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Exploring the Affect Mechanism of Cold-chain Logistics on Agricultural Resources Exploitation

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Abstract
Mineral resources are widely used in the agricultural field that can be used in the production of fertilizer, soil improvement, feed additives, and the carrier of pesticides and herbicides, etc., which plays a role in agricultural development. As a booster of agricultural development, cold-chain logistics holds a pivotal role in promoting agricultural resources exploitation. However, empirical studies focusing on the linkage development of cold-chain logistics and agriculture resources exploitation remain exceptionally sparse. Thus, in this study, a spatial econometric model was proposed to investigate the affect mechanism of cold-chain logistics on agricultural resources exploitation. Statistical and spatial autocorrelation analyses were employed to analyze the spatial and temporal distribution characteristics and the spatial correlation between cold-chain logistics and agriculture in China. In addition, recommendations for the coordinated development of agriculture and logistics were proposed. Results demonstrate that the spatial distribution pattern between agriculture and cold-chain logistics in China is "Henan and Shandong as the center + high in southeast and low in northwest." and "high in the southeast and low in the northwest." In addition, cold-chain logistics of the province and adjacent provinces affect agriculture resources exploitation simultaneously, and cold-chain logistics has a positive driving effect on agricultural resources exploitation. However, regional differences exist in the contribution of each element to agricultural resources exploitation. This study provides a reference value for the coordinated development of agriculture and cold-chain logistics.

Keywords
Cold-chain logistics, Agricultural resources exploitation, Spatial correlation, Driving effect, Spatial econometric model.

Introduction

Cold-chain logistics is an important basis for supporting agricultural industrialization and large-scale development, promoting agricultural transformation and farmers' income increase, and facilitating agricultural resources exploitation. It is also instrumental in meeting the unique and quality consumption needs of urban and rural residents, thereby promoting consumption upgrading and cultivating new growth points. Therefore, exploring the relationship between cold-chain logistics and agricultural resources exploitation is of great practical significance. Moreover, the high-quality coordinated development of agriculture and cold-chain logistics must be promoted, and strategies of expanding domestic demand in China should be implemented.

At present, China is facing various problems such as low prices of agricultural commodities, high production costs, and difficulties in circulation. The excessive consumption of agricultural resources and the increasing pressure of ecological environment hinder the sustainable development of agriculture. In recent years, China's cold-chain logistics has developed rapidly, and the market scale has grown steadily. Despite its growth, China's cold-chain logistics industry, which had a late start, is yet to establish a complete and independent system. It still faces issues such as low cold-chain rate, low capacity of residential cold storage, uneven distribution, low industry concentration, and low profits.

On this basis, numerous scholars all over the world have conducted studies on the high-quality development path of agricultural resources exploitation or cold-chain logistics(Wang et al., 2023; Tao et al., 2023; Hu 2023). However, empirical studies focusing on the interconnection between the two are scarce. Therefore, the affect mechanism between cold-chain logistics and agricultural resources exploitation must be determined. Moreover, the driving effect of cold-chain logistics on agricultural resources exploitation should be analyzed, and recommendations should be proposed for the coordinated development of agriculture and cold-chain logistics.

On the basis of the above analysis, this study reveals the affect mechanism between cold-chain logistics and agricultural resources exploitation. It also analyzes the spatial and temporal distribution characteristics and the spatial correlation between cold-chain logistics and agriculture in China. In addition, a spatial metrology model is proposed to explore the driving effect of cold-chain logistics on agricultural resources exploitation and improve the applicable scenarios and micro-explanations of relevant studies. Finally, this study proposes recommendations for the collaborative development of agriculture and cold-chain logistics according to the results of model regression.

At present, scholars all over the world are accustomed to selecting logistics and economy as the main body of research, and they have conducted numerous studies on the linkage development relationship between the two. Duan studied the effect of logistics on economic development and its affect mechanism and proposed recommendations(Duan 2023). Liu revealed the affect mechanism between logistics and economic development through literature search(Liu 2020). Zhang observed the affect mechanism of logistics on economic growth and proposed targeted recommendations(Zhang 2022). Guo et al. made a qualitative analysis of the relationship between port logistics and economic growth and expounded its affect mechanism(Guo et al. 2022). Aydin et al. theoretically analyzed the effect of logistics on regional economic development(Aydin et al. 2012). Tao analyzed the promotion effect of logistics on regional economic growth(Tao 2023). However, all these studies lacked empirical analysis or data proof.

Xu et al. used panel VAR model and impulse response function to confirm that the development of logistics industry has a significantly positive promoting effect on regional economic growth(Xu et al. 2023). Le demonstrated that logistics has a relatively significant driving effect on economic growth using panel data(Le 2022). Vittorio et al. proved that logistics plays a certain role in promoting economic growth by static panel model(Vittorio et al. 2017). Reza studied the relationship between logistics and economic development based on co-integration test and Granger causality test(Reza 2013). Pan empirically analyzed the effect of China's logistics industry on economic growt(Pan 2022). Coto-Millan et al. collected relevant data from countries worldwide between 2007 and 2012 and estimated the contribution of logistics performance to world economic growth using Mankiw's model(Coto-Millan et al. 2013). Zhao demonstrated that the logistics industry in Shanxi Province, China has a positive pulling effect on economic development utilizing multiple linear models(Zhao 2023). Avelar et al. used structural equation to confirm that the third party logistics has a great role in improving the economic effect of enterprises(Avelar et al. 2022). However, the above studies did not reveal the affect mechanism between the variables.

Chakamera et al. demonstrated a long-term stable relationship between logistics and economic growth in 32 African countries using dynamic panel mode(Chakamera et al. 2020). Sharapiyeva et al. studied the effects of logistics efficiency and infrastructure on the economy with data from 37 landlocked countries(Sharapiyeva et al. 2019). Jin et al. established an enhanced Sallow model to explore the influence of port logistics on regional economy(Jin et al. 2016). Haque et al. proposed an SEM model to explore the role of logistics performance on economic growth(Haque et al. 2018). Wen et al. made an empirical analysis of the relationship between logistics and regional economic growth utilizing a fixed effect mode(Wen et al. 2023). Ding et al. observed the contribution of logistics efficiency to economic growt(Ding et al. 2023). Wang et al. established a variable intercept model to explore the influence of regional logistics capability on economic development(Wang et al. 2021). However, these studies did not investigate the spatial correlation between logistics and economic development.

In sum, the above studies either only performed a simple qualitative analysis of the relationship between logistics and economic growth. However, they did not deeply reveal the affect mechanism between the two nor considered the influence of spatial correlation when modeling. In the present study, the affect mechanism between cold-chain logistics and agricultural resources exploitation was revealed. The statistical and spatial autocorrelation analyses were performed to analyze the spatial and temporal distribution characteristics of cold chain logistics and agriculture in China from 1999 to 2021 referencing to Cui et al. and Náñez et al. (Cui et al., 2022; Náñez et al., 2023). In addition, recommendations for the coordinated development of agriculture and logistics were proposed according to the regression results.

