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Regional Disparities, Distributional Dynamics, and Barriers to the Development of Agricultural Product Cold-Chain Logistics in China

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Abstract: Amid China's ongoing agricultural modernization and green transition, high-quality agricultural product cold-chain logistics plays a critical role in ensuring food safety and promoting sustainable agricultural development. Using provincial panel data from 30 Chinese provinces during 2018 and 2024, this study employs the entropy-weighting method, Dagum Gini coefficient decomposition, kernel density estimation, and the obstacle degree model to examine the temporal evolution, regional disparities, distributional dynamics, and key barriers to agricultural product cold-chain logistics development. Four main findings emerge. First, the national development level increased steadily, although substantial regional disparities persisted, with the eastern region consistently outperforming the central, western, and northeastern regions. Second, the overall Dagum Gini coefficient declined with fluctuations. Between-region disparities constituted the largest source of inequality, followed by within-region disparities and transvariation density. Third, the national kernel density distribution shifted rightward and became more dispersed. The eastern distribution moved rightward and became more concentrated, while an emerging development gradient appeared in the central region. The western region remained at a relatively low level with pronounced internal disparities, whereas growth rates varied substantially within the northeastern region. Fourth, infrastructure was the dominant barrier. Insufficient and spatially uneven infrastructure supply remained the primary constraint. Although the obstacle degree of economic synergy declined, regional disparities persisted. Development capacity improved only slowly, indicating insufficient endogenous momentum. Technological capacity had the lowest obstacle degree. These findings provide an empirical basis for formulating region-specific policies to promote more balanced and high-quality development of agricultural product cold-chain logistics in China.

Keywords: agricultural product cold-chain logistics; regional disparities; distributional dynamics; barriers; entropy-weighting method; Dagum Gini coefficient

1. Introduction and Literature Review

An efficient and well-functioning agricultural product distribution system is strategically important for advancing agricultural and rural modernization and ensuring national food security. China's 2026 No. 1 Central Document calls for the joint construction and sharing of rural delivery and logistics facilities, while emphasizing the integration of passenger, freight, and postal services and increased investment in origin-based precooling, storage, and preservation facilities.

Agricultural product cold-chain logistics constitutes a critical link in the agricultural value chain. By connecting production with markets and urban and rural areas, it helps reduce postharvest losses while maintaining the quality and safety of fresh agricultural products[1]. As China enters the early stage of the 15th Five-Year Plan period, provincial governments are expanding backbone cold-chain networks, upgrading facilities and equipment, and improving distribution systems to reduce product losses and modernize agricultural value chains. Nevertheless, China's cold-chain logistics system remains below the level required to achieve the goal of becoming an agricultural powerhouse. Major challenges include uneven infrastructure provision, high distribution costs, and outdated equipment and technologies[2]. It is therefore essential to clarify the conceptual foundations of cold-chain modernization, develop a multidimensional evaluation framework, and assess regional disparities, distributional dynamics, and key constraints. Such evidence can inform efforts to address infrastructure gaps, strengthen weak links, improve two-way distribution between rural and urban markets[3], and support comprehensive rural industrial revitalization.

Agricultural product cold-chain logistics has attracted extensive scholarly attention. Existing studies can be broadly divided into theoretical and empirical strands.

The theoretical literature has focused primarily on the concept, practical significance, and development pathways of cold-chain logistics. Most studies define agricultural product cold-chain logistics as a modern logistics system that maintains controlled temperatures throughout the transportation and distribution of perishable goods, including fresh food [4-6]. Effective temperature control reduces postharvest losses and preserves product quality. Accordingly, well-developed cold-chain logistics can improve distribution efficiency, enhance agricultural returns and farm household incomes, strengthen food safety, expand the geographic reach of agricultural markets, and facilitate agricultural upgrading[7,8]. Proposed development pathways encompass technological, managerial, and policy dimensions. Technologies such as the Internet of Things, big data, and intelligent sensors can enhance information collection, monitoring, and management capabilities[9]. Logistics network and infrastructure planning should account for regional production conditions and the growing demand for diverse and high-quality agricultural products. Specialized training is also needed to meet the requirements of different market participants[10]. In addition, fiscal and tax policies can reduce firms' operating costs[11], attract private investment, and foster a more coordinated and efficient cold-chain logistics ecosystem.

The empirical literature has examined agricultural product cold-chain logistics from the perspectives of measurement, regional disparities, distributional dynamics, and development constraints. Most studies measure development using multidimensional composite evaluation systems. Zhang[12] assessed the overall performance of the cold-chain sector based on development potential, capacity, and benefits. Li and Zhang[13] adopted a framework encompassing infrastructure support, technological enablement, and scale development, with indicators covering logistics infrastructure, information technology capacity, and logistics development. Zhou[14] focused on digital transformation and constructed an indicator system incorporating digital infrastructure, digital output capacity, and digital development. Other studies have examined cold-chain development from the demand side or indirectly measured and predicted development using key determinants. Tao et al.[15] applied the technology-organization-environment framework to identify configurations of demand conditions. Li and Ye[16] selected indicators covering product supply, socioeconomic conditions, household consumption, and industry scale.Chen et al. [17] used the outputs of six categories of fresh agricultural products as proxies for cold-chain logistics demand and applied the GM (1,1) model to forecast provincial demand for 2023–2027. Their spatial analysis indicates an overall upward trend and persistent disparities between China's coastal and inland regions.

Several studies have employed Dagum Gini coefficient decomposition to examine the sources of regional differences in cold-chain logistics efficiency. Li and Wu[18] measured efficiency across China's four macro regions and found that the eastern and central regions performed best, followed by the northeastern region, while the western region lagged. Li and Peng[19] reported that regional disparities in agricultural product distribution efficiency had narrowed, although between-region disparities remained the largest source of inequality. At the subregional level, Guo and Li[20] evaluated cold-chain logistics development across 12 representative provinces and municipalities and identified pronounced geographic disparities.

Kernel density estimation has also been widely used to characterize distributional dynamics, polarization, and convergence. Zhou et al.[21] found that the distribution of green development in fresh agricultural product cold-chain logistics shifted from unimodal to bimodal, indicating substantial polarization. Wang et al.[22] combined the coefficient of variation with Moran's I and identified a stepwise decline in distribution efficiency from eastern to central and western China, together with significant spatial dependence.

Studies examining key barriers have generally identified influential factors through composite indicator systems or econometric approaches. Ren et al.[23] identified economic development, industrial structure, geographical location, openness, and human-capital investment as major determinants of logistics efficiency, highlighting the constraining effect of spatially uneven location advantages. Using grey relational analysis, Zhang et al.[24] found that cold-chain logistics scale, facility provision, urbanization, agricultural development, and transport infrastructure were closely associated with industry development. Yang[25] employed a Tobit model and reported that information development and

per capita disposable income were significantly associated with agricultural product logistics efficiency.

