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Coupling and Coordinated Development of Rural Supply Chains and Farmers' Income Growth: An Empirical Study of Zhejiang Province

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Abstract

To investigate the coordinated development mechanism between rural supply chains and farmers' income growth, this study constructs a dual-system evaluation indicator system for rural supply chains and farmers' income growth. The entropy weight method is employed for objective weighting, and a coupling coordination degree model is applied to empirically measure the coupling coordination level of the two systems in Zhejiang Province from 2018 to 2024. The results reveal the following: 1) During the study period, the comprehensive index of the rural supply chain in Zhejiang Province rose from 0 to 0.4938, while that of farmers' income growth increased from 0.0836 to 0.3975, indicating rapid growth in both systems. 2) The coupling coordination degree improved from 0 (extreme incoordination) to 0.6656 (high coordination), achieving a five-level leap in coordination grade. 3) The relative development type underwent a dynamic adjustment sequence of "supply-chain-lagged → synchronous → income-growth-lagged → synchronous → income-growth-lagged." In 2024, the *P* value was 1.2423, suggesting that supply chain development slightly outpaced farmers' income growth. 4) The year-on-year growth rate, the number of 5G base stations, and per capita tertiary industry net income were the three indicators with the highest weights. Building on these findings, this paper proposes policy recommendations from the perspectives of improving rural logistics infrastructure, promoting the digital transformation of supply chains, establishing a long-term mechanism for farmers' income growth, and strengthening the enabling role of digital inclusive finance. On a methodological note, given the single-province, seven-observation ($N = 7$) sample, this study is a descriptive time-series assessment of coordinated development rather than a test of reciprocal causal effects; in addition, the reported 2018 value of zero for the supply-chain index and for the coordination degree is a mechanical artifact of min-max normalization at the base year, not an actual state of extreme incoordination.

Keywords

Rural Supply Chain, Farmers' Income Growth, Coupling Coordination Degree, Entropy Weight Method, Zhejiang Province

1. Introduction

The report to the 20th National Congress of the Communist Party of China explicitly calls for "upholding the priority development of agriculture and rural areas and steadily promoting the revitalization of rural industries, talent, culture, ecology, and organizations," while emphasizing "efforts to promote the common prosperity of all people" (Xu & Zhang, 2026). The 2024 No. 1 Central Document further sets out plans to "raise the level of rural industrial development" and "promote farmers' income growth through multiple channels," placing the development of modern rural circulation systems and farmers' income growth at the core of the rural revitalization strategy (Tian et al., 2024; Wang et al., 2024). As a critical link connecting agricultural production, circulation, and consumption, the rural supply chain encompasses multiple segments, including the upward flow of agricultural products, the downward flow of industrial goods, logistics and distribution, and information services. It serves as a vital pillar for smoothing urban-rural economic circulation, unlocking rural consumption potential, and fostering growth in farmers' operating and wage income. Compared with the traditional concept of rural e-commerce, the rural supply chain places greater emphasis on the systematic development of logistics infrastructure, express delivery networks, and the scale of the circulation industry, thereby more comprehensively reflecting the development level of the modern rural circulation system.

As a pioneer in the digital economy and an important practitioner of the "Digital Commerce for Agriculture" strategy, Zhejiang Province ranks among the top nationally in rural supply chain development. According to data from the Zhejiang Provincial Post Administration (2025), the province's express delivery volume reached 32.18 billion pieces in 2024, maintaining a leading position nationwide for consecutive years. Data from the Zhejiang Provincial Department of Commerce show that online retail sales of agricultural products in the province amounted to approximately 138 billion yuan in 2024. The number of 5G base stations surged from 15,800 in 2019 to 266,000 in 2024, representing a leapfrog expansion of rural digital infrastructure (Zhang & Zhang, 2024; Zhejiang Provincial Communications Administration, 2025). The value-added of transport, storage, and postal services grew from 185.3 billion yuan in 2018 to approximately 275.7 billion yuan in 2024, with the logistics industry's role in supporting economic growth steadily strengthening (Miao et al., 2024). Meanwhile, the per capita disposable income of rural residents in Zhejiang rose from 27,302 yuan in 2018 to 42,786 yuan in 2024, and the urban-rural income ratio narrowed from 2.0355 to 1.8295, demonstrating remarkable achievements in farmers' income growth (Tian et al., 2024; Xu & Zhang, 2026). Nevertheless, several questions warrant systematic empirical examination: Has the rapid expansion of the rural supply chain effectively translated into sustained growth in farmers' income? Has a virtuous interaction formed between supply chain development and farmers' income growth? At what level does the coordinated development of the two systems stand?

From a theoretical perspective, the relationship between rural supply chains and farmers' income growth is not a simple linear promotion but rather a complex interactive coupling mechanism. On the one hand, a well-developed rural supply chain promotes farmers' income growth by reducing circulation costs, broadening marketing channels for agricultural products, creating non-agricultural employment, and enhancing accessibility to digital financial services (Xu & Zhang, 2026; Qiu et al., 2024; Guan et al., 2024). On the other hand, rising farmer incomes feed back into supply chain development by expanding the rural consumer market, increasing willingness to participate in digitalization, and improving the rural business environment (Lai et al., 2024; Tian et al., 2024). However, the development rhythms of the two systems may not always align: supply chain infrastructure investment is characterized by large upfront costs and long payback periods, potentially leading to a situation where "the supply chain races ahead while income growth lags." Conversely, when farmers' income growth lacks industrial support, a dilemma of "income growth leading while the supply chain lags" may also arise. Synergetics provides a powerful analytical framework for studying inter-system coordination; it emphasizes that subsystems within an open system generate synergistic effects through nonlinear interactions, driving the system from disorder to order (Haken, 1977). Therefore, scientifically measuring the coupling coordination level of the two systems and revealing their dynamic evolution patterns carry important theoretical value and practical significance for promoting a virtuous interaction between rural supply chains and farmers' income growth, and for advancing rural revitalization and common prosperity.

It should be emphasized that the two-way interaction pathways outlined above are theoretical hypotheses grounded in synergetics. With panel data from only one province (Zhejiang) and seven annual observations (2018-2024, $N = 7$), this study does not attempt to identify or estimate causal effects in either direction; rather, it provides a descriptive measurement of how the comprehensive levels and coordination degree of the two systems evolved over time.

