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Study of the Spatial Spillover Effects of the Efficiency of Agricultural Product Circulation in Provinces along the Belt and Road under the Green Total Factor Productivity Framework

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Abstract: This paper bases on panel data from 30 provinces and municipalities in China spanning the period of 2010 to 2021 to examine the evolving mechanisms and influencing factors of agricultural product circulation efficiency in the provinces along the Belt and Road Initiative (BRI) within the context of green total factor productivity (TFP). The study research employs various methodologies including the SBM-DDF model, GML index, system GMM, and global Moran's I index. The findings are as follows: Initially, the provinces along the BRI exhibit an overall negative growth trend in the green TFP of agricultural product circulation, with a noticeable decline observed particularly after the initiation of the BRI in 2014. Secondly, foreign investment levels significantly contribute to the positive enhancement of green TFP in agricultural product circulation among the provinces along the BRI. Eventually, environmental regulations, government support, and the level of international trade in agricultural products exert significant negative impacts. Thirdly, the results of spatial effect tests reveal substantial spatial spillover effects in the green TFP of agricultural product circulation among the provinces along the BRI, as demonstrated through examinations utilizing three distinct spatial matrices.

Keywords: Belt and Road; Green Total Factor Productivity of Agricultural Product Circulation; System GMM; Spatial Spillover

1. Introduction

The growth of green total factors productivity plays a significant role in the high-quality development of agriculture and the modernization of the agricultural sector. It is of paramount importance for shaping a new development paradigm in the circulation of agricultural products, with a focusing on "internal circulation," consolidating the foundational position of agriculture, ensuring the smooth circulation of agricultural products, particularly food security, and promoting comprehensive rural revitalization. The growth of green total factor of productivity refers to the efficient allocation and comprehensive utilization of resources in the agricultural production process through the improvement of resource utilization efficiency, promotion of the greening and sustainable development of agricultural products, and reduction of environmental pollution and resource waste. This is a shared global challenge. In China, agriculture serves as the bedrock and a crucial pillar of the national economy and the circulation of agricultural products is an essential link in the agricultural industry chain. Therefore, enhancing the green total factor productivity in the circulation of agricultural products is of utmost importance for achieving high-quality agricultural development.

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As one of the world's largest producers and consumers of agricultural products, China regards the establishment of a sound and efficient agricultural product circulation system as a crucial pathway to achieve the goal of becoming an agricultural powerhouse and an essential component of comprehensive agricultural modernization. Particularly, since the proposal of the Belt and Road Initiative (BRI) in 2014, green agriculture and sustainable agricultural development have become important indicators for China's agricultural products to gain a competitive advantage in the global market. The BRI aims to promote economic cooperation and connectivity among countries and regions along its routes, including Asia, Europe, and Africa. As a pivotal industry in many countries and regions, agriculture plays a significant role in achieving regional economic integration and common development through the circulation of agricultural products.

Provinces along the Belt and Road, as important participants in the BRI, have distinctive characteristics in terms of traditional agricultural production, processing, and sales. Some regions have a favorable economic development trend and advanced agricultural technology, nevertheless are limited by limited resources, which hinders the full exploitation of their advantages in technological innovation. In contrast, other regions possess abundant agricultural resources but lag behind in economic development, and their agricultural product circulation efficiency is hampered by inadequate transportation and logistics infrastructure. The proposal of the BRI imposes higher requirements on the development of agricultural product circulation in provinces along its routes.

Within China's existing agricultural product circulation system, various factors such as complex circulation structure, lengthy distribution channels, unclear circulation subjects and low level of organization and informatization hinder the efficiency of development of the agricultural product circulation system, making it difficult for China to fully participate in global market competition. With the deepening trade exchanges between provinces along the Belt and Road and neighboring countries and regions, the convergence of agricultural economy, technological facilities, and development concepts, provinces along the Belt and Road can actively adjust their existing agricultural product circulation systems, seizing opportunities, improve the green total factor productivity of their agricultural product circulation, and effectively drive the coordinated development of neighboring provinces and regions along the routes.

Based on these considerations, this study aims to explore the current development status of agricultural product circulation efficiency in provinces along the Belt and Road under the framework of green total factor productivity. It analyzes the influencing factors from multiple perspectives, including environmental regulations, foreign investment, and the level of international trade in agricultural products. The study focuses on the development of green total factor productivity in agricultural product circulation in provinces along the Belt and Road, investigating the existence of spatial spillover effects, and examines whether the proposal of the Belt and Road Initiative can drive the overall development of green total factor productivity in agricultural product circulation in China.

2. Literature Review and Theoretical Analysis

The agricultural product circulation industry, as the leading industry in the layout of the agricultural sector, plays a crucial role in the implementation of China's agricultural power strategy, as highlighted in the Central Document No. 1 of 2023. Within this strategy, the research on green total factor productivity in agricultural product circulation has become a key aspect of the ongoing transformation and upgrading of agricultural modernization. The goal of agricultural product circulation is to efficiently convert farmers' products into products that meet consumer needs while ensuring consumer satisfaction. Under the framework of green total factor productivity, agricultural product circulation can be seen as a means to improve agricultural production efficiency. Specifically, optimizing agricultural product circulation can reduce product losses to enhance

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product quality, shorten the sales cycle, and lower costs, thereby improving production efficiency.

Wang Yiming (2020) argues that China has transitioned to a stage of high-quality development, shifting from "high-carbon growth" to "green growth," with a focus on strengthening the construction of the circulation system in the circulation sector and promoting a higher level of openness to the outside world. Zhao Liange, Huang Guiqin, and others (2021) explore the growth path of China's agricultural product circulation industry by establishing an intermediary effect model in the labor market. Qi Feng and Feng Menglong (2020) propose accelerating the construction of quality standards for agricultural products, promoting the development of large-scale agricultural product circulation channels, and thus improving supply chain efficiency.