The existing literature provides three important foundations for the present study. First, multidimensional indicator systems offer a useful basis for evaluating agricultural product cold-chain logistics development. Second, spatial and distributional methods, including Dagum Gini coefficient decomposition and kernel density estimation, provide effective approaches for identifying regional disparities and distributional dynamics. Third, studies at the macro and industry levels have identified a broad range of potential determinants and constraints.

Nevertheless, three limitations remain. First, development levels, regional disparities, and constraints have generally been examined separately, with limited integration of their relationships within a unified analytical framework. Second, applications of Dagum Gini decomposition and kernel density estimation to agricultural product cold-chain logistics remain relatively limited, particularly in nationwide analyses covering an extended period. Third, existing studies tend to provide relatively static assessments of determinants and constraints. Few studies combine an obstacle degree model with spatial and temporal perspectives to identify how key barriers vary across regions and stages of development. To address these gaps, the present study develops an integrated framework encompassing development-level measurement, disparity decomposition, distributional analysis, and dynamic barrier diagnosis.

Specifically, this study first evaluates the development level of agricultural product cold-chain logistics across China. It then combines Dagum Gini coefficient decomposition with kernel density estimation to identify the sources and magnitude of regional disparities and characterize their distributional dynamics. Finally, the obstacle degree model is employed to identify the principal constraints across regions and stages of development. The resulting evidence is expected to inform more targeted policies for promoting high-quality and spatially balanced development of agricultural product cold-chain logistics.

2. Research Design

2.1 Construction of the Indicator System

This study conceptualizes regional agricultural product cold-chain logistics as a complex adaptive system. The system comprises four dimensions: infrastructure, technological capacity, development capacity, and economic synergy (Figure 1). Guided by systems theory and synergy theory, indicator selection follows the principles of scientific validity, systematic coverage, and operational feasibility. The resulting framework reflects the distinctive characteristics of agricultural product cold-chain logistics and its interactions with regional economic development, thereby capturing both current development conditions and future development potential.

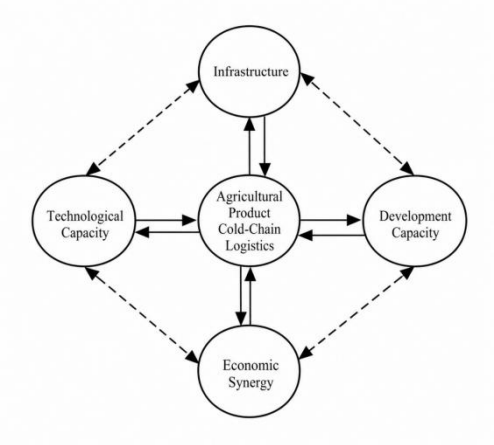


Figure 1. Conceptual framework of the evaluation system

Infrastructure constitutes the physical foundation of agricultural product cold-chain logistics. This dimension captures the availability of essential facilities and network coverage. The number of cold-chain enterprises and refrigerated vehicles, together with cold-storage capacity[26,27], directly reflects the supply of specialized cold-chain infrastructure. Freight volume, freight turnover, and highway mileage characterize transportation capacity and the geographical coverage of cold-chain services[28-30]. The number of broadband subscribers serves as a proxy for the coverage of information infrastructure. Greater broadband penetration can facilitate rural e-commerce and[25], in turn, stimulate demand for origin-based precooling, cold storage, and integrated transportation services.

Technological capacity represents the operational and knowledge base supporting the development of agricultural product cold-chain logistics. Total power of agricultural machinery reflects the scale of agricultural production. Larger-scale and more mechanized agricultural production can increase demand for origin-based precooling, cold storage, and temperature-controlled transportation. Grain yield per hectare captures agricultural productivity and commercialization. Regions with higher agricultural productivity generally handle larger volumes of marketable agricultural products and consequently generate greater demand for preservation and cold-chain services. Value added and employment in transportation, storage, and postal services capture the scale of logistics-related economic activity and the associated labor capacity supporting cold-chain operations[20][22][31][32].

Development capacity captures market demand and the broader socioeconomic conditions that support the expansion of cold-chain logistics[15]. Gross regional product reflects economic scale and the fiscal capacity of local governments to invest in cold-chain infrastructure[31]. Per capita gross regional product represents household purchasing power. Higher-income consumers generally have stronger demand for fresh and high-quality agricultural products[33,34], thereby stimulating demand for refrigerated transport and last-mile delivery. The resident population reflects both the potential market size for fresh agricultural products and the labor pool available to logistics services. Employment in the primary sector indicates the scale of agricultural production and the potential supply of products requiring origin-based cold-chain services[23]. Gross agricultural output value captures the overall scale

and commercialization of agricultural production. Higher output generally translates into greater product flows and stronger demand for interregional cold-chain transportation.

Economic synergy captures the reciprocal relationship between cold-chain logistics and the regional economy. Per capita disposable income of rural residents reflects the financial capacity of agricultural producers[35,36] and rural households to invest in preservation, storage, and related facilities[25]. Express-delivery volume indicates the development of last-mile logistics networks and their capacity to connect agricultural products with end consumers. General public budget expenditure on agriculture, forestry, and water affairs measures government support for agricultural and rural development and provides a potential source of public investment in cold-chain infrastructure and related services[37].The resulting evaluation system comprises four dimensions and 19 indicators. Table 1 summarizes the indicators, codes, units, and supporting references.

Table 1. Indicator system for agricultural product cold-chain logistics development

Dimension	Indicator	Code	Unit	References
Infrastructure	Cold-chain enterprises	X1	enterprises	[25][26][27][28][29][30]
	Refrigerated vehicles	X2	vehicles	
	Cold-storage capacity	X3	metric tons	
	Freight volume	X4	10,000 metric tons	
	Freight turnover	X5	100 million ton-km	
	Highway mileage	X6	10,000 km	
	Broadband subscribers	X7	10,000 subscribers	
Technological capacity	Total power of agricultural machinery	X8	10,000 kW	[20][22][31][32]
	Grain yield per hectare	X9	kg/ha	
	Value added: transportation, storage, and postal services	X10	CNY 100 million	
	Employment: transportation, storage, and postal services	X11	10,000 persons	
Development capacity	Gross regional product	X12	CNY 100 million	[15][23][31][33][34]
	Resident population	X13	10,000 persons	
	Per capita gross regional product	X14	CNY/person	
	Gross agricultural output value	X15	CNY 100 million	
	Employment in the primary sector	X16	10,000 persons	
Economic synergy	Per capita disposable income of rural residents	X17	CNY	[25][35][36][37]
	Express-delivery volume	X18	10,000 items	
	Public budget expenditure on agriculture, forestry, and water affairs	X19	CNY 100 million	

2.2 Data Sources

The analysis used panel data for 30 provincial-level regions from 2018 to 2024. Tibet, Taiwan, Hong Kong, and Macao were excluded because comparable data are unavailable. Data were collected from the China Statistical Yearbook, China Rural Statistical Yearbook, China Agriculture Yearbook, the China Cold Chain Alliance website, the National Bureau of Statistics of China, and provincial statistical yearbooks. Missing observations were imputed using linear interpolation to maintain a balanced panel.