Against this background, this study uses panel data from Zhejiang Province for 2018-2024 to construct an evaluation system comprising 12 indicators across four dimensions—supply chain infrastructure, supply chain operational scale, income level, and income structure and quality. In particular, the supply chain subsystem incorporates core logistics indicators such as express delivery volume and the value-added of transport, storage, and postal services. The entropy weight method is used for objective weighting, and the coupling coordination degree model is applied to empirically measure the comprehensive development levels, coupling coordination degree, and relative development types of the two systems. The findings are intended to provide decision-making references for Zhejiang Province and, by extension, the whole country in promoting the coordinated development of modern rural circulation systems and farmers' income growth.

2. Research Design

2.1. Indicator System Construction

Following the principles of scientific rigor, systematicity, operability, and data availability, and drawing on the theoretical connotations of rural supply chains and farmers' income growth as well as Zhejiang's development realities, this study constructs a coupling coordination evaluation indicator system comprising 2 first-level subsystems, 4 second-level dimensions, and 12 third-level indicators (see **Table 1**; Shu et al., 2023; Wang et al., 2024; Wang & Weng, 2026).

Throughout this paper, the terms "farmers," "rural residents," and "rural permanent residents" refer to the SAME population: rural permanent residents as defined in the Zhejiang Statistical Yearbook. All per-capita income indicators (X1 - X3) are measured on this uniform rural-permanent-resident basis, and indicator labels have been aligned accordingly to avoid mixing statistical calibers.

The rural supply chain subsystem covers two dimensions: supply chain infrastructure and supply chain operational scale. For the infrastructure dimension, the number of broadband subscribers (Y1), the number of 5G base stations (Y2), and the length of rural delivery routes (Y3) are selected to reflect, respectively, the scale of rural network coverage, the level of new digital communication infrastructure, and the accessibility of last-mile logistics. Among these, the number of 5G base stations, as a core indicator of new infrastructure, effectively captures the empowering effect of digital technology on rural supply chains (Shu et al., 2023; Guo & Lyu, 2024); the length of rural delivery routes directly reflects the depth of coverage of the "last mile" in rural logistics (Mi & Meng, 2023; Wang & Weng, 2026). For the operational scale dimension, online retail sales of agricultural products (Y4), express delivery volume (Y5), and value-added of transport, storage, and postal services (Y6) are selected to reflect, respectively, the scale of agricultural e-commerce transactions, the total volume of express logistics services, and the economic contribution of the logistics industry. Unlike existing studies that mostly use e-commerce agglomeration indicators such as "the number of specialized e-commerce villages," this study selects express delivery volume and value-added of transport, storage, and postal services as the core measures of operational scale; these two logistics indicators better capture the essential feature that distinguishes a "supply chain" from "e-commerce"—namely, the operational scale and economic output of the physical circulation network (Mi & Meng, 2023; Miao et al., 2024).

A further note on indicator caliber: province-wide series for broadband subscribers (Y1), 5G base stations (Y2), express delivery volume (Y5), and the value-added of transport, storage and postal services (Y6) are used as PROXY measures of rural supply-chain development, because continuous rural-specific time series are not published for all of these variables. This proxy treatment is defensible for Zhejiang over 2018-2024, a period in which 4G/5G networks, broadband, and express-delivery coverage extended to virtually all administrative villages; nevertheless these aggregates also reflect urban circulation activity, so they should be read as upper-bound proxies for rural supply-chain development rather than exact rural measures.

Table 1. Coupling coordination evaluation indicator system for rural supply chains and farmers' income growth.

Subsystem	Dimension	Indicator	Variable	Weight
Rural Supply Chain Subsystem	Supply chain Infrastructure	Broadband subscribers (10,000 households)	Y1	0.0929
		5G base stations (10,000 units)	Y2	0.1063
		Rural delivery routes (km)	Y3	0.0530
	Supply chain operational scale	Online retail of agricultural products (100 million yuan)	Y4	0.0619
		Express delivery volume (100 million pieces)	Y5	0.0786
		Value-added of transport, storage & postal services (100 million yuan)	Y6	0.1011
Farmers' Income Development Subsystem	Income level	Per capita disposable income of rural residents (yuan)	X1	0.0812
		Per capita tertiary industry net income of rural permanent residents (yuan)	X2	0.0999
		Year-on-year growth rate (%)	X3	0.1086
	Income structure and quality	Digital inclusive finance index	X4	0.0631
		Urban-rural income ratio	X5	0.0885
		Primary industry labor productivity (10,000 yuan/person)	X6	0.0648
Total				**1.0000**

The farmers' income growth subsystem covers two dimensions: income level and income structure and quality. For the income level dimension, per capita disposable income of rural residents (X1), per capita tertiary industry net income of rural permanent residents (X2), and the year-on-year growth rate (X3) are selected to reflect, respectively, the absolute level of income, the contribution of the service sector to farmers' income growth, and the dynamic trend of income growth. For the income structure and quality dimension, the Digital Inclusive Finance Index (X4), the urban-rural income ratio (X5), and primary industry labor productivity (X6) are selected to reflect, respectively, the inclusiveness of digital financial services, the urban-rural income distribution, and agricultural production efficiency. Among these, the urban-rural income ratio is a negative indicator: the smaller its value, the narrower the urban-rural income gap (Zhao et al., 2025). The Digital Inclusive Finance Index uses data released by the Institute of Digital Finance at Peking University (Shen et al., 2025; Yu & Wu, 2026) and reflects the supporting role of digital finance in farmers' income growth (Thi My An & Thanh Tri, 2025).

Conceptual refinement: to avoid conflating income outcomes with their determinants, the income subsystem is here labeled the "farmers' income development subsystem." Within it, per capita disposable income (X1), per capita tertiary-industry net income (X2), and the year-on-year growth rate (X3) are direct income OUTCOME measures, whereas the Digital Inclusive Finance Index (X4), the urban-rural income ratio (X5), and primary-industry labor productivity (X6) are ENABLING CONDITIONS that support income growth rather than direct measures of income; they enter the comprehensive index as development-supporting factors, consistent with the subsystem's broadened label.