In previous studies evaluating the efficiency of agricultural product circulation, many domestic and foreign scholars did not consider environmental factors and the pollution caused by the circulation industry. Instead, they mainly analyzed agricultural product circulation efficiency from the perspectives of expected output and input. Zhang Yongqiang, Zhang Xiaofei, and others (2017) used factor analysis to construct a measurement system for agricultural product circulation efficiency that includes 11 basic indicators across four dimensions: scale, efficiency, speed, and cost. They divided the evolution of China's agricultural product circulation efficiency into four main stages and emphasized that the integration of agricultural products and e-commerce would be a major direction for future development. Cheng Shuqiang, Liu Yanan, and others (2017) focused on the western region of China and used the Malmquist index analysis to measure the efficiency of agricultural product circulation in that region, providing relevant improvement suggestions.

With the rapid development of the rural economy and the acceleration of urbanization in China, especially against the backdrop of green economy and low-carbon industrial transformation, it is essential to incorporate a green circulation evaluation system into the construction of agricultural product circulation efficiency indicators. This should be done by comprehensively considering the practical impact of environmental factors in the process of agricultural product circulation and seeking a development path for a green agricultural product circulation system that is suitable for China's market economy conditions.

Based on this study proposes hypothesis 1: Under the framework of green total factor productivity, green technological innovation can promote sustainable agricultural development and improve the efficiency of agricultural product circulation.

Environmental regulation can directly influence or even alter the production and pollution discharge patterns of enterprises, thereby compelling them to adopt green production and pollution control technologies. Mainstream Western economists believe that the root cause of environmental degradation is the confusion of property rights and market failure. They hope that environmental regulations such as environmental taxes and carbon trading can address these issues. From the perspective of academic development, most scholars have explored the relationship between environmental regulation and agricultural production efficiency within the framework of green total factor productivity. However, there is limited research on the relationship between environmental regulation and agricultural industry circulation efficiency.

Huang Weihua, Qi Chunjie, and others (2021) measured the green total factor productivity of wheat from an environmental regulation perspective using the Malmquist-Luenberger index. They found that China's wheat industry exhibits extensive growth at the expense of the ecological environment. Hu Xueping, Le Dong (2022) measured provincial panel data from 2007 to 2018 in China and found that the improvement of environmental regulation can promote the development of China's agricultural total factor productivity, and there is a significant spatial spillover effect between the two. Zhan Jintao, Xu Yujiao (2019) explored the causal relationship between agricultural green productivity and food security from different perspectives of environmental regulation. They found that appropriate environmental policies can promote

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the growth of agricultural green productivity and the sustainable development of food security.

The Porter hypothesis proposes that environmental regulation has a dual effect on the green total factor productivity of agricultural product circulation. On the one hand, environmental regulation compels enterprises related to agricultural product circulation to improve pollution emission standards, which increases their circulation costs and inhibits the development of green total factor productivity in agricultural product circulation. On the other hand, environmental regulation can promote the transformation and upgrading of relevant enterprises, improve resource utilization efficiency, and reduce unintended outputs, thereby promoting the improvement of green total factor productivity in product circulation.

Based on this, this study proposes hypothesis 2: In China's existing agricultural product circulation system, the intensity of environmental regulation will hinder the development of green total factor productivity in agricultural product circulation.

The inception of the "Belt and Road" initiative has exerted a positive influence on the development of the agricultural industry in provinces along the Belt and Road route in China. This impact is particularly significant in the realm of agricultural circulation, presenting both greater opportunities and challenges. On one hand, owing to the uneven levels of economic development among the provinces along the Belt and Road, disparities exist in terms of agricultural production, cultivation practices, transportation infrastructure, and government support. Consequently, with the gradual increase in foreign investment and the continuous opening up of the agricultural product market, certain economically lagging regions may prioritize enhancing agricultural production efficiency at the expense of ecological preservation, inadvertently neglecting the imperative of sustainable agricultural practices.

Scholars such as Li Huiru and Jiang Jun (2019), who focused on China's export trade, contend that the "Belt and Road" initiative has the potential to invigorate export trade in the regions along its route. Through the utilization of the double-difference method for policy evaluation, they discover that the promotional effects of the initiative lack stability and sustainability, exhibiting variations across different regions. Additionally, researchers like Zhang Jianqing and Dong Jieming (2019) argued that foreign trade exerts a discernible influence on the green total factor productivity of provinces along the Belt and Road route.

On the other hand, provinces along the Belt and Road route in China, as key participants in this initiative, stand to benefit from the introduction of advanced agricultural production technologies, quality and safety control techniques for agricultural products, and the experiences in agricultural product circulation management from other countries and regions. In parallel, they are able to access broader cooperation opportunities in the agricultural product market, thereby enhancing the competitiveness of their local agricultural product markets and stimulating the development of agricultural product circulation in neighboring cities and regions.

Based on this, Hypothesis 3 is proposed in this paper: Within the framework of green total factor productivity, there exists a "spatial spillover effect" in the development of agricultural product circulation efficiency in provinces along the Belt and Road route in China.

3. Materials and Methods

3.1. Research methods

Regarding the study of green total factor productivity, it refers to the ability to maximize production efficiency by considering factors such as environment, resources, and economy while utilizing existing resources. It takes into account not only the quantity of agricultural output but also the quality of output and environmental impacts. When measuring green total factor productivity, both domestic and international schol-

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ars commonly use methods such as Data Envelopment Analysis (DEA), Malmquist index, SBM model, and Stochastic Frontier Analysis (SFA).

The DEA model, a non-parametric method, evaluating the relationship between inputs and outputs of production activities to determine the optimal production frontier. However, the DEA model has limitations in measuring green production efficiency as it cannot account for potential waste in resource utilization and potential missing outputs, which may lead to biased evaluation results. To overcome this issue, scholars have proposed the SBM model as an improved version of DEA.

The SBM model considers the potential differences between inputs and outputs and evaluates green total factor productivity by measuring resource utilization efficiency and environmental benefits. Compared to the traditional DEA model, the SBM model provides more accurate and reliable evaluation results, better reflecting the actual situation of green production efficiency. The SBM (Slacks-Based Measure) model is a slack-based method that considers multiple input and output factors to comprehensively assess efficiency in the production process.