3. Measurement of Agricultural Product Cold-Chain Logistics Development

The entropy weight method (EWM), which is grounded in Shannon's information entropy theory, objectively determines indicator weights according to the degree of variation across evaluation units[38]. Compared with subjective methods such as the analytic hierarchy process and analytic network process, the entropy-weighting method assigns weights objectively and reduces the influence of researcher judgment[39]. This study uses the entropy-weighting method to construct agricultural product cold-chain logistics development indices at the national, regional, and provincial levels.

Table 2 reports the development indices for 30 provinces from 2018 to 2024. At the national level, the index increased from 0.221 in 2018 to 0.297 in 2024, indicating a sustained improvement. This upward trend coincided with increasing policy attention to cold-chain logistics, including the emphasis placed on strengthening urban-rural cold-chain logistics infrastructure in 2019.

The broader policy environment and market development provided favorable conditions for the expansion of cold-chain logistics. In the context of China's carbon-peaking and carbon-neutrality goals, the sector has also increasingly adopted energy-efficient equipment, new-energy refrigerated vehicles, and greener cold-storage facilities, contributing to improvements in cold-chain logistics efficiency.

All four macro-regions followed the national upward trend, although substantial differences in development levels persisted. The eastern region recorded the highest development level throughout the study period, whereas the western region remained at the lowest level.

Table 2. Agricultural product cold-chain logistics development index by province, 2018-2024

Region	Province	2018	2019	2020	2021	2022	2023	2024
	Beijing	0.219	0.268	0.239	0.254	0.277	0.262	0.277
	Fujian	0.240	0.253	0.279	0.280	0.319	0.315	0.330
	Guangdong	0.560	0.580	0.631	0.667	0.688	0.718	0.762
	Hainan	0.098	0.110	0.136	0.134	0.143	0.148	0.157
	Hebei	0.257	0.277	0.304	0.307	0.316	0.350	0.371
Eastern	Jiangsu	0.413	0.435	0.482	0.497	0.509	0.549	0.576
	Shandong	0.439	0.433	0.455	0.508	0.524	0.562	0.579
	Shanghai	0.412	0.390	0.393	0.437	0.429	0.432	0.454
	Tianjin	0.111	0.111	0.109	0.143	0.146	0.138	0.148
	Zhejiang	0.316	0.329	0.362	0.423	0.427	0.466	0.513
	Mean	0.306	0.319	0.339	0.365	0.378	0.394	0.417
	Anhui	0.260	0.272	0.260	0.288	0.323	0.343	0.361
	Shanxi	0.170	0.142	0.142	0.179	0.177	0.190	0.190
	Henan	0.387	0.386	0.415	0.406	0.431	0.455	0.474
Central	Hubei	0.244	0.260	0.267	0.279	0.294	0.339	0.358
	Hunan	0.263	0.267	0.278	0.273	0.279	0.312	0.325
	Jiangxi	0.182	0.181	0.173	0.209	0.214	0.235	0.246
	Mean	0.251	0.251	0.256	0.272	0.286	0.312	0.326
	Gansu	0.095	0.107	0.125	0.113	0.144	0.138	0.143
	Inner Mongolia	0.177	0.166	0.151	0.186	0.197	0.221	0.231
	Guangxi	0.159	0.174	0.203	0.196	0.205	0.225	0.233
	Guizhou	0.103	0.123	0.147	0.131	0.142	0.162	0.169
Western	Ningxia	0.065	0.062	0.059	0.072	0.069	0.067	0.071
	Qinghai	0.051	0.047	0.031	0.053	0.049	0.052	0.055
	Shaanxi	0.177	0.160	0.165	0.196	0.198	0.214	0.226
	Sichuan	0.298	0.285	0.290	0.324	0.334	0.383	0.395
	Xinjiang	0.129	0.122	0.128	0.163	0.170	0.195	0.195

	Yunnan	0.179	0.178	0.194	0.223	0.225	0.252	0.261
	Chongqing	0.154	0.146	0.155	0.185	0.187	0.197	0.205
	Mean	0.144	0.143	0.150	0.167	0.175	0.192	0.199
Northeastern	Liaoning	0.231	0.225	0.208	0.246	0.247	0.260	0.265
	Jilin	0.116	0.115	0.145	0.129	0.127	0.136	0.141
	Heilongjiang	0.131	0.144	0.168	0.160	0.164	0.181	0.184
	Mean	0.160	0.161	0.174	0.178	0.179	0.192	0.197
National	Mean	0.221	0.225	0.236	0.255	0.265	0.283	0.297

4. Regional Disparities and Their Decomposition

Following the regional classification adopted by the National Bureau of Statistics of China, the 30 provinces are grouped into four regions: eastern, central, western, and northeastern China. Dagum Gini coefficient decomposition is then employed to assess regional disparities in agricultural product cold-chain logistics development[40].

4.1 Overall Disparity and Source Decomposition

Table 3 presents the Dagum Gini coefficients and their decomposition results. The overall Gini coefficient declined slightly but fluctuated over the study period, decreasing from 0.298 in 2018 to approximately 0.296 in 2024. This indicates that overall disparities in agricultural product cold-chain logistics development narrowed only marginally during the study period. The modest decline occurred against the backdrop of policy support provided by the 14th Five-Year Plan for Cold-Chain Logistics Development. Between-region disparities constituted the largest source of overall inequality, accounting for approximately 58%-62% of the total and showing a slight increase in contribution relative to the beginning of the study period. Transvariation density made a smaller contribution, indicating that the overlapping component of regional distributions contributed less to overall disparity. The contribution of within-region disparities remained relatively stable[41]. These findings suggest that uneven spatial distributions of key inputs continue to reinforce regional differences. Strengthening interregional coordination, developing context-specific cooperation platforms[42], and implementing targeted policy measures may therefore help reduce persistent regional disparities and promote more balanced development.