The remainder of this study is organized as follows. Section 2 introduces the methods of this study and establishes a spatial econometric model of the affect mechanism of cold-chain logistics on agricultural resources exploitation. Section 3 analyzes the spatial and temporal distribution characteristics and the spatial correlation between cold-chain logistics and agriculture. The driving effect of cold-chain logistics on agricultural resources exploitation by spatial metrology model is also observed in this section. Section 4 summarizes the conclusions and offers recommendations according to the model regression results.

Material and Methods

Affect mechanism analysis between cold-chain logistics and agricultural resources exploitation

Agricultural resources mainly include economic resources and mineral resources such as nitrogen, phosphorus, potassium and urea. The affect mechanism relationship between cold-chain logistics and agricultural resources exploitation can be analyzed from two aspects. First, agricultural resources exploitation will drive regional economy, expand social consumption demand, and encourage investment in cold-chain logistics. Consequently, a beneficial cycle will be created, wherein agricultural resources exploitation positively affects the growth of cargo turnover, network mileage, and added benefits of cold-chain logistics. The affect mechanism is as follows: agricultural resources exploitation→regional economic growth→increase of social consumption demand→increase of social cold-chain logistics demand→resources exploitation of cold-chain logistics and agricultural resources exploitation→regional economic growth→increase of investment in cold-chain logistics→ development of cold-chain logistics. Second, the increase in the demand for social cold-chain logistics will result in the lack of supply capacity of social cold-chain logistics. In the short term, poor transportation and a backlog of agricultural commodities can limit the potential for agricultural resources exploitation. However, the lack of supply capacity of cold-chain logistics will result in the rise of freight prices, attract social capital flow to the construction of cold-chain logistics infrastructure, and gradually improve the supply capacity of social cold-chain logistics. Consequently, a relative balance will exist between the demand of cold-chain logistics and the supply capacity of cold-chain logistics. In this process, the gradually reduced freight prices will bridge the potential gap of freight needed for agricultural resources exploitation, promote agricultural growth, and form a cyclic process of mutual promotion between cold-chain logistics and agricultural resources exploitation. Therefore, the increase of cargo turnover and network mileage of cold-chain logistics will promote agricultural resources exploitation. The affect mechanism is as follows: increase of cargo turnover and network mileage of cold-chain logistics→improvement of the supply capacity of cold-chain logistics→agricultural resources exploitation. The added benefit of cold-chain logistics is the monetary embodiment of cold-chain logistics to provide the results for society through logistics activities in a certain time period. It is the core index reflecting the development of cold-chain logistics, and the increase of this index will directly stimulate agricultural resources exploitation. The affect mechanism between cold-chain logistics and agricultural resources exploitation is shown in Figure 1.

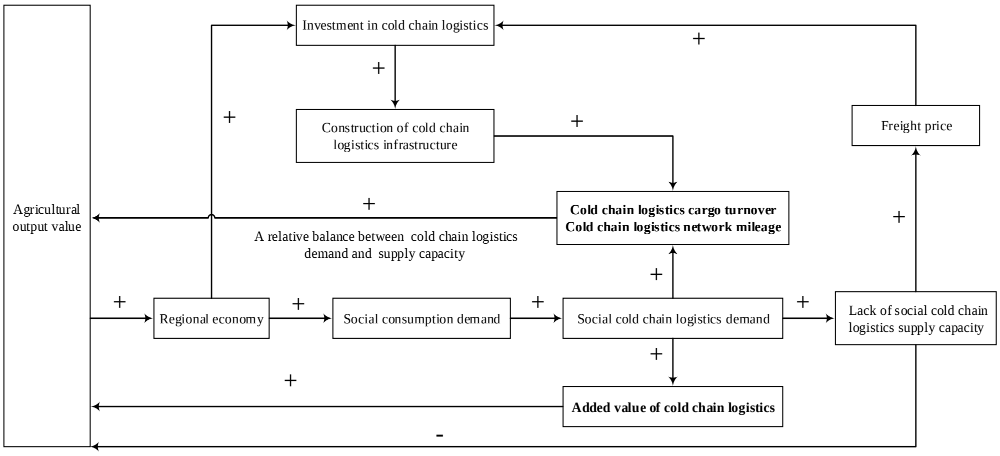

Fig. 1. Affect mechanism between cold-chain logistics and agricultural resources exploitation

Global spatial autocorrelation analysis

The global spatial autocorrelation analysis can reveal the significance of spatial correlation and difference of the whole region. It can also determine whether the attribute values of each spatial unit have agglomeration characteristics. The global Moran's index is commonly employed to measure global spatial autocorrelation, and its value is between −1 and 1. A global Moran's index that is greater than 0 indicates that all units present a state of agglomeration; if it is less than zero, all units are discrete; and if it is equal to zero, the units are random. The calculation formula of the global Moran's index I is as follows:

$$I = \frac{N\sum_{i=1}^{N}\sum_{j=1, j\neq i}^{N} W_{ij} Z_i V_j}{(N-1)\sum_{i=1}^{N}\sum_{j=1, j\neq i}^{N} W_{ij}} \qquad (1)$$

where N is the number of selected provinces, Z_i is the standardized value of the added value of cold-chain logistics or agricultural output value in province i, V_j is the standardized value of the added value of cold-chain logistics or agricultural output value in province j, and W_{ij} is the spatial weight matrix of geographical distance in the studied region.

Local spatial autocorrelation analysis

Local spatial autocorrelation analyses can further show the degree of correlation between one attribute of each spatial unit and another attribute of other units in the whole region. Such analyses can also detect spatial differences and determine the spatial hotspots or high-incidence areas of spatial unit attribute values. The local Moran's index is commonly employed to measure local autocorrelation. The calculation formula of the local Moran's index I_i is as follows:

$$I_i = Z_i' \sum_{j=1}^{N} W_{ij} V_j' \qquad (2)$$

where N is the number of selected provinces, Z_i' is the standardized value of added benefit of cold-chain logistics in province i, V_j' is the standardized value of agricultural output value in province j, and W_{ij} is the spatial weight matrix of the geographical distance in the studied region.