2.2. Research Methods

Range standardization. To eliminate dimensional differences among indicators and unify their directional orientation, the range standardization method is applied to the raw data. For positive indicators:

$$x'_{ij} = \frac{x_{ij} - \min\{x_j\}}{\max\{x_j\} - \min\{x_j\}} \tag{1}$$

For negative indicators (the urban-rural income ratio):

$$x'_{ij} = \frac{\max\{x_j\} - x_{ij}}{\max\{x_j\} - \min\{x_j\}} \tag{2}$$

where x_{ij} is the original value of the j-th indicator in the i-th year, and x'_{ij} is the standardized value. After standardization, all indicators take values in [0, 1].

Entropy weight method. To avoid the bias inherent in subjective weighting, the entropy weight method is used to objectively determine indicator weights. Its basic principle is as follows: the greater the dispersion of an indicator's data, the smaller its information entropy, the richer the information it contains, and the larger its weight should be. First, the proportion of the i-th year under the j-th indicator is calculated; then the information entropy is computed:

$$p_{ij} = \frac{x'_{ij}}{\sum_{i=1}^{n} x'_{ij}},\ e_j = -k\sum_{i=1}^{n}\left(p_{ij}\ln p_{ij}\right),\ k = \frac{1}{\ln n} \tag{3}$$

where n is the number of evaluation years ($n = 7$). Finally, the weight of each indicator is calculated:

$$w_j = \frac{1 - e_j}{\sum_{j=1}^{m}\left(1 - e_j\right)} \tag{4}$$

Coupling coordination degree model. On the basis of weights determined by the entropy weight method, the comprehensive index of the rural supply chain (f_1) and the comprehensive index of farmers' income growth (f_2) are constructed:

The coupling coordination degree model originates from synergetics and the coupled human-natural systems (CHANS) framework. Haken (1977) established synergetics to describe how subsystems within an open system generate macroscopic order through nonlinear interactions; Liu et al. (2007) further formalized the complexity of coupled human and natural systems in Science, providing the conceptual foundation for measuring reciprocal interactions between socio-economic and ecological sub-systems. The method has since been applied to a wide range of rural and agricultural contexts, including telecoupled governance of sustainable wine production in Australia (Marola et al., 2020) and the resilience of rural peatland social-ecological communities in the United Kingdom (Flood et al., 2022). This study draws on these methodological precedents and adapts the coupling coordination framework to examine the interactive relationship between rural supply chains and farmers' income growth.

$$f_1 = \sum_{j=1}^{m} w_j y_j^*, \quad f_2 = \sum_{j=1}^{m} w_j x_j^* \tag{5}$$

where y_j^* and x_j^* are the standardized supply chain and income growth indicators, respectively. The coupling degree C reflects the intensity of interaction between the two systems:

$$C = 2\sqrt{\frac{f_1 f_2}{\left(f_1 + f_2\right)^2}} \tag{6}$$

$C \in [0, 1]$; the closer C is to 1, the stronger the interactive coupling between the two systems. However, the coupling degree reflects only the intensity of interaction and cannot distinguish the level of development. The coordination degree D is therefore introduced:

$$D = \sqrt{C \cdot T}, \quad T = af_1 + bf_2 \tag{7}$$

where T is the comprehensive coordination index, and a and b are undetermined coefficients. Given that rural supply chains and farmers' income growth are equally important in rural revitalization, $a = b = 0.5$ is adopted. A relative development coefficient P is introduced to determine the relative development type of the two systems:

$$P = \frac{f_1}{f_2} \tag{8}$$

When $P < 0.8$, the type is supply-chain-lagged; when $0.8 \le P \le 1.2$, it is synchronous development; and when $P > 1.2$, it is income-growth-lagged. The grading criteria for the coordination degree D are as follows: $D = 0$, extreme incoordination; (0, 0.2], serious incoordination; (0.2, 0.3], moderate incoordination; (0.3, 0.4], low incoordination; (0.4, 0.5], reluctant coordination; (0.5, 0.6], moderate coordination; (0.6, 0.7], high coordination; (0.7, 0.8], extreme coordination; and

(0.8, 1.0], superior coordination.

Interpretive boundary: within this framework, the coupling degree C and coordination degree D measure the normalized co-movement and balanced-development level of the two systems' comprehensive indices. They do not test whether the two systems causally influence one another. This descriptive scope is inherent to the coupling coordination model when applied to a single regional time series and is stated explicitly here; causal claims would require multi-province panel data and formal identification strategies.

2.3. Data Sources

This study uses panel data from Zhejiang Province for 2018-2024 as the research sample. The data are primarily drawn from the Zhejiang Statistical Yearbook, the Zhejiang Provincial Bureau of Statistics, the Zhejiang Provincial Post Administration, the Zhejiang Provincial Communications Administration, the Zhejiang Provincial Department of Commerce, the Zhejiang Survey Office of the National Bureau of Statistics, and the Peking University Digital Inclusive Finance Index (Shen et al., 2025). Specifically, express delivery volume comes from the annual statistical bulletins of the Zhejiang Provincial Post Administration (2025); the number of 5G base stations comes from the annual communications industry development statistical bulletins of the Zhejiang Provincial Communications Administration (2025); value-added of transport, storage, and postal services comes from national economic accounting data of the Zhejiang Provincial Bureau of Statistics (2025); data on per capita tertiary industry net income of rural permanent residents, the urban-rural income ratio, and primary industry labor productivity are obtained from the Zhejiang Statistical Yearbook and the Zhejiang Survey Yearbook; and the Digital Inclusive Finance Index uses the fourth-phase data released by the Institute of Digital Finance at Peking University. Individual missing data are supplemented by linear interpolation or trend extrapolation. As 5G had not yet been commercially deployed in 2018, the number of base stations in that year is 0, which is consistent with the actual state of technological development. For full reproducibility, the missing-data treatment is specified as follows. Linear interpolation was not required for any indicator-year. Trend extrapolation from preceding-year official values was applied only to provisional 2024 values that remained preliminary at the time of analysis: online retail sales of agricultural products (approximately 138 billion yuan), value-added of transport, storage and postal services (approximately 275.7 billion yuan), the length of rural delivery routes (approximately 274,000 km), and the Digital Inclusive Finance Index (approximately 465). The 2018 rural delivery-route value (approximately 200,000 km) is a linearly interpolated estimate, whereas the 2018 5G base-station count is a genuine zero because 5G had not yet entered commercial service. All estimated values are flagged with "approximately/about" in the text; the complete raw data panel is available from the corresponding author upon request.