Table 3. Overall disparity and decomposition by source

Year	Overall Gini	Contribution (%)		
		Within-region	Between-regions	Transvariation density
2018	0.298	23	58	18
2019	0.299	22	62	16
2020	0.302	23	62	15
2021	0.294	23	62	15
2022	0.291	23	62	15
2023	0.292	24	58	18
2024	0.296	23	59	17

4.2 Within-Region Disparities

As shown in Table 4, the eastern region exhibited the largest within-region disparity, which increased slightly despite fluctuations. This finding indicates pronounced heterogeneity within China's most developed region. Leading cities, supported by stronger capital accumulation, technological capacity, and industrial agglomeration, established relatively advanced cold-chain systems at an earlier stage. In contrast, agricultural counties and smaller cities generally faced greater constraints in industrial scale and fiscal capacity, resulting in comparatively weaker infrastructure and widening internal disparities.

Within-region disparities in the central and western regions were lower than those in the eastern region but generally increased over the study period, also with some fluctuations. Both regions remained in a process of catching up with the eastern region. Initial central government investment and coordinated policy support may have promoted relatively balanced infrastructure development across provinces. However, as agricultural production became more commercialized and interregional distribution expanded, differences in the allocation of cold-chain hubs and related resources may have contributed to increasing internal disparities.

The northeastern region exhibited the smallest within-region disparity in 2024. Its Gini coefficient declined substantially from 0.242 in 2018 to 0.141 in 2024, despite annual fluctuations. This indicates that the development of agricultural product cold-chain logistics became progressively more balanced across provinces within the northeastern region.

4.3 Between-Region Disparities

Table 4 also reports the between-region Gini coefficients for 2018-2024. The average coefficients, in descending order, were eastern-northeastern (0.408), eastern-western (0.377), central-northeastern (0.287), central-western (0.252), eastern-central (0.249), and western-northeastern (0.206). Thus, the largest disparity occurred between the eastern and northeastern regions, followed by that between the eastern and western regions, whereas the western–northeastern pair exhibited the smallest disparity. The pronounced differences between the eastern and other regions are likely associated with disparities in economic development, policy and regulatory support[16], enterprise concentration, and cold-chain infrastructure.

The central region occupied an intermediate position among the four regions, with its average pairwise Gini coefficients relative to the eastern, western, and northeastern regions all remaining at approximately 0.25. Although these disparities were still substantial, they were considerably smaller than the eastern-northeastern gap. The relatively stronger economic performance associated with the Rise of Central China Strategy has provided a favorable foundation for the development of agricultural product cold-chain logistics in the central region[21].

Table 4. Within-region and between-region disparities in agricultural product cold-chain logistics development

Year	Within-region				Between-region					
	Eastern Region	Central Region	Western Region	Northeastern Region	Eastern Central Region	Eastern Western Region	Eastern Northeastern Region	Central Western Region	Central Northeastern Region	Western Northeastern Region
2018	0.261	0.149	0.160	0.242	0.245	0.364	0.411	0.253	0.300	0.226
2019	0.246	0.166	0.152	0.230	0.244	0.370	0.421	0.253	0.308	0.209
2020	0.254	0.183	0.081	0.238	0.262	0.362	0.424	0.225	0.302	0.178
2021	0.251	0.141	0.146	0.233	0.254	0.375	0.410	0.234	0.273	0.207
2022	0.243	0.157	0.149	0.225	0.246	0.386	0.404	0.255	0.277	0.204
2023	0.256	0.149	0.144	0.241	0.246	0.379	0.396	0.259	0.281	0.209
2024	0.254	0.153	0.240	0.141	0.249	0.402	0.390	0.284	0.267	0.207
Mean	0.252	0.157	0.153	0.221	0.249	0.377	0.408	0.252	0.287	0.206

5. Distributional Dynamics of Agricultural Product Cold-Chain Logistics Development

Dagum Gini coefficient decomposition quantifies the magnitude and sources of regional disparities but does not capture changes in the shape or location of the underlying distributions[43].

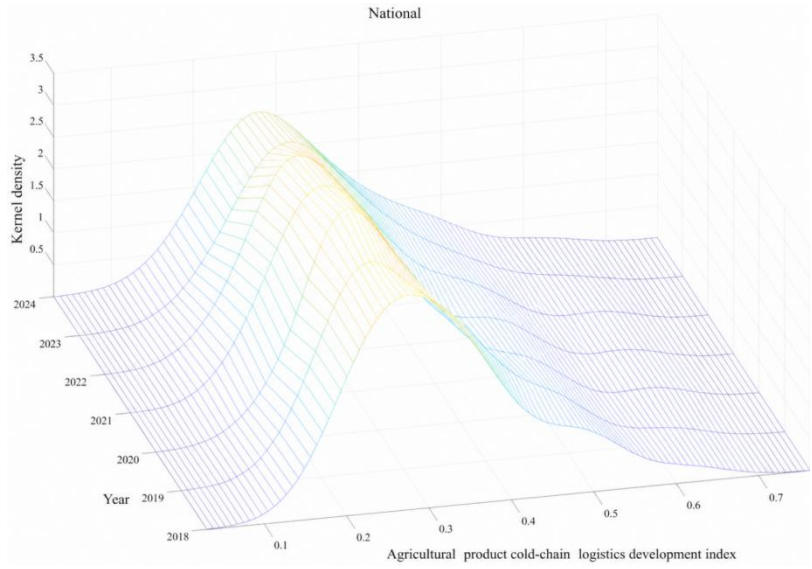
Kernel density estimation was therefore employed to examine the temporal evolution and spatial clustering of agricultural product cold-chain logistics development[44]. As a nonparametric method, kernel density estimation can characterize changes in distributional location, dispersion, and polarization without imposing a specific parametric form.

Figure 2 illustrates the distributional dynamics of agricultural product cold-chain logistics development at the national and regional levels from 2018 to 2024.

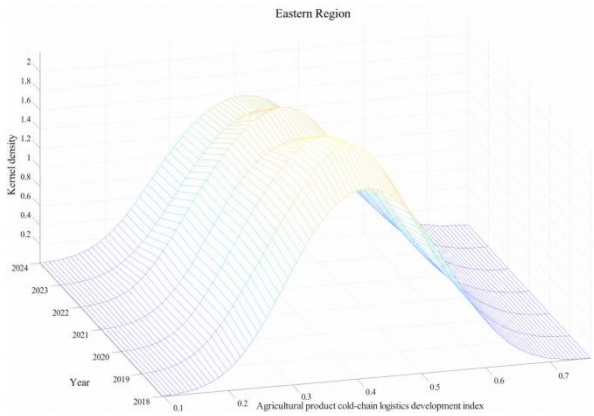
At the national level, the main density peak shifted markedly to the right, indicating an overall improvement in cold-chain logistics development across provinces. The density curves alternated between wider and flatter and narrower and more concentrated shapes, suggesting that the degree of regional dispersion fluctuated over time. The distribution remained predominantly unimodal between 2018 and 2020. From 2021 onward, a secondary peak gradually became more apparent, suggesting increasing differentiation and the emergence of distinct development clusters as the overall development level increased. Provinces in the eastern region, benefiting from stronger economic foundations and more developed infrastructure, formed a relatively high-level cluster. In contrast, some provinces in the central and western regions remained at medium or relatively low development levels, potentially reflecting weaker production capacity and interregional connectivity.