Construction of the driving effect model

The added benefit, network mileage, and cargo turnover of cold-chain logistics in 31 provinces of China from 1999 to 2021 are selected as independent variables, and agricultural output value is taken as the dependent variable. Hong Kong, Macao, and Taiwan are not included in the analysis due to lack of data. Referring to the SEM model by Zeini et al(Zeini et al. 2023), the spatial econometric model of the driving effect of cold-chain logistics on agricultural resources exploitation in this study is established, as shown as follows:

$$LnY_{it} = \rho W_{ij} LnY_{it} + \beta_{1i} LnX_{1it} + \beta_{2i} LnX_{2it} + \beta_{3i} LnX_{3it} + \varepsilon_{it} + \chi_{1i} W_{ij} LnX_{1it} + \chi_{2i} W_{ij} LnX_{2it} + \chi_{3i} W_{ij} LnX_{3it} + \gamma_i + \delta_t \quad (3)$$

where i indicates the province, t denotes the year, Y_{it} is the agricultural output value of province i in year t, X_{1it} is the added value of cold-chain logistics of province i in year t, X_{2it} is the cargo turnover of cold-chain logistics of province i in year t, X_{3it} is the network mileage of cold-chain logistics of province i in year t, β_{1i} is the elasticity coefficient of the added value of cold-chain logistics of province i, β_{2i} is the elasticity coefficient of the cargo turnover of cold-chain logistics of province i, β_{3i} is the elasticity coefficient of the network mileage of cold-chain logistics of province i, W_{ij} is the spatial weight matrix of geographical distance in the studied area, ρ is the spatial correlation coefficient whose value is between −1 and 1, $W_{ij} LnY_{it}$ is the effect of agricultural output value of other provinces on the agricultural output value of province i in year t, $W_{ij} LnX_{1it}$ is the spillover effect of the added benefit of cold-chain logistics of other provinces on province i in year t, $W_{ij} LnX_{2it}$ is the spillover effect of the cargo turnover of cold-chain logistics of other provinces on province i in year t, $W_{ij} LnX_{3it}$ is the spillover effect of the network mileage of cold-chain logistics of other provinces on province i in year t, χ_{1i} is the spillover coefficient of the added value of cold-chain logistics of other provinces on province i in year t, χ_{2i} is the spillover coefficient of the cargo turnover of cold-chain logistics of other provinces on province i in year t, χ_{3i} is the spillover coefficient of the network mileage of cold-chain logistics of other provinces on province i in year t, γ_i is the individual fixed effect, δ_t is the time fixed effect, and ε_{it} is the random disturbance term.

Stationary analysis

The unit root test of the data should be initially performed prior to the regression analysis of time-series cross-sectional data(Sébastien and Shuping, 2021; Hepsag 2021). Common units root test methods include the same root test method (e.g., LLC and Breitung t-stat) and the different root test method (e.g., IPS, ADF–Fisher chi-square, and PP–Fisher chi-square). When conducting the unit root test, the data should be tested in sequence in three cases: including the individual intercept term and the time trend term, only the individual intercept term, and none. When all test forms do not reject the null hypothesis, the unit root process exists. Otherwise, if the null hypothesis is rejected in only one case, then the data are stable.

Equilibrium relationship analysis

Time-series cross-sectional data often exhibit consistent trend components. Analyzing time-series cross-sectional data with consistent trend components can also yield a genuine and reliable illusion. To prevent spurious regression, co-integration test based on unit root test must be performed to judge whether a long-term and stable co-integration relationship exists between variables(Pascalau et al. 2022; Martins and Rodrigues, 2021). Common co-integration test methods include Johansen–Fisher, Kao, and Pedroni tests.

Statistical analysis

Statistical analysis is often conducted to understand and reveal the relationship, change rule, and development trend between variables using mathematical statistics and analysis of the quantitative relationship of the scale, speed, scope, and degree of the research object. In this study, the level of agriculture and cold-chain logistics was visualized, and the spatial and temporal distribution characteristics of agriculture and cold-chain logistics were visually analyzed based on the relevant data.

Results and Recommendations

Spatial and temporal distribution characteristics of agricultural resources and cold-chain logistics

The spatial and temporal distribution characteristics of agricultural resources and cold-chain logistics were statistically analyzed. The sum of agricultural mineral resources and economic resources can be expressed by agricultural output value, so the added benefit of cold-chain logistics and agricultural output value in 1999 and 2021 were selected to measure the level of cold-chain logistics and agricultural resources based on the spatial analysis scale of 31 provinces in China. The data were derived from the “China Statistical Yearbook,” and “China Logistics Yearbook.”

Figure 2 shows that the main production areas of agricultural output value in 1999 are Shandong, Henan, and Jiangsu, whereas the secondary production areas are Sichuan, Hubei, Hunan, Guangdong, Fujian, Zhejiang, Anhui, Hebei, and Liaoning. The spatial distribution characteristics are the combination of circular and sheet distributions, and the overall pattern of “three main and nine secondary” is presented. Figure 3 shows that the main production areas of agricultural output value in 2021 are Shandong, Henan, and Sichuan, whereas the secondary production areas are Yunnan, Guangxi, Guangdong, Hubei, Hunan, Anhui, Jiangsu, Hebei, and Heilongjiang. The spatial distribution characteristics still present the pattern of “three main and nine secondary.”

Overall, the provinces with higher agricultural output value in China are mainly distributed in the eastern and central regions and western provinces such as Sichuan and Yunnan. In addition, the provinces with lower agricultural output value are mainly distributed in the northwest region, showing a spatial distribution pattern of “Henan and Shandong as the centre + high in the southeast and low in the northwest.” The characteristics of agricultural output value present a pattern of “high in the southeast and low in the northwest” in 1999 are more significant than those in 2021. The specific performance is that the number of provinces in the fourth and fifth echelons of the northwest region in 1999 is higher than that in 2021.

Figures 4 and 5 shows that the decentralized spatial distribution characteristics of the value added of cold-chain logistics in China gradually weakened, whereas the regional aggregation characteristics gradually strengthened. The specific performance is that eight provinces are in the first and second echelons of the added benefit of cold-chain logistics in 1999, showing a zonal distribution. In 2021, 13 provinces are in the first and second echelons of the added benefit of cold-chain logistics, which are characterized by the combination of circular and sheet distributions, indicating that the regional agglomeration characteristics are obviously enhanced.

Overall, the added benefit of cold-chain logistics in China presents a spatial distribution pattern of “high in the southeast and low in the northwest,” which is consistent with the spatial distribution pattern of agricultural output value. This spatial distribution pattern of the added benefit of cold-chain logistics in 2021 is higher than that in 2021. The specific performance is that the number of provinces in the second and third echelons of the southeastern region in 2021 is higher than that in 1999.

Figures 2 and 4 show that the spatial distribution pattern of “high in the southeast and low in the northwest” of China’s agricultural output value is more significant compared with the spatial distribution pattern of “high in the southeast and low in the northwest” of the added benefit of cold-chain logistics in 1999. Figures 3 and 5 show that the spatial distribution pattern of agricultural output value and the added benefit of cold-chain logistics is the same in 2021. The added value of cold-chain logistics and agricultural output value are in the same echelon without Shanghai, Zhejiang, Guangdong, Sichuan, and other provinces, showing the characteristics of “low added value of cold-chain logistics–low agricultural output value” and “high added value of cold-chain logistics–high agricultural output value.”

The reason why agricultural output value in China presents a spatial distribution pattern of “Henan and Shandong as the centre + high in southeast and low in northwest” is that the northwest region has scarce precipitation and dry climate, which is not suitable for agricultural planting. In comparison with the northwest region, the southeast region is more suitable for agricultural resources exploitation because of its abundant land resources, suitable climate, and less natural disasters. Especially, Henan and Shandong, characterized by a warm temperate monsoon climate and rich agricultural resources, have been major agricultural provinces since ancient times. In addition, China's main agricultural mineral resources are concentrated in the eastern and central regions where their mining technology is mature and transportation is convenient. It is very beneficial to the mining and transportation of agricultural mineral resources. Although some western provinces are rich in agricultural mineral resources, immature mining technology and poor road conditions limit the development of agriculture in this province.