3. Empirical Results and Analysis

3.1. Development Status of Rural Supply Chains and Farmers' Income Growth in Zhejiang Province

In terms of rural supply chain development, Zhejiang Province achieved remarkable results from 2018 to 2024. Regarding digital infrastructure, broadband subscribers increased from 26.48 million to 37.674 million, with an average annual growth rate of 6.0%. The number of 5G base stations grew from zero to 266,000, and the coverage of 4G/5G networks in rural areas increased substantially (Zhang & Zhang, 2024). The length of rural delivery routes expanded from approximately 200,000 km to about 274,000 km, continuously improving the last-mile logistics distribution network (Mi & Meng, 2023; Wang & Weng, 2026). In terms of operational scale, online retail sales of agricultural products grew from 66.76 billion yuan to approximately 138 billion yuan, more than doubling. Express delivery volume increased from 10.11 billion pieces to 32.18 billion pieces, with an average annual growth rate of 21.3%, ranking first in the country for consecutive years. The value-added of transport, storage, and postal services rose from 185.3 billion yuan to approximately 275.7 billion yuan, with the logistics industry's contribution to economic growth steadily strengthening (Miao et al., 2024). Zhejiang has initially formed a rural supply chain system supported by digital infrastructure, anchored by express logistics, and characterized by agricultural e-commerce (Shu et al., 2023).

In terms of farmers' income growth, from 2018 to 2024 the income level of rural residents in Zhejiang continued to rise and the income structure was continuously optimized. Per capita disposable income of rural residents increased from 27,302 yuan to 42,786 yuan, with an average annual nominal growth rate of 7.8%, ranking first among all provinces for consecutive years (Xu & Zhang, 2026). Per capita tertiary industry net income of rural permanent residents rose from 2762 yuan to 5961 yuan, an increase of 115.8%, reflecting a significant increase in the contribution of the service sector to farmers' income growth. The urban-rural income ratio narrowed from 2.0355 to 1.8295, indicating a continuously narrowing urban-rural income gap and demonstrating the effectiveness of building a demonstration zone for common prosperity (Zhao et al., 2025). The Digital Inclusive Finance Index rose from 357.45 to approximately 465, with digital financial services such as digital credit, mobile payments, and agricultural insurance rapidly expanding in rural areas, effectively alleviating financing constraints for farm households and new agricultural business entities (Shen et al., 2025; Thi My An & Thanh Tri, 2025; Yu & Wu, 2026). Primary industry labor productivity increased from 113,500 yuan/person to 215,000 yuan/person, reflecting a steady improvement in the level of agricultural modernization (Lai et al., 2024; Guo & Lyu, 2024). However, it should also be noted that the momentum of farmers' income growth has fluctuated: after reaching a high of 10.39% in 2021, the year-on-year growth rate fell to 6.58% in 2022, rebounded slightly to 7.31% in 2023, and stood at 6.1% in 2024. The foundation for sustained and stable income growth still needs to be consolidated.

3.2. Indicator Weight Analysis

The weights of all indicators calculated using the entropy weight method are presented in Table 1 and Figure 1. Among the 12 indicators, the year-on-year growth rate (X3) has the highest weight at 0.1086, reflecting the prominent impact of the volatility of farmers' income growth on the evaluation of system coordination. The number of 5G base stations (Y2) ranks second (0.1063), indicating that the rapid expansion of new digital infrastructure from scratch during 2018-2024 provided the richest discriminating information and was a key factor driving the increase in the supply chain composite index. Per capita tertiary industry net income (X2, 0.0999) and value-added of transport, storage, and postal services (Y6, 0.1011) follow, reflecting the important contributions of service-sector income growth and logistics industry scale expansion to the two systems. Broadband subscribers (Y1, 0.0929) and the urban-rural income ratio (X5, 0.0885) also have relatively high weights, indicating that the level of network penetration and changes in the urban-rural income gap are important factors affecting coordinated development.

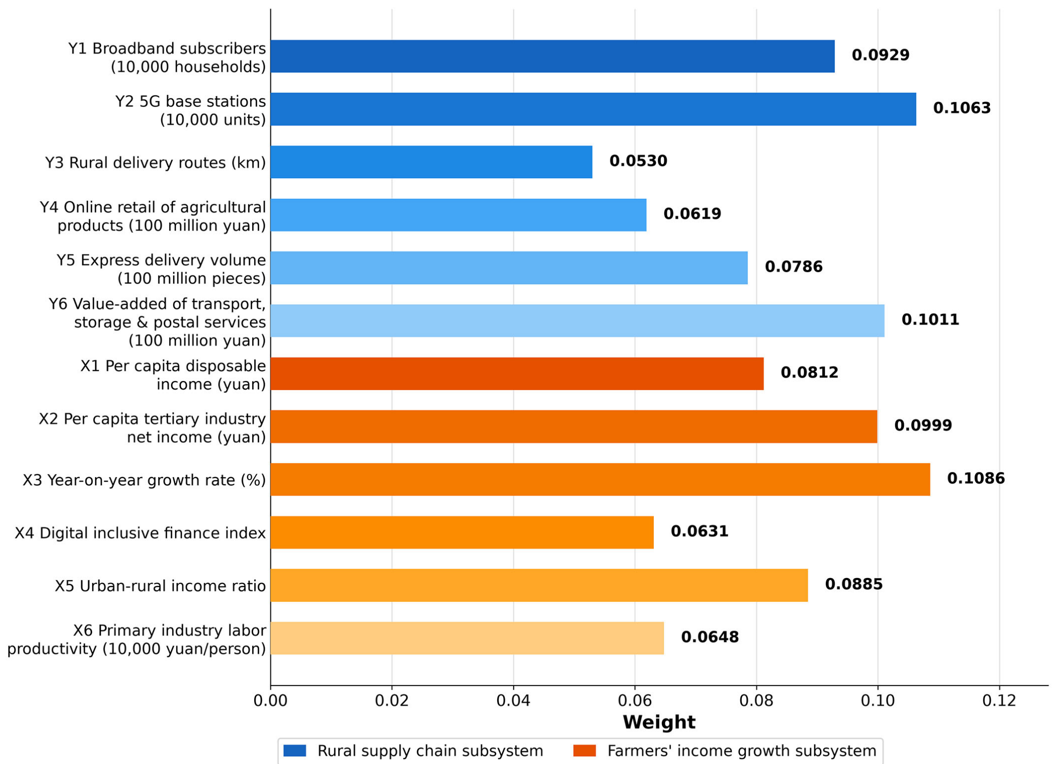


Figure 1. Entropy weights of rural supply chain and farmers' income growth indicators (2018-2024).