The DDF model（directional distance function） can consider the interrelationship between multiple input and output factors. It is used to determine the technical efficiency of the production process by calculating the relative efficiency of each agricultural product circulation unit in terms of resource utilization and output performance. By introducing directional differences, the DDF model can more comprehensively evaluate green total factor productivity in agricultural product circulation, fully considering the interactions between various factors, and provide more accurate results for understanding the influencing factors.

The GML (Global Malmquist-Luenberger) index is an extended version of the Malmquist-Luenberger index used to measure the temporal changes and technological progress of green total factor productivity in agricultural product circulation. Based on the relative efficiency values calculated from the DDF model, the GML index assesses the changes in productivity by comparing the differences in relative efficiency and technological progress between two time points. When the GML index is greater than 1, it indicates an increase in expected output and a decrease in undesired output, leading to an improvement in green total factor productivity. Conversely, when the GML index is less than 1, it indicates an increase in undesired output and a decrease in expected output, resulting in a decline in green total factor productivity.

3.2. Variable selection and source

In terms of input variable selection, this study chooses three factors: capital input, labor force, and transportation infrastructure. Regarding the fixed capital input in agricultural product circulation, this study adopts the method used by Wang Renxiang and Kong Deshu (2014), which replaces fixed capital input with the fixed asset input of transportation, warehousing, and postal services; wholesale and retail trade; and accommodation and catering industries, multiplied by the final consumption rate, the share of household consumption in final consumption and the Engel coefficient (national average). As for the selection of labor force indicators, there is no publicly available data specifically for the employment in agricultural product circulation, considering the large workforce involved. Some scholars substitute the number of employees in transportation, warehousing, and postal services; wholesale and retail trade; and accommodation and catering industries. Although this method provides easily accessible data, it lacks specificity and persuasiveness. Therefore, this study selects the number of relevant enterprises in agricultural product circulation as a proxy for labor input. In terms of transportation infrastructure, this study uses the sum of railway, road, and waterway mileage as a representation.

Regarding the selection of expected output variables, for the total output value of agricultural product circulation, the same method as that for the fixed capital input in agricultural product circulation is employed. For agricultural product trade, this study

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uses the total volume of agricultural product imports and exports as a proxy. For unexpected output variables, this study uses the total carbon emissions and chemical oxygen demand (COD) in the process of agricultural product circulation.

Based on the aforementioned input-output indicators, this study employs Stata 16.0 software to measure the green total factor productivity of agricultural product circulation in 30 provinces and municipalities (excluding Tibet) in China. The geometric method of the annual green total factor productivity index of agricultural product circulation in the 30 provinces and municipalities is taken as the national green total factor productivity index of agricultural product circulation for that year. The geometric mean of the annual green total factor productivity index of agricultural product circulation in the Belt and Road Initiative (BRI) provinces is taken as the green total factor productivity index of agricultural product circulation for the BRI provinces for that year. Due to incomplete and severe missing data in Tibet, this study excludes Tibet when measuring the green total factor productivity of agricultural product circulation in both the national and BRI provinces. The sample period for this study is from 2010 to 2021, and the data sources include the national and provincial Statistical Yearbooks, China Environmental Statistical Yearbook, carbon accounting databases, Tonghuashun database, and China Rural Statistical Yearbook. In cases of missing data during the data collection process, linear interpolation is used for data completion.

3.3. Green total factor productivity in the agricultural product circulation of provinces along the Belt and Road Initiative, from a national perspective

Overall, from 2010 to 2021, the green total factor productivity in the agricultural product circulation of provinces along the Belt and Road Initiative, viewed from a national perspective, exhibited a negative growth trend. Moreover, the average annual index of green total factor productivity in the agricultural product circulation of the Belt and Road provinces was lower than the national average. Specifically, the average annual index of green total factor productivity in the agricultural product circulation of the entire country from 2010 to 2021 was 0.9915, with an average annual decline rate of 0.85%. For the Belt and Road provinces during the same period, the average annual index of green total factor productivity in the agricultural product circulation was 0.9923, with an average annual decline rate of 0.77%.

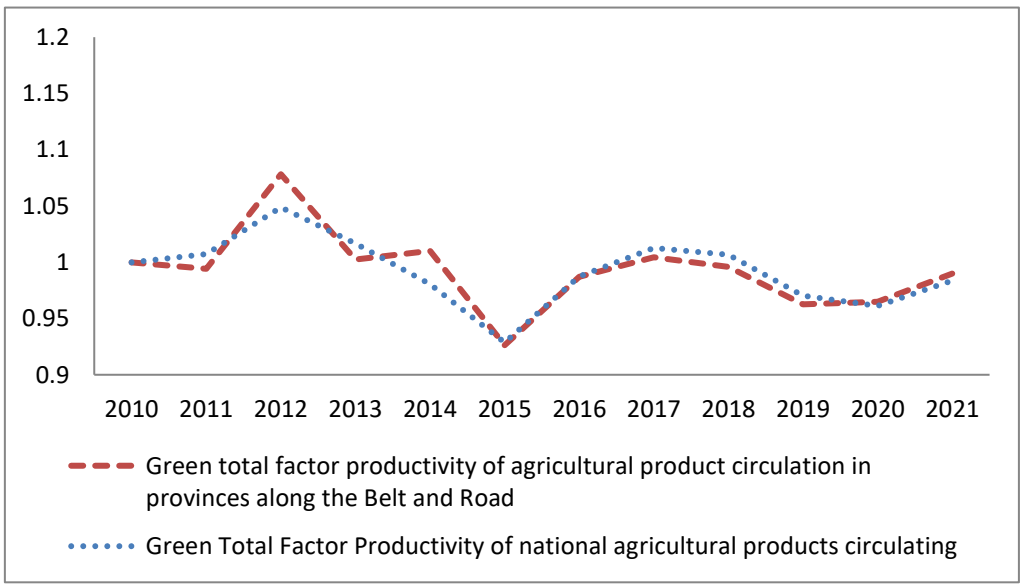

Figure 3-1. Green total factor productivity in the agricultural product circulation of provinces along the Belt and Road Initiative, from a national perspective