The reasons why that the added value of China’s cold-chain logistics presents a spatial distribution pattern of “high in the southeast and low in the northwest” is as follows.

(1) Cold-chain resources. The hardware facilities and enterprises of cold-chain logistics in China are distributed unevenly, showing a distribution pattern of “more in the east and middle and less in the west.” Cold-chain infrastructure is mainly concentrated in the coastal and developed cities. However, the central and western regions of China, handle the majority of the country’s wholesale trading of fresh agricultural commodities, are experiencing a lack of cold-chain resources and display a relative lag in their development.

(2) Policy condition. The southeast region of China has a huge demand for fresh agricultural commodities, so most of the provinces in this region attach great importance to the development of cold-chain logistics and provide good supporting policies. The northwest region pays more attention to the development of the energy industry, equipment manufacturing industry, and animal husbandry.

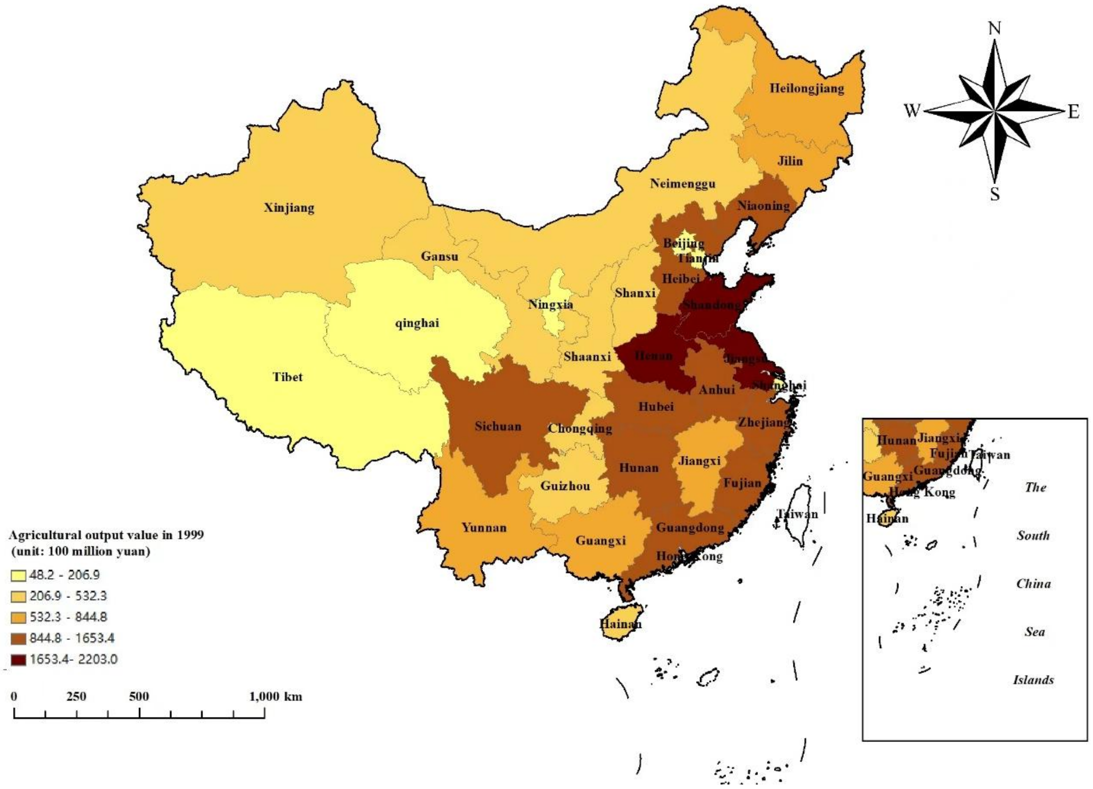

Fig. 2. Spatial distribution map of agricultural output value of provinces in 1999

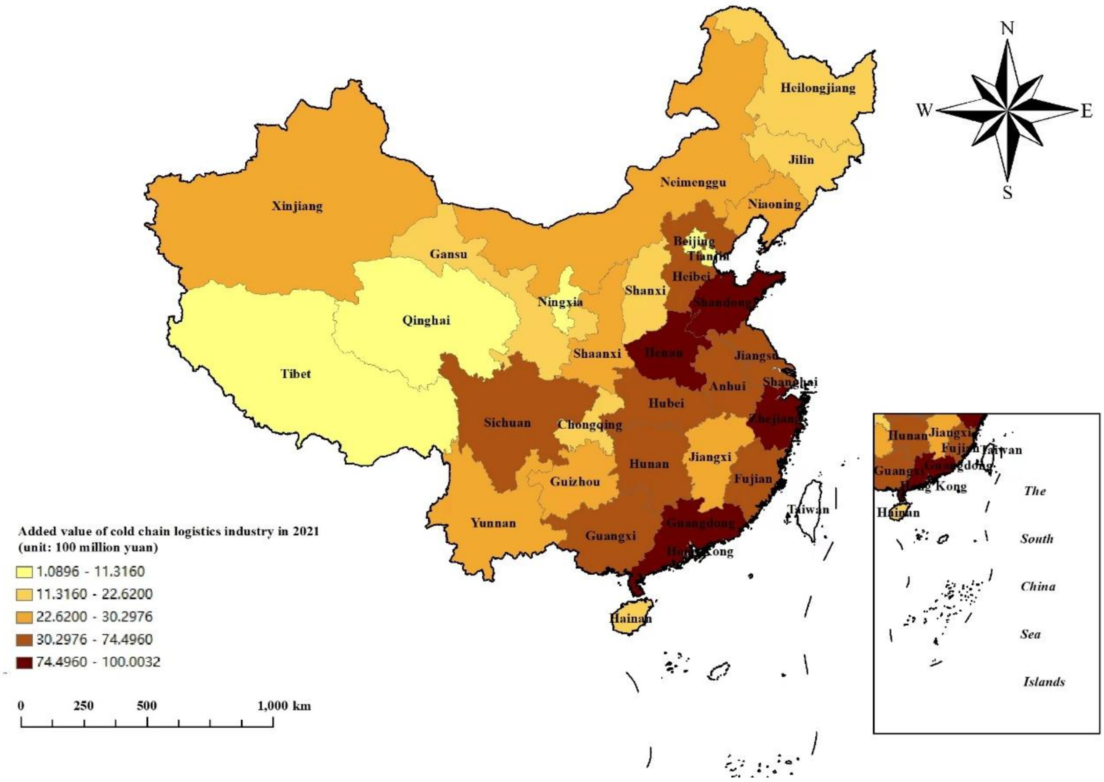

Fig. 3. Spatial distribution map of agricultural output value of provinces in 2021