Regional distributions exhibited distinct evolutionary trajectories. In the eastern region, the main peak remained at a relatively high index level and shifted steadily to the right. The distribution evolved from a relatively simple unimodal pattern toward a multimodal pattern, while the peak height increased during 2022-2024. These features indicate that the eastern region maintained an early-mover advantage and sustained its leading position, with an increasing concentration of provinces at higher development levels. In the central region, the distribution initially shifted leftward during 2018-2019 before moving

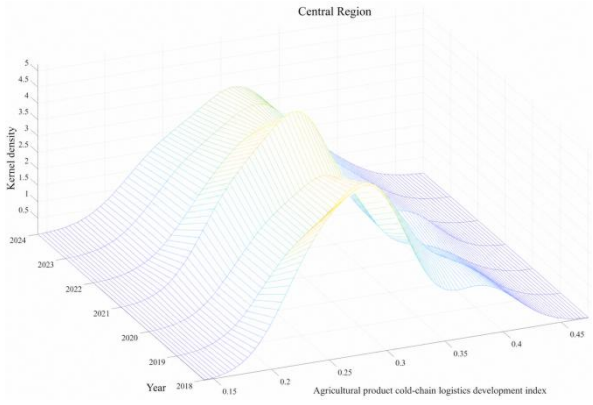
markedly rightward from 2020 to 2024. It also evolved from a unimodal to a multimodal pattern, accompanied by an increase in the main peak after 2022. These patterns suggest substantial improvement in the overall development level, together with increasing heterogeneity among provinces. The western region exhibited a rightward shift while remaining at relatively low index levels. Its peak gradually increased, while the distribution became narrower, indicating improvements in the overall development level and a gradual catch-up process under continued policy support. The northeastern region displayed a fluctuating trajectory, with the distribution shifting leftward, then rightward, and subsequently leftward again. Multimodal features became more pronounced in later years, while the main peak remained relatively low and the distribution wide. These characteristics indicate considerable heterogeneity and an unstable development trajectory, highlighting persistent challenges in regional coordination.



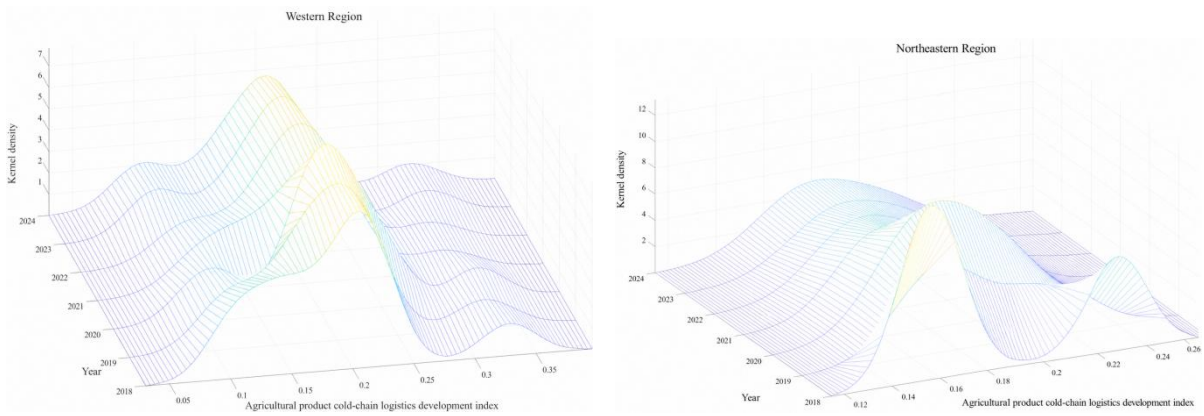
(a) National



(b) Eastern region



(c) Central region



(d) Western region (e) Northeastern region

Figure 2. Kernel density distributions of agricultural product cold-chain logistics development

6. Identification of Key Barriers

The high-obstacle indicators identified by the model correspond closely to well-documented bottlenecks in China's agricultural product cold-chain logistics system. Shortages of refrigerated vehicles (X2) and cold-storage capacity (X3) are directly related to gaps in first-mile cold-chain services at production origins. Postharvest losses of fruits, vegetables, and other fresh products remain substantially higher than those in developed economies, while origin-based storage, preservation, and precooling facilities remain insufficient. The study reports national postharvest losses of 18%–25% and annual losses exceeding CNY 100 billion associated with cold-chain discontinuities. The high obstacle degree of express-delivery volume (X18) reflects constraints on distribution channels for transporting agricultural products from rural production areas to external markets. In counties with underdeveloped commercial systems, high rural logistics and last-mile delivery costs constrain online sales and reduce private-sector incentives to invest in origin-based cold-chain facilities. Policy interventions since 2020 have repeatedly prioritized the development of origin-based cold-chain facilities and integrated cold-chain service networks. The consistency between these policy priorities and the high-obstacle indicators identified by the model provides contextual support for the model's diagnostic relevance. Nevertheless, this consistency should be interpreted as supportive evidence rather than causal evidence, as the descriptive design of the study does not establish causal relationships.

The preceding analysis demonstrates substantial regional disparities in the development of agricultural product cold-chain logistics. To identify the factors constraining further improvement, the obstacle degree model was applied to annual data for 2018-2024. Obstacle degrees were calculated at both the criterion and indicator levels for the infrastructure, technological capacity, development capacity, and economic synergy subsystems. The factors were then ranked according to their obstacle degrees to identify the most binding constraints and provide an empirical basis for targeted policy recommendations[45,46].

6.1 Criterion-Level Barriers

Table 5 reports the obstacle degrees of the four first-level criteria from 2018 to 2024. Based on their period averages, the criteria were ranked as infrastructure, economic synergy, development capacity, and technological capacity, with corresponding average obstacle degrees of 38.26%, 24.21%, 21.63%, and 14.93%, respectively.

Infrastructure remained the dominant barrier throughout the study period. Its obstacle degree was consistently high, increasing from 38.36% in 2018 to 39.13% in 2019, fluctuating between approximately 38% and 39% thereafter, and declining to 37.25% in 2023 and 37.30% in 2024. Its seven-year average of 38.26% was substantially higher than those of the other criteria, indicating that inadequate infrastructure supply was the primary constraint on cold-chain logistics development. Cold-chain infrastructure requires substantial investment across postharvest precooling, transportation, storage, and distribution. Each stage involved considerable expenditures on equipment, energy, and labor[47]. In regions with limited fiscal capacity or insufficient private investment, these high costs can slow facility development and constrain the expansion of cold-chain services.