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From the changes in the index of green total factor productivity in agricultural product circulation, the overall situation is not optimistic. Moreover, from 2010 to 2021, the index of green total factor productivity in agricultural product circulation of provinces along the Belt and Road Initiative was mostly lower than the national index, and it exhibited significant fluctuations. Specifically, in the years 2011, 2015, 2016, 2018, 2019, 2020, and 2021, the index of green total factor productivity in agricultural product circulation of the Belt and Road provinces was below 1, indicating a deterioration in the green total factor productivity of agricultural product circulation. In the remaining years, the green total factor productivity in agricultural product circulation showed some improvement to a certain extent. After 2019, the provinces along the Belt and Road Initiative experienced an upward trend in green total factor productivity in agricultural product circulation.

3.4 Green total factor productivity in agricultural product circulation in provinces along the Belt and Road Initiative.

As provinces along the Belt and Road Initiative, our country acts as both the promoter and participant of the initiative. Agriculture, being one of its important economic pillars, has a significant impact on the development of green total factor productivity in agricultural product circulation. The initiative was proposed at the end of 2013, and this study will analyze the development of green total factor productivity in agricultural product circulation in provinces along the Belt and Road Initiative during two periods: pre-initiative (2010-2013) and post-initiative (2014-2021).

Table 3-1. Green total factor productivity in agricultural product circulation in provinces along the Belt and Road Initiative.

Province	2010—2013			2014—2021		
	GTFPCH	GTC	GEC	GTFPCH	GTC	GEC
Inner Mongolia	1.098	1.110	0.988	0.916	1.000	0.916
Liaoning	1.054	1.069	0.986	0.960	0.957	1.003
Jilin	0.972	0.964	1.008	1.000	1.023	0.978
Heilongjiang	1.072	1.107	0.968	0.929	1.000	0.929
Shanghai	1.002	1.000	1.002	1.000	1.000	1.000
Zhejiang	1.035	0.968	1.069	0.981	0.975	1.006
Fujian	1.015	1.005	1.009	0.984	0.984	1.000
Guangdong	1.029	0.996	1.033	0.954	0.970	0.983
Guangxi	1.002	1.013	0.988	0.952	0.954	0.999
Hainan	1.047	0.971	1.078	0.994	1.036	0.959
Chongqing	1.031	1.022	1.009	0.985	0.995	0.990
Yunnan	1.028	1.047	0.982	0.970	0.960	1.010
Shaanxi	1.003	0.986	1.017	0.994	1.002	0.992
Gansu	1.013	1.027	0.986	0.979	0.978	1.001
Qinghai	1.008	1.004	1.003	1.001	1.024	0.978
Ningxia	0.952	0.947	1.005	0.988	0.995	0.993
Xinjiang	1.002	0.999	1.004	1.001	1.004	0.997
Mean	1.021	1.013	1.008	0.976	0.991	0.984

Overall, before the proposal of the Belt and Road Initiative (2010-2013), the green total factor productivity index in agricultural product circulation in the provinces along the Belt and Road was 1.021, with an average annual growth rate of 2.1% over the

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four-year period. After the proposal of the Belt and Road Initiative (2014-2021), the green total factor productivity index in agricultural product circulation in these provinces was 0.976, with an average annual decline of 2.4% over the seven-year period.

Looking at individual provinces and cities, during the pre-proposal period (2010-2013), out of the 17 provinces and cities along the Belt and Road, 15 provinces and cities achieved effective growth in green total factor productivity in agricultural product circulation. Only Jilin and Ningxia experienced a decline in green total factor productivity, showing a downward trend. After the proposal of the Belt and Road Initiative (2014-2021), only four provinces and cities, namely Jilin, Shanghai, Qinghai, and Xinjiang, achieved effective growth in green total factor productivity in agricultural product circulation. Among them, only Xinjiang and Qinghai achieved effective growth in green total factor output change, while the remaining 13 provinces and cities experienced a deterioration in green total factor productivity change, showing a downward trend.

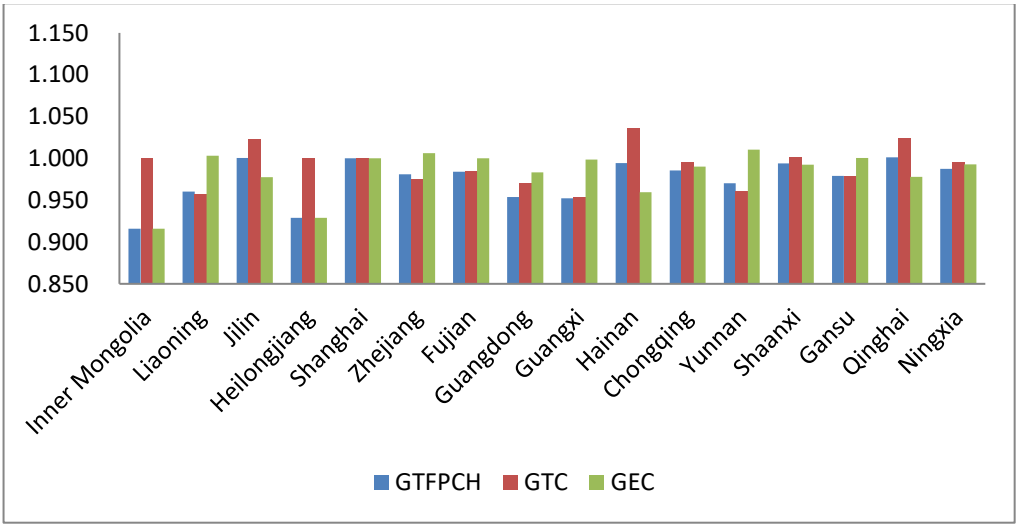

Figure 3-2: Changes in Key Indexes of Frontier Provinces along the "Belt and Road" Initiative from 2014 to 2021.