From the perspective of dimension weights, the income level dimension (X1 - X3) has the highest combined weight at 0.2897, indicating that the absolute level of farmers' income, the contribution of the service sector, and growth dynamics are the primary dimensions driving the evaluation of both systems. The supply chain infrastructure dimension (Y1 - Y3) ranks second with a combined weight of 0.2522, suggesting that infrastructure construction such as 5G, broadband, and delivery routes constitutes the core support for the supply chain system. The supply chain operational scale dimension (Y4 - Y6) has a combined weight of 0.2416, and the income structure and quality dimension (X4 - X6) has a combined weight of 0.2164, with the two being relatively close. Overall, at the current stage, the coordinated development of rural supply chains and farmers' income growth in Zhejiang is still primarily driven by infrastructure construction and aggregate income growth, but the importance of optimizing income structure and enhancing supply chain operational efficiency is gradually emerging.

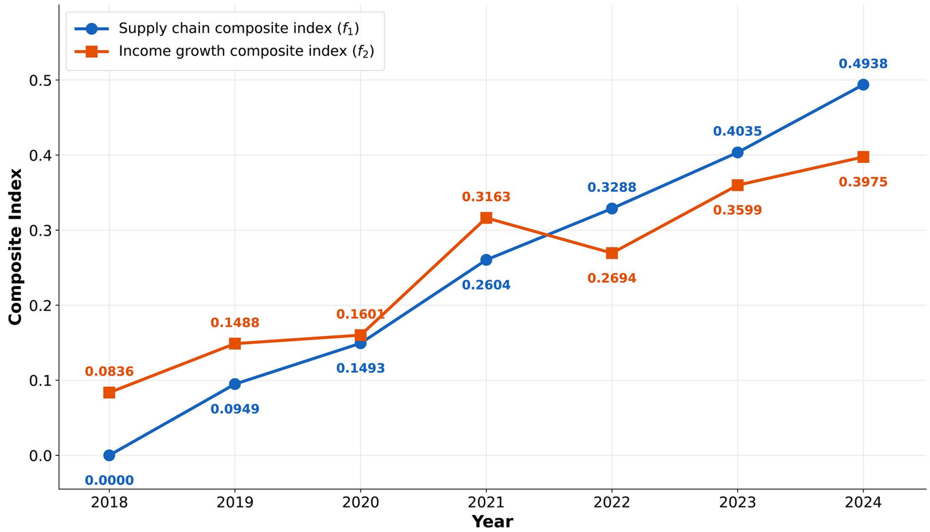
3.3. Composite Index Results

Based on Equation (5), the comprehensive index of the rural supply chain (f_1) and that of farmers' income growth (f_2) in Zhejiang Province for 2018-2024 are calculated (see **Table 2**; Wang et al., 2024), and the temporal changes in the two composite indices are shown in **Figure 2**.

Table 2. Composite indices and coupling coordination results for Zhejiang Province (2018-2024).

Year	f_1 Supply chain index	f_2 Income growth index	C Coupling degree	T Comprehensive coord. index	D Coordination degree	Coordination grade	P Dev. coefficient	Development type
2018	0.0000	0.0836	0.0000	0.0418	0.0000	Extreme incoordination	—	—
2019	0.0949	0.1488	0.9752	0.1219	0.3448	Low incoordination	0.6378	Supply-chain-lagged
2020	0.1493	0.1601	0.9994	0.1547	0.3932	Low incoordination	0.9330	Synchronous
2021	0.2604	0.3163	0.9953	0.2884	0.5357	Moderate coordination	0.8234	Synchronous
2022	0.3288	0.2694	0.9951	0.2991	0.5455	Moderate coordination	1.2203	Income-growth-lagged
2023	0.4035	0.3599	0.9984	0.3817	0.6173	High coordination	1.1212	Synchronous
2024	0.4938	0.3975	0.9941	0.4457	0.6656	High coordination	1.2423	Income-growth-lagged

As shown in **Table 2** and **Figure 2**, the comprehensive index of the rural supply chain (f_1) in Zhejiang Province rose continuously from 0 in 2018 to 0.4938 in 2024, with a significant average annual increase and strong growth momentum. In particular, growth was most pronounced during 2019-2021, when f_1 increased cumulatively by 0.2604, mainly driven by the large-scale construction of 5G base stations, the rapid growth of express delivery volume, and the swift rise in online retail sales of agricultural products. During 2022-2024, f_1 continued to grow steadily, increasing cumulatively by 0.2334, reflecting a new phase in which supply chain infrastructure construction shifted from rapid expansion to efficiency improvement (Guo & Lyu, 2024; Miao et al., 2024).



Note to Table 2: The 2018 values $C = 0$ and $D = 0$ ("extreme incoordination") arise mechanically because min-max normalization sets every base-year supply-chain indicator—and hence f_1—to zero. They are normalization artifacts and do not represent the actual coordination state in 2018, when supply-chain activity was already substantial (e.g., 26.48 million broadband subscribers and 10.11 billion parcels). The substantive coordination trend should be read from 2019 onward.

Figure 2. Changes in composite indices of rural supply chain and farmers' income growth in Zhejiang Province (2018-2024).

