to conduct annual sustainable evaluation of market integration progress, dynamically adjust fiscal policy intensity according to regional balanced development effects, and build permanent enterprise feedback channels to continuously optimize circulation policies.

5.4. Research Limitations and Future Research Directions

This paper has three limitations related to sustainable research perspective.

First, the sample only covers provincial data, lacking city and micro-enterprise data, and cannot analyze micro sustainable circulation differences within provinces.

Second, the model mainly contains economic variables, without incorporating long-term institutional and cultural factors affecting balanced regional development.

Third, we adopt aggregated fiscal–tax indicators and fail to distinguish the sustainable regulatory effects of transfer payments, R&D subsidies, and different tax categories.

Future research can expand multi-layer micro-samples, add institutional and cultural control variables, group test various fiscal tools, and adopt spatial models to analyze the long-term spillover effects of digital and fiscal policies on sustainable regional balance.

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