From the perspective of efficiency composition, the green total factor productivity (GTFPCH) in agricultural product circulation can be expressed as the product of green technology change index (GTC) and green technology efficiency index (GEC). After the proposal of the Belt and Road Initiative in 2014, the GTFPCH in the provinces along the Belt and Road decreased by 4.5%, with GTC declining by 2.2% and GEC declining by 2.4%. The mean values of both GTC and GEC were less than 1, indicating a deterioration in efficiency.

At this critical moment of transformation in modern agricultural development, the level of green technology plays a crucial role in establishing a sound modern agricultural product circulation system and ensuring high-quality development of agricultural product circulation. Technological backwardness can lead to issues for instance redundant capital, redundant transportation infrastructure, and redundant labor in the circulation process. It can also result in wastage of resources, inefficiency, and low quality in the production process, further reducing the development of green total factor productivity in agricultural product circulation. Additionally, Figure 3-2 shows that the GTFP in Inner Mongolia, Jilin, Heilongjiang, Hainan, and Qinghai provinces is mainly affected by low green technology efficiency, especially in Inner Mongolia and Heilongjiang, where agricultural green technology progress index is significantly higher than the technology application efficiency. This indicates that these two provinces have not effectively translated the achievements of agricultural green technology progress into the production and circulation field.

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To improve the development of green total factor productivity in agricultural product circulation, it is important to promote green technology progress and enhance the efficiency of agricultural technology application. This can be achieved by improving agricultural product circulation efficiency, optimizing the circulation system, enhancing circulation quality and services and strengthening the competitiveness of agricultural products. It is necessary to explore and innovate in technology research and development, resource guarantee, environmental governance, and green technology application to enhance the level of green total factor productivity in agricultural product circulation in the provinces along the Belt and Road Initiative.

4. Analysis of Influencing Factors of Green Total Factor Productivity of Agricultural Product Circulation in Provinces along the Belt and Road

4.1 Model building and variable selection

This study focuses on 17 provinces along the Belt and Road in China (excluding Tibet) and uses panel data from 2010 to 2021. Drawing references from relevant literature, the study selects six indicators to observe their impact on green total factor productivity in agricultural product circulation (GTFPCH) in the provinces along the Belt and Road. The selected indicators include the lagged development level of GTFPCH, international trade level of agricultural products, environmental regulations, government support, foreign direct investment (FDI) in the agricultural product circulation sector, and transportation infrastructure for agricultural product circulation.

To avoid the problem of overidentification in the model estimation process, the selection of lagged periods should be less than one-third of the entire study period, as recommended by Holtzeakin and Schwartz. Therefore, this study sets the lagged two periods of GTFPCH as the focus to explore their impact on the development of green total factor productivity in agricultural product circulation.

Furthermore, in order to ensure the consistency of result estimation, this study uses the dynamic generalized method of moments (GMM) estimation approach, specifically the system GMM, when conducting the correlation tests with panel data. The analysis of the factors influencing green total factor productivity in agricultural product circulation in the provinces along the Belt and Road is conducted using Stata 16.0 software. The data used in the study are derived from the "China Environmental Statistical Yearbook," national and provincial statistical yearbooks, and the "China Rural Statistical Yearbook." In cases of missing values, linear interpolation is used for data completion. The model dynamic panel settings are as follows:

$$GTFPCH_{it} = \alpha_0 + \alpha_1 GTFPCH_{i(t-2)} + \alpha_2 ER_{it} + \alpha_3 GP_{it} + \alpha_4 FDI_{it} + \alpha_5 TP_{it} + \alpha_6 RIT_{it} + \varepsilon_{it}$$

Among them, GTFPCH is the explained variable, and the explanatory variables include GTFPCH lagged behind the second stage of development level L2.GTFPCH, environmental regulation ER, government support GP, foreign investment level FDI, agricultural product circulation and transportation infrastructure TP, and agricultural product international trade level RIT, the specific indicators are set as follows:

Factor	Indicator	Measurement Method	Symbol
Technological factors	**The lagged two-period development level of Green Total Factor Productivity of China's agriculture**	**Calculated results of the study**	**L2.GTFPCH**
	Government sup-	**Government fiscal expenditure in the**	**GP**

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	port	relevant aspects of agricultural product circulation	
Environmental factors	Foreign investment level	Foreign Direct Investment (FDI) as a percentage of GDP	FDI
	Environmental regulation	The number of environmental protection proposals in the two sessions	ER
	Infrastructure development for agricultural product distribution and transportation	Total mileage of highways, railways, and waterways	TP
	International trade level of agricultural products	Total value of agricultural product import and export trade as a percentage of the total value of agricultural, forestry, animal husbandry, and fishery production.	RIT

4.1.1 variable descriptive statistics

Variable types	Variable symbols	Variable names	Sample size	Mean	Standard deviation	Min	Max
Dependent variable	GTFPCG	Green total factor productivity of agricultural product circulation	240	0.996	0.086	0.612	1.559
	L2.GTFPCH	The lagged two-period development level of Green Total Factor Productivity of China's agriculture	170	0.999	0.092	0.612	1.559
Independent variable	ER	Environmental regulation	240	402.004	368.784	252	2471
	GP	Government support	240	827.693	439.360	123.368	3009.98
	FDI	Foreign investment level	240	54.933	75.013	102.661	290.3996
	TP	Infrastructure development for agricultural product distribution and transportation	240	133441.4	67259.57	14584.39	331891.2
	RIT	International trade level of agricultural products	240	0.352	1.114	0.001	7.14145

4.2 Analysis of empirical results

Variable	System GMM model	
	Coefficient（Z-value）	P-value

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L2.GTFPCH	-0.1924049* (-1.840)	0.066
ER	-0.0001091** (-1.97)	0.049
GP	-0.000045*** (-3.80)	0.000
FDI	0.0005733*** (2.90)	0.004
TP	0.000000155(1.52)	0.128
RIT	-0.0147594**(-2.15)	0.032
Constant	1.22255***(11.82)	0.000
Wald statistic	173947.41	
Wald associated probability	0.000	
Arellano-Bond(1)	0.069	
Arellano-Bond(2)	0.121	
Sargan tests	0.952	
Hansen tests	0.997	

Note: *, **, *** significant at 10%, 5% and 1% levels.