The comprehensive index of farmers' income growth (f_2) rose with fluctuations from 0.0836 in 2018 to 0.3975 in 2024, maintaining an overall upward trend but with volatility. It is noteworthy that f_2 was not zero in 2018 (0.0836), mainly because the urban-rural income ratio was at its maximum in that year and became 0 after negative standardization, whereas indicators such as the Digital Inclusive Finance Index and primary industry labor productivity already had a certain base in the base period, yielding a positive f_2 after weighting. During 2019-2021, f_2 grew rapidly, reaching 0.3163 in 2021, driven by the steady growth of per capita disposable income, the substantial increase in tertiary industry net income, and the continuous narrowing of the urban-rural income gap. In 2022, f_2 fell to 0.2694, mainly due to increased downward pressure on the macroeconomy and the decline in the year-on-year growth rate of farmers' income from 10.39% to 6.58%. In 2023-2024, f_2 recovered steadily, reaching 0.3599 and 0.3975, respectively, with the income growth trend gradually rebounding (Xu & Zhang, 2026).

A comparison of the two systems shows that during 2018-2019 f_1 was lower than f_2, indicating that supply chain development was relatively lagging. In 2020, f_1 (0.1493) and f_2 (0.1601) were essentially on par. In 2021, f_2 (0.3163) overtook f_1 (0.2604), exhibiting an alternating leadership pattern. In 2022, f_1 again substantially exceeded f_2, with the gap reaching 0.0594; in 2023 the gap narrowed to 0.0436, but in 2024 it widened again to 0.0963. This dynamic change indicates that rural supply chain development and farmers' income growth in Zhejiang do not follow a simple unidirectional driving relationship; rather, they exhibit different lead-lag patterns in different years, and there is a certain time lag in the transmission of supply chain investment to income growth (Tian et al., 2024; Wang et al., 2024).

It should be noted that this alternating lead-lag pattern is descriptive: the annual composite indices trace relative timing only and, with a single province and seven observations, cannot establish whether (or with what magnitude and lag) supply-chain investment causally drives farmers' income growth.

3.4. Coupling Coordination Degree Analysis

From the perspective of the coupling degree C (see **Table 2** and **Figure 3**), with the exception of 2018, when $f_1 = 0$ resulted in $C = 0$, the C values for 2019-2024 all remained above 0.97, reaching a peak of 0.9994 in 2020. This indicates an extremely strong interactive coupling between the rural supply chain and farmers' income growth systems: the standardized comprehensive indices of the two systems show a high degree of synchronous co-movement, i.e., they rise and evolve along closely matched paths, which is consistent with—but does not by itself prove—a close interdependent relationship. It must be emphasized that a high coupling degree C reflects only normalized co-movement and cannot establish reciprocal causal effects; such causal inference would require cross-regional panel data and formal statistical testing, which lie beyond the single-province, seven-observation design of this study. The high coupling degree shows that rural supply chain development and farmers' income growth in Zhejiang do not operate independently but exhibit significant linkage effects: the improvement of the supply chain provides channels for agricultural product circulation and rural consumption upgrading, while the growth of farmers' income expands market space for supply chain services (Haken, 1977; Liu et al., 2007).

From the perspective of the coordination degree D, from 2019 to 2024 the coordination degree of rural supply chains and farmers' income growth in Zhejiang improved substantially. The 2018 value of $D = 0$ is a mechanical by-product of min-max normalization (all base-year supply-chain indicators equal the sample minimum and are standardized to zero), rather than evidence of actual extreme incoordination; it is therefore excluded when interpreting the substantive trajectory. Anchored at the first valid observation in 2019, the coordination grade progressed from low incoordination (2019-2020), through moderate coordination (2021-2022), to high coordination (2023-2024). Specifically, in 2018 $D = 0$ (extreme incoordination), mainly because the base-period supply chain data were zero. In 2019 $D = 0.3448$ (low incoordination), and the two systems began to enter a low-level coupling stage. In 2020 $D = 0.3932$ (low incoordination), with the coordination degree approaching the 0.4 threshold. In 2021 $D = 0.5357$ (moderate coordination), breaking through 0.5 and achieving a qualitative transformation from "incoordination" to "coordination." In 2022 $D = 0.5455$ (moderate coordination), with the coordination degree still increasing slightly despite the decline in f_2. In 2023 D = 0.6173 (high coordination), successfully crossing the 0.6 threshold. In 2024 D = 0.6656 (high coordination), continuing to improve and only 0.0344 away from the "extreme coordination" range.

In terms of growth stages, 2020-2021 was the period of fastest improvement in coordination degree, with D jumping from 0.3932 to 0.5357, an increase of 0.1425. This leap was closely related to the intensive policy measures introduced in Zhejiang during the same period: in 2020, Zhejiang comprehensively promoted digital village construction and vigorously implemented the "Digital Commerce for Agriculture" strategy; in 2021, Zhejiang was designated as a demonstration zone for common prosperity, and policies for rural supply chain infrastructure and farmers' income growth were implemented in tandem, driving the two systems to achieve a leap from low-level coupling to high-level coordination. In 2022, affected by the macroeconomic downturn, the farmers' income growth composite index declined, and the increase in D narrowed to 0.0098. In 2023-2024, with economic recovery and the cumulative effect of policies, D increased by 0.0718 and 0.0483, respectively, and the coordination grade remained firmly in the high coordination range.

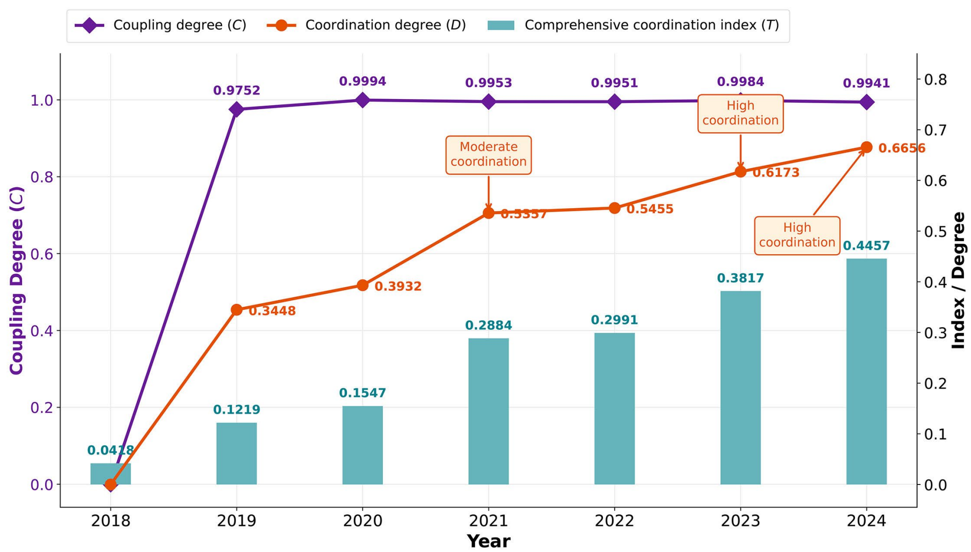


Figure 3. Coupling coordination degree of rural supply chain and farmers' income growth in Zhejiang Province (2018-2024).