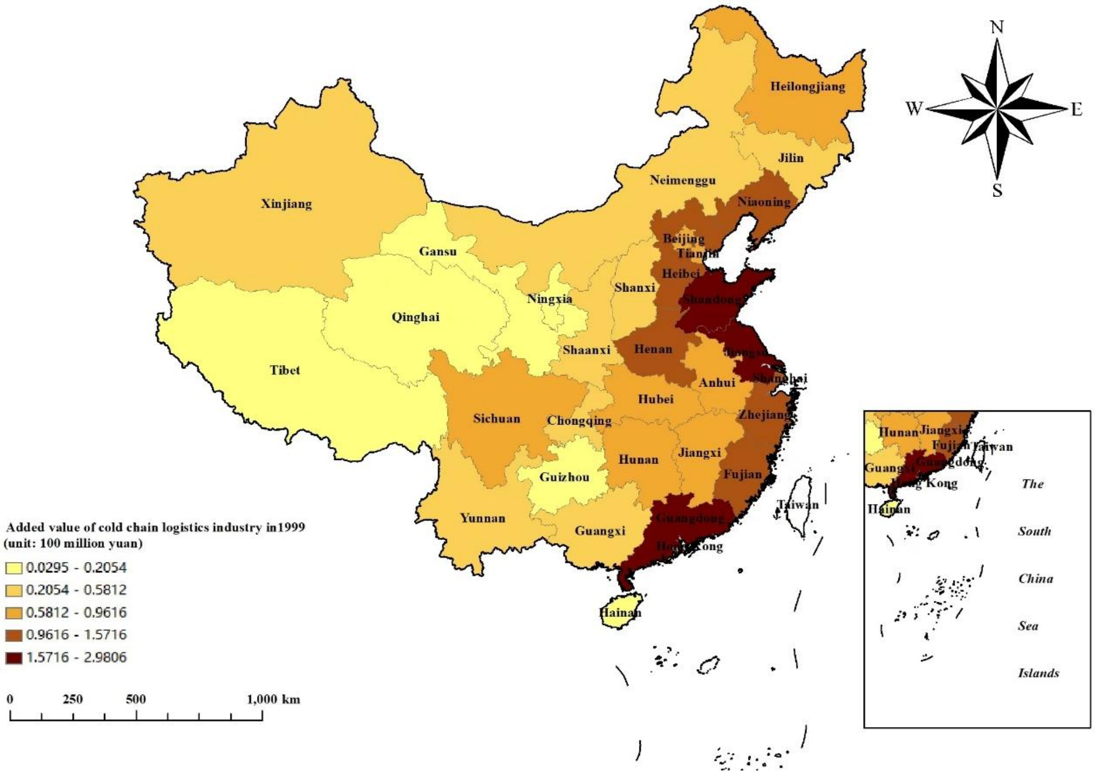

Fig. 4. Spatial distribution of the added benefit of cold-chain logistics of provinces in 1999

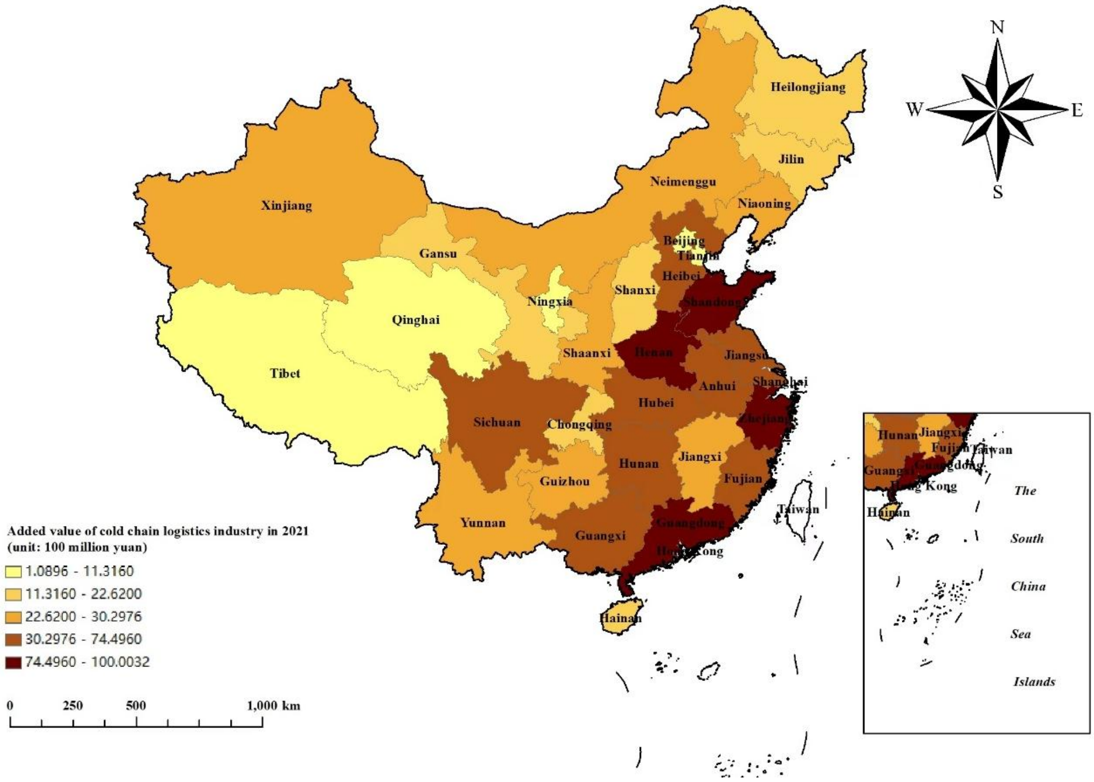

Fig. 5. Spatial distribution of the added benefit of cold-chain logistics of provinces in 2021

Global spatial autocorrelation between agricultural resources and cold-chain logistics

Global autocorrelation analysis was performed to determine the spatial correlation between agriculture and cold-chain logistics in each province. The results of the global Moran's index of each research project in 1999 and 2021 are shown in Table 1. After testing, the global Moran's index between agricultural output value and the added value of cold-chain logistics in 1999 and 2021 are 0.254872 and 0.356421, with Z statistics of 2.494615 and 3.214481, respectively, indicating a spatial autocorrelation between agriculture and cold-chain logistics.

Tab. 1. Global Moran's index and test between agricultural output value and the added benefit of cold-chain logistics

Item	I	E[I]	Variance	Z	P
Agricultural output value and the added value of cold-chain logistics in 1999	0.254872	−0.033333	0.012413	2.494615	<0.001
Agricultural output value and the added value of cold-chain logistics in 2021	0.356421	−0.033333	0.022569	3.214481	<0.001

Local spatial autocorrelation between agricultural resources and cold-chain logistics

Local spatial autocorrelation analysis was performed to investigate the local spatial autocorrelation and spatial distribution heterogeneity between agriculture and cold-chain logistics of various provinces in 1999 and 2021. Figure 6 shows that the H–H agglomeration provinces (provinces with high agricultural output value are surrounded by provinces with high added benefit of cold-chain logistics) in 1999 are Jiangsu, Zhejiang, and Fujian. The L–L agglomeration provinces (provinces with low agricultural output value are surrounded by provinces with low added benefit of cold-chain logistics) are Xinjiang, Tibet, Gansu, and Qinghai. The H–L agglomeration province (provinces with high agricultural output value are surrounded by provinces with low added benefit of cold-chain logistics) is Sichuan. Figure 8 shows that the H–H agglomeration provinces in 2021 are Shandong, Guangdong, Jiangsu, Zhejiang, and Fujian; the L–L agglomeration provinces are Gansu, Qinghai, Tibet, Xinjiang, and Ningxia; and H–L agglomeration province is still Sichuan.