Economic synergy represented the second-largest barrier but declined steadily over time. Its obstacle degree decreased from 25.09% in 2018 to 22.89% in 2024, with a period average of 24.21%. This downward trend may be associated with rising rural incomes under the Rural Revitalization Strategy and the expansion of two-way distribution networks connecting rural production areas with urban markets and manufactured goods with rural consumers. Nevertheless, persistent differences in agricultural returns and policy support across regions suggest that the economic linkages supporting cold-chain development remain uneven and could be further strengthened.

Development capacity remained relatively stable as a constraint. Its obstacle degree fluctuated between 21.22% and 21.94%, with a period average of 21.63%. This stability suggests that constraints on endogenous development changed little during the study period and that no substantial improvement in development capacity was achieved. Economic growth and consumption upgrading increased demand for food safety and quality[48], thereby strengthening the market foundation for cold-chain services. However, uneven regional development continued to limit overall progress. Improvements in management innovation, workforce development, and enterprise competitiveness remained insufficient to generate stronger endogenous momentum for sector development.

Technological capacity had the lowest obstacle degree and remained relatively stable. Its values ranged from 14.69% to 15.18%, with a period average of 14.93%. This suggests that technological progress has alleviated some constraints on cold-chain development. The wider adoption of refrigeration and preservation technologies has improved operational precision and efficiency, while greater standardization has reduced some barriers to technology adoption. However, a low obstacle degree should not be interpreted as evidence of a uniformly high technological level. Many origin-based cold-storage facilities and refrigerated vehicles still have limited digital, information, and

intelligent capabilities. These limitations constrain end-to-end temperature monitoring, product traceability, and real-time coordination between production areas and markets, thereby restricting the enabling effects of technological advancement.

Table 5. Criterion-level obstacle degrees (%)

Year	Infrastructure	Technological capacity	Development capacity	Economic synergy
2018	38.36	14.82	21.73	25.09
2019	39.13	14.69	21.52	24.66
2020	38.54	15.01	21.94	24.51
2021	38.68	15.05	21.85	24.42
2022	38.57	15.18	21.63	24.50
2023	37.25	14.78	21.22	23.41
2024	37.30	14.96	21.52	22.89
Mean	38.26	14.93	21.63	24.21

6.2 Indicator-Level Barriers

Table 6 reports the six highest-ranked indicator-level barriers and their obstacle degrees from 2018 to 2024. Express-delivery volume (X18), refrigerated vehicles (X2), and freight turnover (X5) consistently ranked among the top three, with X18 exhibiting the highest obstacle degree, followed by X2 and X5. These indicators therefore represented the most binding constraints on agricultural product cold-chain logistics development. The obstacle degree of X18 declined over the study period. The expansion of rural e-commerce networks and growing demand for outbound agricultural-product distribution increased express-delivery volumes and strengthened rural logistics connectivity, thereby partially alleviating last-mile constraints. Nevertheless, X18, X2, and X5 remained the three leading barriers in 2024.

The fourth through sixth positions alternated among gross regional product (X12), total power of agricultural machinery (X8), and cold-storage capacity (X3). In 2018, the ranking was X12, X8, and X3, whereas from 2019 to 2024, it changed to X8, X12, and X3. The ranking of X12 declined, while X8 moved above X12 and remained in fourth place after 2020. The obstacle degree of X8 increased substantially. This pattern may reflect persistent regional differences in agricultural mechanization associated with terrain, production conditions, and economic capacity. In areas with relatively low levels of agricultural mechanization, insufficient production efficiency and weaker equipment support may constrain the integration of agricultural production with cold-chain operations, thereby limiting the development of agricultural product cold-chain logistics.

By dimension, X2, X3, and X5 were all classified under infrastructure, with their combined obstacle degree reaching 23.61% in 2021. X18, representing economic synergy, recorded an obstacle degree of 19.61% in 2018. X8, belonging to technological capacity, reached 5.80% in 2024. X12, representing development capacity, recorded 5.52% in 2018. These results demonstrate that infrastructure constituted the greatest dimensional barrier, whereas X18 accounted for the largest share of the obstacle degree within the economic synergy dimension.

Table 6. Leading indicator-level obstacle factors and obstacle degrees (%)

Year	First-ranked factor	Second-ranked factor	Third-ranked factor	Fourth-ranked factor	Fifth-ranked factor	Sixth-ranked factor
2018	X18(19.61)	X2(9.46)	X5(8.46)	X12(5.52)	X8(5.47)	X3(5.20)
2019	X18(19.45)	X2(9.42)	X5(8.56)	X8(5.45)	X12(5.40)	X3(5.14)
2020	X18(19.41)	X2(9.44)	X5(8.68)	X8(5.52)	X12(5.42)	X3(5.12)
2021	X18(19.38)	X2(9.66)	X5(8.68)	X8(5.65)	X12(5.27)	X3(5.16)
2022	X18(19.63)	X2(9.70)	X5(8.73)	X8(5.70)	X12(5.22)	X3(5.07)
2023	X18(19.08)	X2(9.60)	X5(8.49)	X8(5.63)	X12(5.03)	X3(4.87)
2024	X18(18.38)	X2(9.74)	X5(8.51)	X8(5.80)	X12(4.99)	X3(4.81)
Mean	19.28	9.57	8.59	5.60	5.26	5.05

7. Conclusions and Policy Implications

7.1 Conclusions

This study constructed a multidimensional evaluation system for agricultural product cold-chain logistics based on infrastructure, technological capacity, development capacity, and economic synergy. The entropy-weighting method, Dagum Gini coefficient decomposition, kernel density estimation, and obstacle degree model were integrated to assess development levels, decompose regional disparities, characterize distributional dynamics, and identify binding barriers.

Four main conclusions emerge. First, the development level of agricultural product cold-chain logistics increased steadily from 2018 to 2024. The eastern region consistently recorded the highest development index, whereas the western region remained at the lowest level. Second, overall disparities declined despite some fluctuations, with between-region differences constituting the largest source of disparity. Third, the national kernel density distribution shifted rightward, indicating overall improvement. In the eastern region, the distribution also moved rightward and became increasingly concentrated at high levels. The central region exhibited growing differentiation, whereas the western region remained at a comparatively low level while retaining substantial internal disparities. In the northeastern region, the main density peak shifted repeatedly in both directions, indicating unstable and insufficiently coordinated development. Fourth, infrastructure constituted the principal barrier to further development. Although technological capacity exhibited the smallest obstacle degree, the limited depth of technology adoption continued to constrain its potential enabling effects.