Initially, regarding the GTFPCH equation, the Wald statistic and Wald associated probability at the 1% level, thereby rejecting the null hypothesis that "all explanatory variables are equal to zero." Subsequently, the Arellano-Bond autocorrelation test indicates that the P-values for AR(1) and AR(2) are 0.069 and 0.121, respectively, thus accepting the null hypothesis of "no autocorrelation in the disturbance term." As for the Sargan and Hansen tests, the P-values are 0.952 and 0.997, respectively, supporting the null hypothesis that "all instrumental variables are effectively valid." These findings suggest that the system GMM model is appropriately specified and, consequently, the estimation results hold a high level of reliability.

Regarding the relationship between L2.GTFPCH and agricultural green total factor productivity, the analysis reveals a significant negative correlation, passing the 10% significance level test. This finding can be interpreted in two main aspects. Firstly, the economic development levels among the provinces along the Belt and Road exhibit significant disparities. In order to expedite the enhancement of agricultural circulation efficiency, certain provinces may resort to compromising the ecological environment, thereby resulting in a decline in the development of green agricultural circulation efficiency. Secondly, due to the time lag associated with implementing environmental regulations and government support, the progress of green total factor productivity in agricultural circulation may experience a delayed effect. Thirdly the inadequacies within the agricultural circulation system, characterized by a complex and redundant circulation structure, as well as duplicative circulation functions, serve as fundamental barriers to the advancement of green circulation in the provinces along the Belt and Road.

There exists a significant negative correlation between environmental regulations and agricultural green total factor productivity, passing the 5% significance level test. This relationship can be explained from two perspectives. Firstly, stricter environmental regulations impose higher operating costs on agricultural circulation enterprises. As enterprises engaged in the production, circulation, and sales of agricultural products, they require additional technology, equipment, and manpower to meet environmental requirements. In such circumstances, the development space for these enterprises becomes constrained, leading to a negative impact on their green total factor productivity. Secondly, this study uses the number of environmental protection proposals during the annual sessions of the National People's Congress and the Chinese People's Political Consultative Conference as an indicator of environmental regulations. The formulation and implementation of environmental protection policies involve time lags and their implementation varies across different provinces due to disparities in regional development levels. Therefore, environmental regulatory measures should be based on the actual development conditions of agricultural circulation in the provinces along the Belt and Road. Specific issues need to be analyzed on a case-by-case basis, ensuring the protection of the interests of the main entities involved in agricultural product circulation,

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primarily farmers. Additionally, efforts should be made to cultivate a new generation of agricultural professionals who are knowledgeable and passionate about agriculture, and integrate the concepts of green and sustainable development throughout the entire agricultural product circulation chain. This approach will contribute to the improvement of agricultural green total factor productivity.

There exists a significant negative correlation between government support and agricultural green total factor productivity, passing the 1% significance level test. Government support can lead to increased dependence of agricultural circulation enterprises. Support measures such as government subsidies and preferential policies may diminish the motivation and willingness of enterprises to engage in green production. As a result, some enterprises may be more inclined to pursue higher profits through traditional, resource-intensive, and high-emission methods. This ultimately leads to a decline in agricultural green total factor productivity.

There is a significant negative correlation between the level of international trade in agricultural products and agricultural green total factor productivity, passing the 1% significance level test. On one hand, international trade in agricultural products involves transportation and storage on a global scale, which leads to increased emissions of pollutants such as carbon and chemical oxygen demand. This in turn increases pollution and energy consumption in the agricultural circulation process, further impacting agricultural green total factor productivity. On the other hand, international trade in agricultural products can result in trade barriers and technology transfer, posing challenges for relevant agricultural circulation enterprises such as higher market entry barriers, lack of green technological innovation, and low competitiveness in product markets. This leads to a deterioration in agricultural green total factor productivity. Furthermore, in the global agricultural market, China does not have a competitive advantage in the import and export of bulk agricultural products. During this period of significant global upheaval, the global agricultural market is unstable and China's total trade volume of agricultural products has been declining in recent years, particularly in terms of importing certain agricultural products where it is subject to restrictions imposed by other countries. Therefore, to improve the current development challenges in agricultural green total factor productivity, it is necessary to leverage the "Belt and Road" initiative. Provinces along the Belt and Road should utilize their agricultural production, cultivation, and processing advantages to develop specialty agricultural products, build brand images for these products, establish sound models for the development of specialty agricultural product circulation and enhance the export of specialty agricultural products. This will drive comprehensive development in surrounding regions and overall economic growth.

The correlation between transportation infrastructure development in agricultural circulation and agricultural green total factor productivity is theoretically positive, indicating that a well-developed infrastructure should have a positive impact on productivity. Sound infrastructure facilitates efficient and cost-effective agricultural circulation, promotes marketization and internationalization of agricultural products, and ultimately enhances agricultural green total factor productivity. However, the practical relationship is influenced by various complex factors. Firstly, the adequacy of transportation infrastructure investments in the Belt and Road provinces may not meet the requirements for improving agricultural green total factor productivity. Insufficient investment in infrastructure construction in certain provinces hampers the transportation and circulation of agricultural products, thereby impeding the progress of agricultural green total factor productivity. Secondly, the benefits of infrastructure investments can be offset by other factors. For instance, government-imposed environmental regulations increase operational costs for agricultural circulation enterprises, thereby attenuating the influence of infrastructure development on agricultural green total factor productivity. Lastly, the effectiveness of transportation infrastructure investments is contingent on the level of government support for agricultural production and circulation. Even with robust infrastructure, its maximum benefits may not be realized in the absence of adequate government support in these realms. Hence, government support acts as a pivotal factor influ-

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encing agricultural green total factor productivity in agricultural circulation. In conclusion, the relationship between transportation infrastructure development and agricultural green total factor productivity in agricultural circulation is not unidirectional but rather influenced by a multitude of factors. While infrastructure investments can enhance agricultural green total factor productivity, it is imperative to concurrently reinforce government support for agricultural production and circulation, uphold robust environmental regulations, and optimize the resulting benefits.