On the whole, the spatial analysis results in 1999 and 2021 show that the L–H agglomeration provinces (provinces with low agricultural output value are surrounded by provinces with high added value of cold-chain logistics) do not exist, and the proportion of L–H agglomeration provinces is small, indicating a strong spatial correlation between agriculture and cold-chain logistics. The H–H and L–L agglomeration provinces are concentrated in the coastal and western areas, which indicate a more significant spatial positive correlation between cold-chain logistics and agriculture in the coastal and western areas than other areas. With the continuous development of China's cold-chain logistics, the number of the H–H agglomeration provinces in 2021 has increased compared with 1999, indicating that cold-chain logistics has a significant driving effect on agricultural resources exploitation.

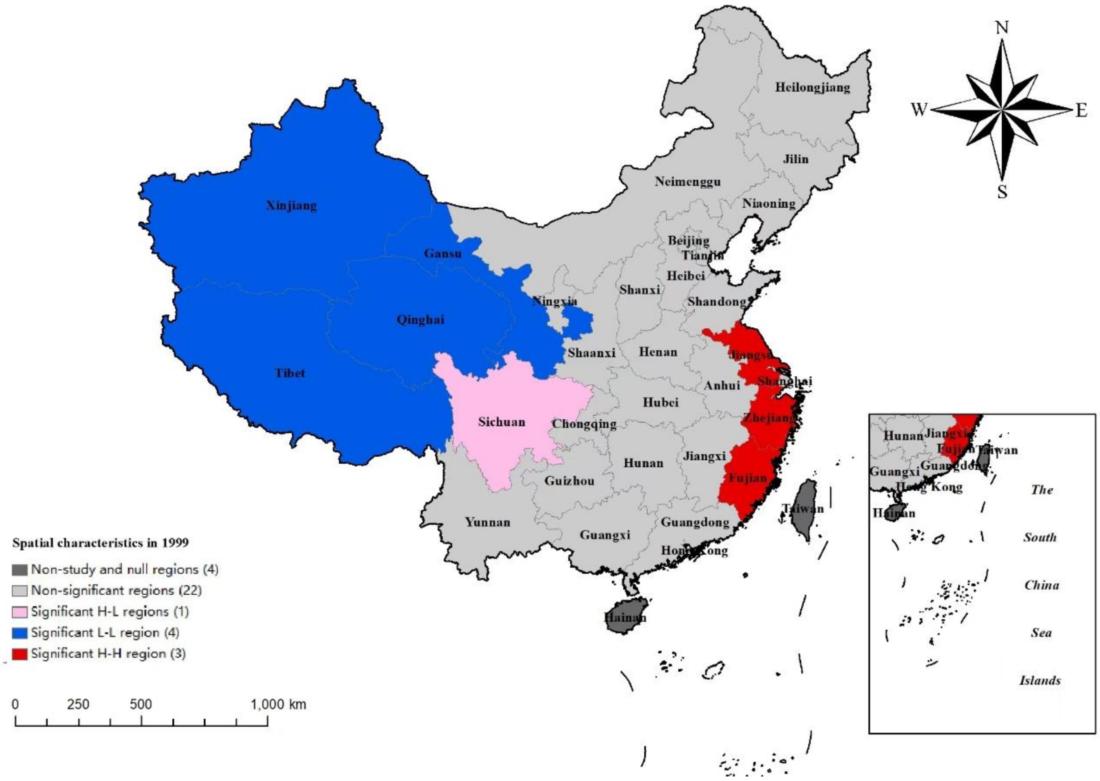

Fig. 6. LISA cluster chart in 1999

Fig. 7. LISA significance chart in 1999

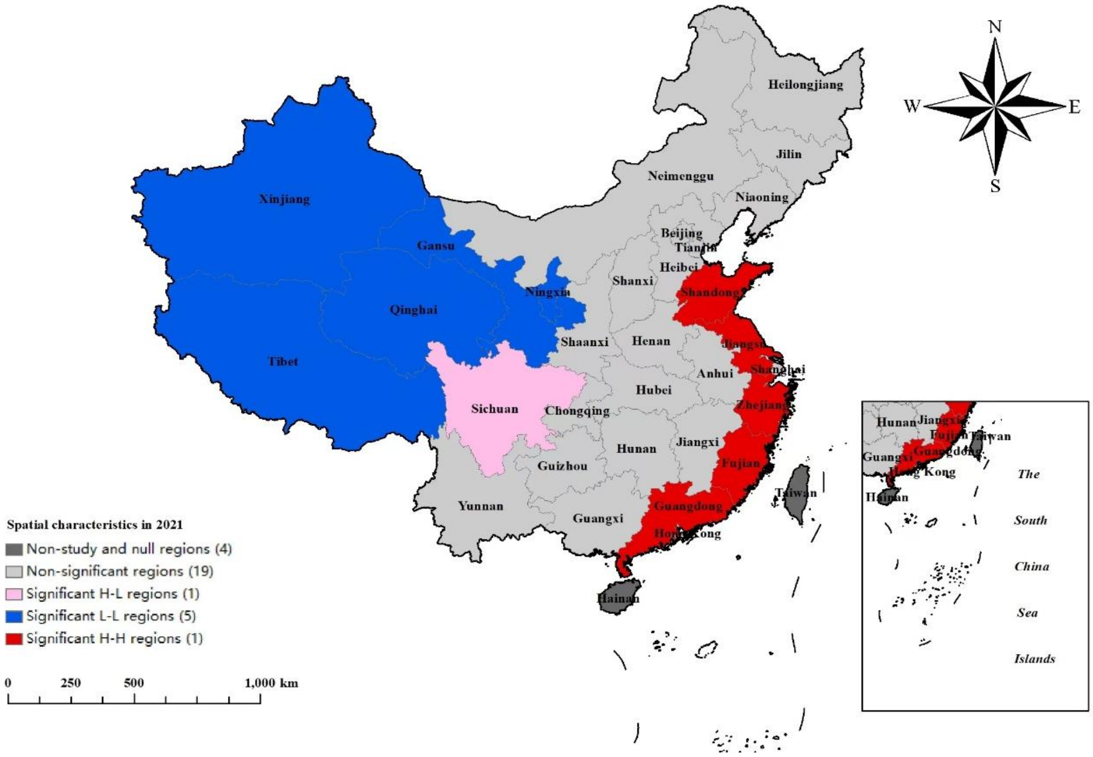

Fig. 8. LISA cluster chart in 2021

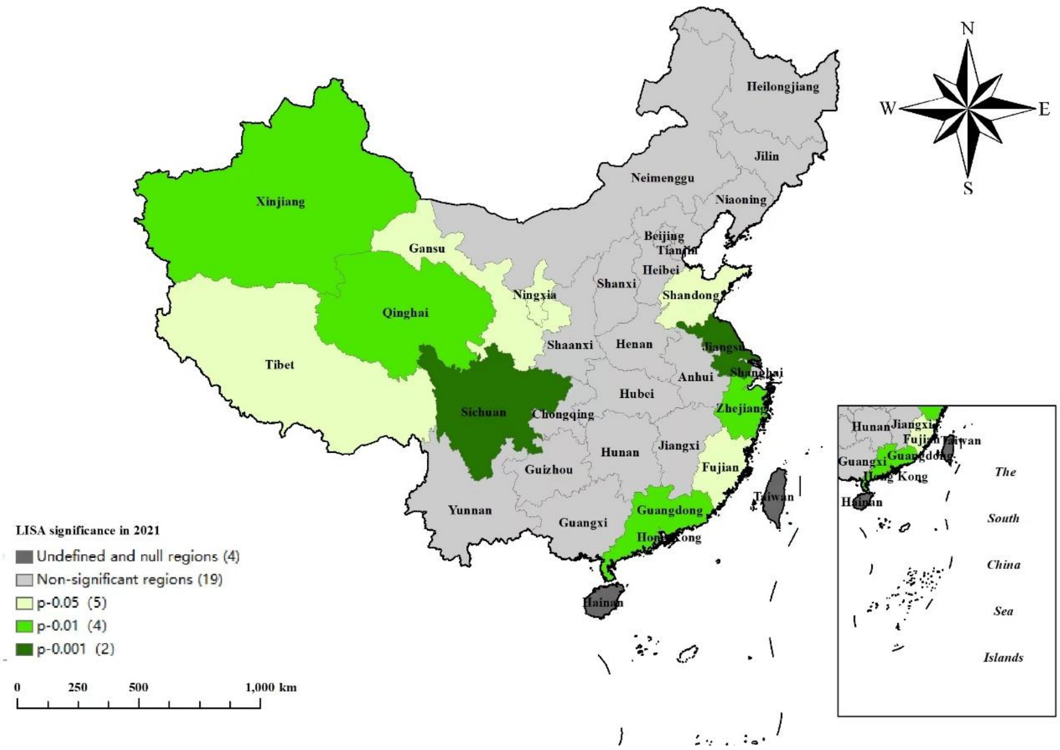

Fig. 9. LISA significance chart in 2021

Unit root test

Five test methods, namely, LLC, Breitung, IPS, ADF–Fisher, and PP–Fisher, were selected to test the data. Referencing to Chansombuth 's practice, all variables and their first-order difference variables were tested (Chansombuth 2023). Results were shown in Table 2.and the test results are shown in Table 2. The results of the LLC test show that no homogeneous panel unit root exists in all zero-order variables. The results of the Breitung, IPS, and ADF–Fisher tests show that unit roots exist in some zero-order variables. The results of the PP–Fisher test shows that LNY has no unit roots at the significance level of 5%. The LLC and Breitung tests show that no homogeneous panel unit root exists for all first-order difference variables at the significance level of 5%. A consistent conclusion can be obtained by combining the test results of different panel unit roots, that is, LNY, LNX1, LNX2, and LNX3 have first-order single internality.

Table 2. Results of time unit root test of time-series cross-sectional data

Variables/Methods	LLC	Breitung	IPS	ADF–Fisher	PP–Fisher
LNY	0.0045**	0.9235	0.9043	0.9153	0.9905
D(LNY)	0.0000**	0.0014**	0.0045**	0.0089**	0.0015**
LNX1	0.0015**	0.0086**	0.3409	0.3952	0.0449**
D(LNX1)	0.0000**	0.0000**	0.0015**	0.0074**	0.0000**
LNX2	0.0024**	0.9999	0.8427	0.0000**	0.0000**
D(LNX2)	0.0000**	0.0005**	0.0452**	0.0000**	0.0000**
LNX3	0.0000**	0.0017**	0.0974	0.1809	0.0000**
D(LNX3)	0.0000**	0.0000**	0.0016**	0.0024**	0.0000**

Note: ** indicates that it is significant at the 5% level.

Co-integration test