7.2 Policy Implications

7.2.1 Advance Cold-Chain Modernization across Multiple Dimensions

Infrastructure policies should prioritize a more efficient spatial allocation of cold-chain facilities. Governments can increase support for cold-chain infrastructure and strategically locate cold-chain bases and consolidation centers according to production origins and product clusters. Fiscal investment and incentives for private capital should be directed particularly toward the less-developed western and northeastern areas. Dedicated construction funds and regional cold-chain hubs can help expand full-chain service capacity and improve operating efficiency. Technology policies should promote the

integration of logistics information platforms, facilitate data sharing, and enhance intelligent operations. Advanced digital technologies, such as the Internet of Things and blockchain, can facilitate end-to-end monitoring and deeper integration across cold-chain stages. Policies aimed at strengthening development capacity should also enhance managerial and technical training and establish origin-based cold-chain workforce systems aligned with market demand. Universities can offer relevant courses, while university-enterprise partnerships can strengthen practical and problem-solving capabilities. To improve economic synergy, rural e-commerce should be leveraged to strengthen two-way distribution between outbound agricultural products and inbound consumer goods. Deeper integration between cold-chain logistics and agricultural production can further enhance coordination across production, distribution, and consumption.

7.2.2 Establish Region-Specific Development Mechanisms

The eastern region should capitalize on its strong market demand, well-established infrastructure, and advanced technology adoption to accelerate digital and intelligent upgrading. The development of cross-border cold chains, premium fresh-food supply chains, and shared urban distribution systems can further reinforce its role as a national hub for innovation. The central region should leverage its transportation advantages and abundant agricultural resources to strengthen backbone logistics networks and connections between production areas and consumer markets. Developing regional consolidation and distribution centers can further facilitate interregional flows of agricultural products. The western and northeastern regions should leverage rural development policies to improve the efficiency of cold-chain resource allocation. Priority should be given to origin-based facilities and cold-chain supply chains for distinctive local products, thereby enhancing agricultural value added and increasing farmers' incomes.

7.2.3 Build a Multi-Stakeholder Ecosystem for Sustainable Development

Government agencies should strengthen strategic planning and policy coordination, improve supporting measures related to land, finance, and taxation, and reinforce oversight of cold-chain logistics enterprises through effective regulatory and inspection mechanisms. Firms should accelerate technological and business-model innovation, adopt green equipment and technologies, and develop more integrated, efficient, and low-carbon logistics services. Research institutions and universities should strengthen collaboration in training interdisciplinary professionals for modern agricultural product cold-chain logistics. Greater coordination among industry, universities, research institutions, and users can help address shared technological bottlenecks and support the high-quality development of agricultural product cold-chain logistics.

References

[1]Zhai XL, Nie YB, Yan TY. Current status, problems, and countermeasures of agricultural product circulation in China under rural revitalization: A comprehensive assessment based on whole-process tracking data for four categories of agricultural products. Rural Economy 2025;(4):121–128. [in Chinese]

[2]Cheng H, Zhou X, Sun J, et al. Assessing the efficacy of agricultural cold chain facility expansion in China. J Stored Prod Res 2024;105:102244. https://doi.org/10.1016/j.jspr.2024.102244.

[3]Zhang XL. Mechanisms and pathways of digitally empowered innovation in rural circulation under the rural revitalization strategy. Contemporary Economic Management 2024;46(4):47–53. [in Chinese]

[4]Liu Y. Construction of an evaluation system for the safe operation of cold-chain logistics. China Shipping Gazette 2023;(28):68–70. [in Chinese]

[5]Zhang XC, Ding YZ. The origin paradox of cold-chain logistics for fresh agricultural products and countermeasures. Agricultural Economics and Management 2022;(4):71–80. [in Chinese]

[6]Xue M, Jia Y. Development strategies for cold-chain logistics of fresh agricultural products. Chinese Journal of Agricultural Resources and Regional Planning 2022;43(12):56, 74. [in Chinese]

[7]Zhu PF. The impact of modern rural logistics on rural residents' consumption level and structure. Social Sciences in Guangdong 2021;(3):44–53. [in Chinese]

[8]Han J, Sun C, Ji Z, et al. Smart cold chain logistics for fresh agricultural products: Key technologies, challenges, and future trends. Trends Food Sci Technol 2026;167:105421. https://doi.org/10.1016/j.tifs.2025.105421.

[9]Liu RY. Current situation and policy recommendations for cold-chain logistics at agricultural production origins. Jiangsu Agricultural Sciences 2020;48(22):311–316. [in Chinese]

[10]Zhang RZ, Liu QY, Liu B, et al. Construction models for origin-based storage, preservation, and cold-chain facilities for agricultural products: A study of fruits and vegetables. Journal of Chinese Agricultural Mechanization 2024;45(12):127–132. [in Chinese]

[11]Zhang M, Li J, Feng W, et al. Review and prospects of the development of agricultural cold-chain logistics in China. Storage and Process 2025;25(11):129–136. [in Chinese]

[12]Zhang L. The impact of cold-chain logistics development on regional agricultural product price stability: Evidence from provinces along the Yangtze River Economic Belt. Journal of Commercial Economics 2025;(2):99–102. [in Chinese]

[13]Li XR, Zhang X. Measurement and determinants of coordination between agricultural e-commerce logistics and the rural economy. Journal of Yunnan University of Finance and Economics 2025;41(11):95–110. [in Chinese]

[14]Zhou L. Measurement and improvement pathways of the digitalization level of the agricultural cold-chain logistics industry in Sichuan Province. Technology and Market 2024;31(12):150–155. [in Chinese]

[15]Tao FM, Zhu R, Yuan BF, et al. Configurational analysis of factors influencing demand for agricultural cold-chain logistics: Based on the TOE framework. Chinese Journal of Agricultural Resources and Regional Planning 2025;46(8):217–227. [in Chinese]

[16]Li SC, Ye J. Demand analysis and forecasting of agricultural cold-chain logistics based on a grey regression model. Journal of Highway and Transportation Research and Development 2022;39(5):166–174. [in Chinese]

[17]Chen Y, Puah CH, Arip MA. Forecasting and spatial distribution analysis of cold chain logistics demand for fresh agricultural products in China. Environ Dev Sustain 2025:1–27. https://doi.org/10.1007/s10668-025-06969-9.