The level of foreign direct investment (FDI) is positively correlated with agricultural green total factor productivity in agricultural circulation and this relationship has been validated through a significant level of 1%. There are several reasons for this positive correlation. Firstly, foreign-invested enterprises often bring advanced technologies and management expertise. By introducing these technologies and experiences, the agricultural circulation sector can benefit from technological advancements and improved management practices, thereby enhancing the level of green total factor productivity. Secondly, foreign investment can promote marketization and internationalization in the agricultural circulation sector. Foreign-invested enterprises typically possess extensive market networks and stronger international business experience, which can drive the development of agricultural trade, improve circulation efficiency, and enhance the quality of agricultural products. Furthermore, foreign-invested enterprises often have stronger financial capabilities and broader social resources. This enables them to contribute to capital investment and infrastructure development in the agricultural circulation sector, thereby improving the efficiency and quality of agricultural circulation. In summary, the positive correlation between the level of foreign direct investment and agricultural green total factor productivity in agricultural circulation can be attributed to the introduction of advanced technologies, improved management practices, market expansion, international trade facilitation, and increased capital investment. These factors collectively contribute to the enhancement of agricultural circulation efficiency and quality.

5.Spatial dependence test for green total factor productivity of agricultural product circulation among provinces along the Belt and Road Initiative.

Spatial spillover effects refer to the phenomenon where changes in economic, social, and environmental variables in one region have an impact on the surrounding regions. To further investigate the regional disparities in the green total factor productivity of agricultural product circulation among provinces along the Belt and Road Initiative in China, this study employs the global Moran's I index to test the spatial autocorrelation relationships among 17 provinces along the Belt and Road Initiative (excluding Tibet). The specific model is as follows:

$$\text{GlobalMoran's I} = \frac{\sum_{i=1}^{n}\sum_{j=1}^{n} W_{ij}^{\rho}(X_t-\bar{X})(X_j-\bar{X})}{S^2\sum_{i=1}^{n}\sum_{j=1}^{n} W_{ij}^{\rho}} \quad (1)$$

$$S^2 = \frac{1}{n}\sum_{i=1}^{n}(X_i-\bar{X})^2 \quad (2)$$

$$\bar{X} = \frac{1}{n}\sum_{i=1}^{n} X_i \quad (3)$$

Here, n represents the number of spatial units, X_i and X_j denote the observed values of green total factor productivity of agricultural product circulation in province i and province j, respectively. W_ij^ϱ represents the spatial weight matrix, which reflects the spatial clustering level of green total factor productivity of agricultural product circulation among provinces along the Belt and Road Initiative in China through spatial correlation analysis. In this study, following the approaches of Wu Xuxu (2022), Wang Yufei and Ni Pengfei (2016), and Yan Yaxue and Qi Shaozhou (2017), three types of spatial weight matrices were constructed: geographic adjacency spatial weight matrix, geographic distance spatial weight matrix, and economic spatial weight matrix. These matrices were used to examine the spatial effects of green total factor productivity of agri-

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cultural product circulation among provinces along the Belt and Road Initiative in China under different spatial weight matrices.

The global Moran's I index is a commonly used spatial autocorrelation analysis method that measures the spatial correlation of variables. By using the global Moran's I index, we can determine whether there is a spatial clustering or dispersion trend in the green total factor productivity of agricultural product circulation and reveal the spatial dependency among provinces. When the global Moran's I index approaches 1, it indicates a positive spatial correlation in the green total factor productivity, meaning that high-value areas tend to be surrounded by other high-value areas. Conversely, when the global Moran's I index approaches -1, it indicates a negative spatial correlation, implying that low-value areas are surrounded by other low-value areas. If the global Moran's I index approaches 0, it suggests a random distribution of the green total factor productivity. Therefore, by utilizing the global Moran's I index to measure the spatial spillover effects of green total factor productivity in agricultural product circulation among provinces along the Belt and Road Initiative in China, we can understand the degree of mutual influence among different provinces and the spatial distribution patterns of green total factor productivity in agricultural product circulation.

Spatial Weight Matrix	Moran's I coefficient	Variance	Z--score	P-value
Spatial Weight Matrix based on Geographic Adjacency	**0.154**	**0.035**	**4.508**	**0.000*****
Spatial Weight Matrix based on Geographic Distance	**0.109**	**0.030**	**6.677**	**0.000*****
Spatial Weight Matrix based on Economic Distance	**0.133**	**0.065**	**2.089**	**0.018*****

Note: *** indicates significance at the 1% level.

According to the calculation results of the global Moran's I index, the Moran's I coefficient for the Spatial Weight Matrix based on Geographic Adjacency is 0.154, with a p-value of 0.000. This indicates a significant positive correlation in the green total factor productivity of agricultural product circulation between adjacent provinces. In the geographic adjacency spatial weight matrix, the similarity in economic structure, market demand, and resource utilization among provinces leads to an agglomeration effect in the green total factor productivity of agricultural product circulation. This spatial spillover effect can promote technological cooperation and agricultural product circulation between neighboring provinces, thereby collectively improving the green total factor productivity of agricultural product circulation.

Secondly, the Moran's I coefficient for the Spatial Weight Matrix based on Geographic Distance is 0.109, with a p-value of 0.000. This indicates a significant positive correlation in the green total factor productivity of agricultural product circulation between provinces that are geographically close. This is due to the similarity in natural environmental conditions, resource distribution, and regional development background among these provinces. The proximity in geographic distance facilitates mutual influence and interaction in the green total factor productivity of agricultural product circulation, resulting in spatial clustering effects.