Three co-integration test methods, namely, Johansen–Fisher, Kao, and Pedroni tests, were selected to examine the time-series cross-sectional data, and the test results are shown in Table 3. The Johansen–Fisher test holds that two co-integration equations exist between all variables, indicating two co-integration relationships between variables. The values of Kao and Pedroni tests are also less than 0.05, indicating no co-integration relationship. In summary, a long-term and stable co-integration relationship exists between the added benefit, cargo turnover, and network mileage of cold-chain logistics and agricultural output value.

Table 3. Results of co-integration test of time-series cross-sectional data

Hypothesized	Fisher Stat*	Prob.	Fisher Stat*	Prob.
None	137.5	0.0000	90.36	0.0000
At most 1	68.67	0.0000	41.02	0.0082
At most 2	46.06	0.0019	33.12	0.0602
At most 3	34.72	0.0414	34.72	0.0414
Method		Statistic		Prob.
Kao (ADF)		−2.663671		0.0039
Panel ADF-Statistic		−1.922625		0.0273
Group ADF-Statistic		−3.569937		0.0002

Driving effect of cold-chain logistics on agricultural resources exploitation

The driving effect of cold-chain logistics on agricultural resources exploitation was analyzed based on a spatial econometric model. Table 4 shows that the influence of the network mileage of cold-chain logistics on agricultural growth has a lag period of two years. This result indicates that the change of the network mileage of cold-chain logistics does not affect the growth of agricultural output value in the current year but has a significant effect on the growth of agricultural output value two years later. Agricultural output value will increase by 0.70% for every 1% increase in the added benefit of cold-chain logistics. This finding indicates that the increase of added benefit of cold-chain logistics can greatly promote agricultural growth. The spillover coefficient of added benefit of cold-chain logistics on agricultural growth is −0.49. The reason is that the provinces with extremely large scale of cold-chain logistics will cause the lack of cold-chain resources in other provinces due to the Matthew effect, thereby inhibiting the agricultural resources exploitation of other provinces. The elasticity coefficient of the cargo turnover of cold-chain logistics to agricultural growth is 0.54. The agricultural output value of adjacent region will increase by 0.41% for every 1% increase in the cargo turnover of cold-chain logistics. This result indicates that the increase of the cargo turnover of cold-chain logistics will simultaneously drive the growth of agricultural output value in this province and other provinces. The agricultural output value will increase by 0.19% for every 1% increase in the network mileage of cold-chain logistics. This finding indicates that convenient traffic conditions are conducive to the circulation of agricultural commodities, thereby promoting agricultural resources exploitation. The network mileage of cold-chain logistics has no significant spatial spillover effect on agricultural growth. The reason is that the input of cold-chain logistics can only promote the agricultural growth of the province itself and has no significant promoting effect on the agricultural growth of adjacent provinces.