3.5. Relative Development Type Analysis

The dynamic changes in the relative development coefficient P reveal the unbalanced characteristics of the two systems' development (see Table 2). In 2019, P = 0.6378 < 0.8, indicating a supply-chain-lagged type. At the initial stage of supply chain development, infrastructure such as 5G base stations and express logistics were still in the early construction phase, and their supporting role in farmers' income growth had not yet fully manifested; supply chain development lagged behind the pace of farmers' income growth (Qiu et al., 2024; Guan et al., 2024).

In 2020, the P value rose rapidly to 0.9330, entering the synchronous development range, with the two systems maintaining basically balanced development. During this period, the COVID-19 pandemic objectively accelerated the online sales of agricultural products and the development of express logistics, and supply chain development and farmers' income growth formed a favorable synergistic effect. In 2021, the P value fell to 0.8234, still within the synchronous development range but leaning toward the supply-chain-lagged end, mainly because the year-on-year growth rate of farmers' income reached a cyclical high of 10.39% that year, and f_2 grew faster than f_1.

In 2022, the P value jumped to 1.2203, breaking through the critical value of 1.2 and shifting to the income-growth-lagged type. This shift was closely related to the increased downward pressure on the macroeconomy and the sharp decline in the year-on-year growth rate of farmers' income to 6.58%: f_2 fell from 0.3163 in 2021 to 0.2694, while the supply chain composite index f_1 continued to grow to 0.3288, significantly widening the growth rate gap between the two systems. In 2023, the P value fell back to 1.1212, re-entering the synchronous development range, indicating that with economic recovery and the strengthening of income growth policies, f_2 rebounded to 0.3599 and the development rhythms of the two systems became balanced again. However, in 2024 the P value rose once more to 1.2423, shifting back to the income-growth-lagged type, and the gap between f_1 (0.4938) and f_2 (0.3975) widened to 0.0963. This reflects that, while supply chain infrastructure continued to expand rapidly, the growth rate of farmers' income slowed somewhat, and the efficiency of converting supply chain investment into farmers' income needs to be improved (Xu & Zhang, 2026).

The "fluctuating regression" phenomenon of the P value has profound internal logic. Rural supply chain investment is characterized by large upfront costs and long payback periods. When supply chain infrastructure construction accelerates, the rapid rise of f_1 may temporarily widen the gap with f_2; when the income-enhancing effects of the supply chain gradually transmit to farmers' income, f_2 catches up, and the two systems tend toward balance again (Lai et al., 2024; Tian et al., 2024). The P value exceeding 1.2 again in 2024 indicates that the income-enhancing effect of supply chain construction is still in the process of transmission. Future policies should pay greater attention to the effective conversion of supply chain investment into farmers' income, preventing a sustained disconnect between supply chain development and farmers' income growth.

3.6. Robustness, Sensitivity Analysis, and Limitations

Because this study covers only one province with seven annual observations (N = 7), no inferential statistical test is performed, and the results carry the limitations inherent to a single-case time series. A sensitivity analysis on the coordination weights is therefore reported. Under the baseline equal weights (a = b = 0.5), D equals 0.3447 (2019), 0.3932 (2020), 0.5357 (2021), 0.5456 (2022), 0.6173 (2023), and 0.6656 (2024). Re-weighting to $a = 0.6$, $b = 0.4$ gives 0.3370, 0.3918, 0.5305, 0.5509, 0.6208, and 0.6728, while $a = 0.4$, $b = 0.6$ gives 0.3523, 0.3946, 0.5409, 0.5401, 0.6138, and 0.6584. In every year the coordination grade remains identical (low incoordination in 2019-2020, moderate coordination in 2021-2022, and high coordination in 2023-2024), so the qualitative conclusions are robust to reasonable weight variation. The uncertainty associated with the four trend-extrapolated 2024 values is confined to marginal shifts in the 2024 levels and does not alter any grade or ordering. As a descriptive provincial case, the findings characterize Zhejiang's coordinated-evolution pattern but neither estimate causal effects nor generalize across provinces.

4. Conclusions and Policy Recommendations

4.1. Conclusions

Based on synergetics theory and the coupled human-natural systems framework (Haken, 1977; Liu et al., 2007), this study constructs a dual-system evaluation indicator system for rural supply chains and farmers' income growth. Using the entropy weight method and coupling coordination degree model, it empirically measures the comprehensive development levels, coupling coordination degree, and relative development types of the two systems in Zhejiang Province from 2018 to 2024. The main conclusions are as follows.

First, both the rural supply chain and farmers' income growth composite indices in Zhejiang achieved rapid growth, but their growth trajectories differ. The rural supply chain composite index f_1 increased from 0 in 2018 to 0.4938 in 2024 with strong momentum, driven mainly by 5G base station construction, express delivery volume expansion, and growth in logistics industry value-added. The farmers' income growth composite index f_2 increased from 0.0836 to 0.3975, rising overall but with fluctuations, including a decline in 2022 due to macroeconomic impacts. The two systems exhibited an alternating leadership pattern during 2019-2024 rather than a simple unidirectional driving relationship (Miao et al., 2024).

Second, the coupling coordination degree of the two systems continued to improve, and, on the valid observation range from 2019 to 2024, improving from low incoordination through moderate coordination to high coordination. The coordination degree D reached 0.6656 in 2024; the 2018 value of $D = 0$ is a base-year normalization artifact ($f_1 = 0$ after min-max standardization) rather than a genuine extreme-incoordination state. The coupling degree C remained above 0.97 from 2019 to 2024, indicating a high degree of synchronous co-movement between the two systems' comprehensive indices; this is interpreted as descriptive evidence of coordinated evolution, not as proof of reciprocal causal effects, which would require multi-province panel data and formal causal testing. The period 2020-2021 saw the fastest improvement in coordination degree, in which digital village construction and the common prosperity demonstration zone policy played important catalytic roles (Shu et al., 2023; Wang et al., 2024).