Finally, the Moran's I coefficient for the Spatial Weight Matrix based on Economic Distance is 0.133, with a p-value of 0.018. Although the degree of correlation is slightly lower than that of the geographic adjacency spatial weight matrix, it still shows a certain level of positive correlation. Similar industrial structure, market demand, and economic policies in the economic spatial dimension lead to similar variations in the green total factor productivity of agricultural product circulation among different provinces. This

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implies that economic factors play a role in the spatial distribution of green total factor productivity in agricultural product circulation.

In conclusion, the spatial spillover effects of green total factor productivity in agricultural product circulation among provinces along the Belt and Road Initiative in China are mainly influenced by geographical adjacency, geographic distance, and economic factors. The similarity and proximity between neighboring provinces contribute to positive spatial clustering, effectively enhancing the green total factor productivity of agricultural product circulation along the Belt and Road Initiative. indicates significance at the 1% level

6.Suggestions

6.1 To enhance technological innovation and improve green total factor productivity:

On one hand, optimizing resource allocation is crucial in strengthening resource allocation efficiency within the agricultural product circulation sector. This can be achieved through optimizing land utilization, water resource management and energy utilization, among other aspects, to enhance productivity and resource utilization efficiency.

On the other hand, it is essential to drive the development of agricultural modernization by increasing investment in technology and promoting the modernization and digital transformation of agriculture. Within the framework of constructing a dual-cycle development pattern that integrates both domestic and international markets, the application of technologies such as the Internet of Things, big data, and artificial intelligence can elevate the accuracy of production decision-making and the level of intelligent agricultural production.

Eventually, it is vital to encourage the adoption of sustainable agricultural practices, including organic farming, restoration and conservation of agricultural ecosystems, and climate-smart agriculture. By embracing ecologically friendly agricultural production methods, it becomes possible to mitigate the environmental impact and enhance production efficiency.

By optimizing resource allocation, driving agricultural modernization, and promoting sustainable agricultural practices, it is possible to improve resource utilization efficiency, foster technological advancements, and reduce environmental impact. These endeavors contribute to the enhancement of green total factor productivity within the agricultural product circulation sector.

6.2 To optimize environmental regulations and establish interdepartmental coordination mechanisms:

On one hand, the Chinese government and relevant departments should develop scientific and rational environmental regulatory measures that balance the relationship between environmental protection and the development of the agricultural product circulation industry. It is important to ensure that regulatory measures meet the requirements of green production and circulation, encourage enterprises to adopt sustainable production methods, and provide necessary technological and financial support.

On the other hand, establishing interdepartmental coordination mechanisms for the development of agricultural product circulation is crucial to strengthen policy alignment and resource integration. This includes increasing financial support for agricultural product circulation enterprises, such as loans, venture capital, and innovative financial products. Encouraging financial institutions to innovate financial services by providing financing facilities and risk management tools can effectively promote the improvement of green total factor productivity, the utilization of spatial spillover effects, and the development of the green agricultural product circulation industry.

Lastly, the government should strengthen guidance and supervision of the agricultural product circulation industry to promote standardized development. This can be

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achieved by enhancing market access management, product quality monitoring, and information disclosure, while safeguarding market order and consumer rights.

6.3 To cultivate a new green agricultural product supply chain system and strengthen the coordinated development of the industry chain:

On one hand, in the process of agricultural product circulation development, it is important to establish a green supply chain system and develop a modern agricultural product circulation system. This can be achieved by integrating production, processing, and distribution processes to improve the transparency and efficiency of the supply chain. Strengthening agricultural product quality and safety monitoring and traceability system construction can enhance consumer trust in green agricultural products.

On the other hand, promoting cooperation and synergy among agricultural product circulation enterprises, production enterprises, and consumer enterprises is crucial. This can be achieved through the establishment of information sharing platforms and cooperation mechanisms to strengthen industry chain collaboration, improve total factor productivity, and enhance product quality. Further efforts should be made to promote the construction of green agricultural product brands, increase product added value, and enhance market competitiveness. By extending the industrial chain, developing deep processing, upgrading the value chain, positioning high-end products, and creating a supply chain, efficient internal circulation within the cluster and effective external linkage can be achieved.

Lastly, increasing investment in talent development and technological innovation in the agricultural product circulation field is essential. This involves cultivating specialized and international talent teams, enhancing technological research and development, and innovation capabilities to drive overall improvement in green total factor productivity.

6.4 To establish green demonstration zones and promote coordinated development between regions:

On one hand, with the rapid development of the global economy and the acceleration of globalization, China's "Belt and Road" initiative is gaining recognition and participation from an increasing number of countries. Establishing green demonstration zones in the provinces along the Belt and Road is a crucial measure. By establishing these zones, it is possible to achieve resource complementarity and promote the overall factor productivity and sustainable development of the agricultural product circulation sector. Moreover, the demonstration zones can integrate resources and create innovative models and benchmark enterprises in green agricultural product circulation, attracting investment and talent and driving the development of surrounding areas.

On the other hand, strengthening economic cooperation and coordination among countries along the Belt and Road is also essential. By sharing management experience, technological innovation, and market information, and strengthening resource integration and coordinated development, the maximum spillover effects can be achieved. Additionally, governments can provide preferential policies and investment environments to attract foreign enterprises to participate in the development of the agricultural product circulation industry, thus helping local agricultural product circulation enterprises expand their international markets and enhance their export competitiveness.

Lastly, cooperation along the Belt and Road is not limited to economic cooperation but also encompasses various fields such as politics, culture, and society. Therefore, in promoting the Belt and Road initiative, it is important to highly regard the diverse cultures and historical backgrounds of countries along the route and establish a cooperative relationship based on mutual respect, equality, and mutual benefit. Only by doing so can the long-term and stable development of the Belt and Road initiative be achieved, injecting new vitality into promoting national green, low-carbon transformation, jointly achieving the United Nations' 2030 Sustainable Development Agenda, and building a community of shared future for humanity and nature.

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