Table 5 shows the regression results of elastic and spillover coefficients of variables in different regions, showing that the added benefit of cold-chain logistics has a significant driving effect on agricultural growth in the eastern region and a promoting effect on agricultural growth in the central and western regions. The reason is the uneven distribution of cold-chain hardware facilities and enterprises in China, which shows a distribution pattern of “more middle in the east and less in the west.” However, the resources of cold-chain logistics in the central and western regions, which undertake most of the wholesale trading of fresh agricultural commodities in China, are relatively scarce. The results of spillover effect show the added benefit of cold-chain logistics has an inhibitory effect on the adjacent regions. The agricultural output value in the eastern, central, and western regions will increase by 0.45%, 0.69%, and 0.30% and the agricultural output value in the adjacent regions will increase by 0.36%, 0.51%, and 0.09% for every 1% increase in the cargo turnover of cold-chain logistics, respectively. The reason why the spillover effect of the eastern and central regions on the adjacent regions is more significant is that the eastern provinces with large demand for agricultural commodities drive agricultural resources exploitation of the adjacent regions through cold-chain logistics. In addition, the central provinces with abundant agricultural resources promote the increase of agricultural output value by providing a material basis for the circulation of agricultural commodities between adjacent regions. The agricultural output value of the eastern, central, and western regions will increase by 0.11%, 0.42%, and 0.94% and the agricultural output value in the adjacent regions will increase by 0.02%, 0.11%, and 0.50% for every 1% increase in the network milage of cold-chain logistics, respectively. The reason why the elasticity and spillover coefficients of the network mileage of cold-chain logistics in the western region are considerably larger than those of the network mileage of cold-chain logistics in the eastern region is that the network construction in the eastern region is relatively saturated.

Table 4. Estimation results of time-series cross-sectional data

Variable	Coefficient	Error	t-Statistic	Prob.
C	−0.8602	0.4299	−2.0006	0.0493
LnX1	0.7031	0.0746	9.4150	0.0000
LnX2	0.5449	0.0639	2.2645	0.0266
LnX3(−2)	0.1911	0.0513	3.7189	0.0004
ORLnX1	−0.4919	-0.1527	−3.2218	0.0019
ORLnX2	0.4083	0.1613	2.5305	0.0136
ORLnX3(−2)	0.0218	0.1001	0.2181	0.8280

Table 5. Estimation results of subregional time-series cross-sectional data

Variable	Eastern region	Central region	Western region
LnX1	2.86	2.21	1.81
LnX2	2.21	2.86	3.06
LnX3(−2)	2.66	3.05	2.01
ORLnX1	−2.54	−1.68	−1.99
ORLnX2	2.36	2.04	1.88
ORLnX3(−2)	2.07	2.57	3.55

Conclusions and Recommendations

To explore the affect mechanism of cold-chain logistics on agricultural resources exploitation, a spatial econometric model was proposed in this study. The affect mechanism between cold-chain logistics and agricultural resources exploitation was revealed, the spatial and temporal distribution characteristics and the spatial correlation between cold-chain logistics and agriculture based on the relevant data in 31 provinces of China from 1999 to 2021. In addition, recommendations for the coordinated development of agriculture and logistics were proposed. The following conclusions could be drawn:

(1) The provinces with the largest agricultural output value in China are Shandong, Henan, Sichuan, and Jiangsu, showing a spatial distribution pattern of "Henan and Shandong as the centre + high in southeast and low in northwest." The spatial distribution characteristics of decentralization of the added benefit of cold-chain logistics gradually weakened, and the regional aggregation characteristic gradually strengthened, showing a spatial distribution pattern of "high southeast and low northwest." The added value of cold-chain logistics and agricultural output value are in the same echelon without Shanghai, Zhejiang, Guangdong, Sichuan, and other provinces, indicating the characteristics of "low added value of cold-chain logistics–low agricultural output value" and "high added value of cold-chain logistics–high agricultural output value."

(2) The results of spatial autocorrelation demonstrate that cold-chain logistics in this province and adjacent provinces affect agricultural resources exploitation in this province simultaneously and that a spatial interaffect exists between agriculture and cold-chain logistics. The H–H and L–L agglomeration provinces are concentrated in the coastal and western regions, indicating that cold-chain logistics and agriculture in these regions have a more significant spatial positive correlation than other regions.

(3) Cold-chain logistics has a positive driving effect on agricultural resources exploitation, but regional differences exist in the contribution and spillover effect of each variable on agricultural growth. The added benefit of cold-chain logistics can greatly promote agricultural growth, but a negative spillover effect exists on agricultural growth in neighbouring provinces. The reason why cold-chain logistics in the eastern region has an inhibitory effect on agricultural resources exploitation in the central and western regions is that the development of the central and western regions is relatively backward and the resources of cold-chain logistics are scarce. The cargo turnover of cold-chain logistics has a significant driving effect on agricultural growth and a positive spillover effect on neighbouring provinces, and the spillover effect in the central and eastern regions is more significant than that in the western region. The network mileage of cold-chain logistics has a relatively significant improvement effect on agricultural growth, but it has no significant spatial spillover effect. The spillover and elasticity coefficients of the network mileage of cold-chain logistics in the western region are considerably larger than those in the eastern region with better network construction.

The recommendations are as follows:

(1) It is vital to expand the necessary capital investment in cold-chain logistics, provide effective tax relief policies to cold-chain enterprises. To promote the collaborative development of cold-chain logistics and agriculture in the central and western regions of China, attention should be given to the development of cold-chain logistics

in the central and western regions, narrow the gap between regions, and strengthen the cooperation between provinces with developed cold-chain logistics and underdeveloped provinces.

(2) By accelerating the construction of cold-chain logistics infrastructure in the major ports of advantageous production areas, important distribution centres, main sales areas, logistics bases, and hub airports, the cargo turnover of cold-chain logistics can be increased.

(3) It is critical to accelerate the construction of cold-chain logistics network in underdeveloped areas of central and western regions and strengthen the connection with the developed areas of the supply capacity of cold-chain logistics in the eastern region of China. To avoid excessive investment, the proportion of investment in the network mileage of cold-chain logistics in the eastern region should be set reasonably.

(4) It's important to accelerate the construction of road and transportation networks in the western region, increase investment in Technology research and mining equipment for mining agricultural mineral resources to narrow the regional gap.

The complex relationship between geography and the driving effect of cold-chain logistics on agricultural resources exploitation was investigated in this study based on the relevant data of agriculture and cold-chain logistics in 31 provinces of China from 1999 to 2021. In addition, the applicable scenarios and micro-explanations of relevant studies were enriched. However, practical data on cold-chain logistics are lacking. The analyses based on more and detailed data in future studies can accurately reveal the driving effect and spatial spillover effect of cold-chain logistics on agricultural resources exploitation.

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