[18]Li YH, Wu LQ. The spatiotemporal evolution characteristics of the efficiency of agricultural products cold chain logistics in China. Journal of Jishou University (Social Sciences Edition) 2026;47(5):147–156. https://doi.org/10.13438/j.cnki.jdxb.2026.05.014. [in Chinese]

[19]Li FZ, Peng H. Evaluation and spatiotemporal evolution of agricultural product circulation efficiency in China. Journal of Commercial Economics 2024;(16):89–93. [in Chinese]

[20]Guo MD, Li H. Evaluation of agricultural cold-chain logistics development: Evidence from 12 representative provinces and municipalities. Journal of Commercial Economics 2019;(1):125–127. [in Chinese]

[21]Zhou H, Peng W, Zou X. Green development level and regional disparities of cold-chain logistics for fresh agricultural products. Journal of Beijing Jiaotong University (Social Sciences Edition) 2025;24(2):62–73. [in Chinese]

[22]Wang LK, Qi CJ, Tang LY, et al. Evaluation and spatiotemporal analysis of agricultural product circulation efficiency under the unified national market: A three-dimensional perspective based on modern circulation theory. Issues in Agricultural Economy 2023;(8):127–143. [in Chinese]

[23]Ren XH, An WB, He HY, et al. Evaluation and determinants of logistics efficiency: Evidence from the Chengdu–Chongqing Economic Circle. Scientific and Technological Management of Land and Resources 2024;41(6):97–115. [in Chinese]

[24]Zhang MJ, Yang JQ, Zhang YJ, et al. Grey relational analysis of factors influencing the development of fresh agricultural product cold-chain logistics based on the entropy-weight method. Journal of Lanzhou University of Arts and Science (Social Sciences) 2024;40(4):66–71. [in Chinese]

[25]Yang Y. Measurement and drivers of agricultural product logistics efficiency in China: Evidence from super-efficiency and Tobit models. Journal of Commercial Economics 2022;(24):113–116. [in Chinese]

[26]Bresolin CS, Schneider PS, Rego R, Bandarra Filho EP. Brazilian cold chain panorama. Int J Refrig 2018;90:145–155. https://doi.org/10.1016/j.ijrefrig.2018.04.002.

[27]Raut RD, Gardas BB, Narwane VS, Narkhede BE. Improvement in the food losses in fruits and vegetable supply chain: A perspective of cold third-party logistics approach. Oper Res Perspect 2019;6:100117. https://doi.org/10.1016/j.orp.2019.100117.

[28]Fan X, Zhang Y, Xue J, et al. Exploring the path to the sustainable development of cold chain logistics for fresh agricultural products in China. Environ Impact Assess Rev 2024;108:107610. https://doi.org/10.1016/j.eiar.2024.107610.

[29]Zhang Y, Fan X, Cao Y, et al. Exploring symbiosis: Innovatively unveiling the interplay between the cold chain logistics of fresh agricultural products and the ecological environment. Agriculture 2024;14(4):609. https://doi.org/10.3390/agriculture14040609.

[30]Rossi T, Pozzi R, Pirovano G, Cigolini R, Pero M. A new logistics model for increasing economic sustainability of perishable food supply chains through intermodal transportation. Int J Logist Res Appl 2021;24(4):346–363. https://doi.org/10.1080/13675567.2020.1758047.

[31]Li MJ, Wang J. Demand forecasting for aquatic product cold-chain logistics based on an RBF neural network. Chinese Journal of Agricultural Resources and Regional Planning 2020;41(6):100–109. [in Chinese]

[32]Zhang QJ. The impact of agricultural logistics on the consumption structure of agricultural products under rural revitalization. Journal of Commercial Economics 2025;(21):78–83. [in Chinese]

[33]Wang XP, Yan F. Influencing factors and forecasting model for agricultural cold-chain logistics demand in the Beijing–Tianjin–Hebei region. Fujian Journal of Agricultural Sciences 2018;33(8):870–878. https://doi.org/10.19303/j.issn.1008-0384.2018.08.017. [in Chinese]

[34]Collison M, Collison T, Myroniuk I, Boyko N, Pellegrini G. Transformation trends in food logistics for short food supply chains—What is new? Stud Agric Econ 2019;121(2):102–110. https://doi.org/10.7896/j.1909.

[35]Dong F. The impact of economic openness on standard of living and income inequality in eight countries. Emerg Mark Rev 2014;21:234–264. https://doi.org/10.1016/j.ememar.2014.09.005.

[36]Wang Z, Asghar MM, Zaidi SAH, Nawaz K, Wang B, Zhao W, et al. The dynamic relationship between economic growth and life expectancy: Contradictory role of energy consumption and financial development in Pakistan. Struct Change Econ Dyn 2020;53:257–266. https://doi.org/10.1016/j.strueco.2020.03.004.

[37]Zhang L. Spatial differences in the efficiency of fresh agricultural product cold-chain logistics in China based on a three-stage DEA model. Supply Chain Management 2025;6(8):77–89. [in Chinese]

[38]Shannon CE. A mathematical theory of communication. Bell Syst Tech J 1948;27(3):379–423. https://doi.org/10.1002/j.1538-7305.1948.tb01338.x.

[39]Li QX, Deng Q, Huang YM. Evaluation and interprovincial comparison of high-quality development of the logistics industry in Henan Province: Based on grey relational analysis, entropy weighting, and TOPSIS. Innovation Science and Technology 2020;20(2):72–83. https://doi.org/10.19345/j.cxkj.1671-0037.2020.02.008. [in Chinese]

[40]Dagum C. A new approach to the decomposition of the Gini income inequality ratio. Empir Econ 1997;22(4):515–531. https://doi.org/10.1007/BF01205777.

[41]Zhang Y. Modernization of the green agricultural industrial chain: Measurement, regional disparities, and influencing factors. Technoeconomics and Management Research 2025;(9):1–7. [in Chinese]

[42]Deng MJ, Li YH, Wu LQ, et al. Green development efficiency of cold-chain logistics based on the super-efficiency SBM–GML index model. Journal of Central South University of Forestry and Technology 2024;44(4):189–200. [in Chinese]

[43]Zhang ZQ, Zhang T, Feng DF. Regional differences, dynamic evolution, and convergence of carbon emission intensity in China. Journal of Quantitative and Technological Economics 2022;39(4):67–87. [in Chinese]

[44]Li J, Wang QM. Measurement and spatiotemporal evolution of digital economy development. Statistics and Decision 2022;38(24):73–78. [in Chinese]

[45]Wang R, Zhong YN, Hu XL. Spatiotemporal pattern and obstacle-factor identification of high-quality agricultural insurance development in China. Economic Geography 2025;45(10):192–203. [in Chinese]

[46]Zhu KL, Jin HT. Spatiotemporal pattern and obstacle-factor analysis of agricultural product supply-chain resilience in the Yellow River Basin. Chinese Journal of Agricultural Resources and Regional Planning 2026:1–16. Online ahead of print. https://link.cnki.net/urlid/11.3513.s.20260428.1121.005. [in Chinese]

[47]Liu MJ. Pathways for the high-quality development of agricultural cold-chain logistics. Business Economy 2025;(11):70–72, 81. [in Chinese]

[48]James SJ, James C. The food cold-chain and climate change. Food Res Int 2010;43(7):1944–1956. https://doi.org/10.1016/j.foodres.2010.02.001.

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