Third, the relative development type underwent a dynamic adjustment of "supply-chain-lagged → synchronous → income-growth-lagged → synchronous → income-growth-lagged." In 2019 it was supply-chain-lagged ($P = 0.6378$); in 2020-2021 it was synchronous; in 2022 it shifted to income-growth-lagged ($P = 1.2203$); in 2023 it returned to synchronous ($P = 1.1212$); and in 2024 it shifted again to income-growth-lagged ($P = 1.2423$). This fluctuation indicates that the income-enhancing effect of supply chain infrastructure investment has a transmission time lag (Tian et al., 2024). In 2024, supply chain development continued to outpace farmers' income growth, requiring attention to the balanced development of the two systems.

Fourth, the year-on-year growth rate, the number of 5G base stations, and per capita tertiary industry net income were the top three weighted indicators affecting the coordinated development of the two systems. The year-on-year growth rate had the highest weight (0.1086), indicating that the stability and sustainability of income growth are critical to system coordination. The number of 5G base stations ranked second (0.1063), reflecting the key supporting role of new digital infrastructure in supply chain development. Value-added of transport, storage, and postal services (0.1011) and per capita tertiary industry net income (0.0999) followed closely, validating the rationality of expanding "rural e-commerce" to "rural supply chain" and incorporating logistics industry indicators (Qiu et al., 2024; Wang & Weng, 2026).

4.2. Limitations and Future Research

This study has three limitations that should be acknowledged. First, the sample comprises a single province with seven annual observations (N = 7); the results are therefore a descriptive provincial time-series account, provide no inferential test of causality, and cannot be generalized to other regions. Second, several supply-chain indicators (broadband, 5G, express delivery, transport value-added) are province-wide proxies that may also capture urban circulation activity, and the income subsystem mixes direct income outcomes with enabling determinants. Third, a handful of provisional 2024 values rely on trend extrapolation. Future research should 1) extend the analysis to multi-province panel data and longer time windows to test regional heterogeneity and convergence; 2) adopt rural-specific and more direct income measures where continuous series become available; and 3) formally examine causality using panel econometric or quasi-experimental designs, so that the reciprocal interaction hypothesized from synergetics can be tested rather than assumed.

4.3. Policy Recommendations

First, continuously improve rural digital and logistics infrastructure to consolidate the foundation of supply chain modernization. The number of 5G base stations ranks second in weight in the indicator system, fully demonstrating the critical supporting role of new digital infrastructure in rural supply chain development (Zhang & Zhang, 2024). Efforts should continue to strengthen the construction of

5G networks and gigabit optical networks in rural areas, promote the optimization and integration of rural delivery routes and express logistics stations, and accelerate the development of a three-tier (county-township-village) logistics distribution system. Priority should be given to addressing weaknesses in rural cold chain logistics infrastructure by building pre-cooling, storage and preservation, and cold transport facilities in major agricultural production areas to reduce post-harvest losses. At the same time, attention should be paid to the joint construction, sharing, and balanced layout of infrastructure to avoid redundant construction and idle resources.

Second, promote the digital transformation of agricultural product supply chains to enhance operational scale and quality. In response to the slowing growth of express delivery volume and online retail sales of agricultural products, the integration of e-commerce with distinctive rural industries should be deepened, and new business formats such as live-streaming e-commerce, social e-commerce, and community group buying should be cultivated. Regional public brands such as "Lishui Shangeng" ("Lishui Mountain Farming") and "Sanqu Wei" should be supported in expanding online channels to increase the added value and brand premium of agricultural products. The transport, storage, and postal industries should be encouraged to undergo digital and intelligent transformation, developing intensive models such as smart logistics and joint distribution to improve supply chain operational efficiency (Qiu et al., 2024; Guan et al., 2024). Market-oriented cooperation among postal, express, supply and marketing, and e-commerce entities should be encouraged to open up two-way channels for the upward flow of agricultural products and the downward flow of industrial goods.

Third, establish a sound long-term mechanism for farmers' income growth and smooth the transmission channels from supply chains to income growth. In light of the income-growth-lagged phenomena in 2022 and 2024 and the highest weight of the year-on-year growth rate, efforts should focus on stabilizing expectations for farmers' income growth and broadening income channels. On the one hand, the benefit-linkage mechanism for agricultural products should be improved, and models such as "leading enterprise + cooperative + farm household" should be promoted to enable farmers to share more of the value-added gains from supply chains. On the other hand, employment and entrepreneurship opportunities in rural e-commerce, express logistics, and rural tourism should be actively expanded to increase farmers' wage and operating income (Lai et al., 2024; Tian et al., 2024). Particular attention should be paid to raising per capita tertiary industry net income by developing rural leisure tourism, rural e-commerce services, elderly care, and childcare services as new growth points for farmers' income. Reforms of the rural collective property rights system should be deepened, idle assets should be revitalized, and farmers' property income should be increased.

Fourth, strengthen the enabling role of digital inclusive finance and promote the two systems to advance synergistically toward superior coordination. The Digital Inclusive Finance Index occupies an important weight in the income growth subsystem (Shen et al., 2025; Yu & Wu, 2026). Digital credit, agricultural insurance, mobile payments, and other financial services should be further extended to rural areas to provide convenient financing support for farm households and small, medium, and micro supply chain entities. Financial institutions should be encouraged to develop supply chain finance products tailored to the characteristics of rural supply chains, using real transaction data to provide credit loans and addressing the financing difficulties of agricultural product processing and circulation enterprises. At the same time, a monitoring and evaluation mechanism for the coordinated development of rural supply chains and farmers' income growth should be established to regularly track changes in the coupling coordination degree, promptly identify and correct developmental imbalances, and steadily advance the two systems from "high coordination" toward "superior coordination."

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Author Contributions

Jingxuan Qiu: conceptualization, methodology, formal analysis, data curation, writing—original draft. Yang Li: methodology, investigation, validation, funding acquisition and writing—review & editing. Jiaxi Wu: conceptualization, supervision, resources, funding acquisition, writing—review & editing and project administration. All authors have read and agreed to the published version of the manuscript.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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