The impact of technological advancements on carbon emissions in agriculture and rural areas

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Abstract: Rural agriculture is an essential aspect of carbon emission reduction and sequestration and also has the potential to achieve "carbon peak" and "carbon neutrality." A DEA-Malmquist index model is used to estimate the technical progress of agriculture using panel data from 30 provinces from 2012 to 2021. The evolution trend and spatial correlation of agricultural and rural carbon emissions are measured based on the spatial and temporal dimensions. The dynamic panel spatial lag model was also used to empirically test the mechanism of agricultural technological progress affecting agricultural rural carbon emissions. The results show that: ① There are apparent evolutionary characteristics and spatial agglomeration of agricultural and rural carbon emissions, and carbon pollution between provinces shows a weakening trend ② Agricultural technological progress can effectively drive carbon emission reduction in agriculture and rural areas, and the improvement of the farmers' income structure can effectively regulate the carbon emission reduction efficacy of the total factor productivity, technological efficiency, and technological upgrading ③ The negative spatial spillover effect of agricultural technological progress on carbon emissions is significant; when the introduction of the farmers' income structure as an interaction term, the negative spatial spillover effect of agricultural technological progress is significant. The negative spatial spillover effect of agricultural technological progress on carbon emissions is significant; introducing farmers' income structure as an interaction term weakens the negative spatial spillover effect.

1. Introduction

With the deepening of rural reform and the accelerated modernization of agriculture and rural areas, production in the agricultural sector has risen dramatically, and the quality of life of rural residents has improved significantly. At the same time, however, the production and business model characterized by high consumption of agricultural resources has not changed; green production and low-carbon processing technologies in the farming industry are lagging, and the urgent need to address the challenges of rural human settlements remains prominent, and the problems of atmospheric pollution and carbon emissions caused by production and living are serious. Due to inappropriate large-scale production patterns, China's arable land area for food production has stagnated and has shown a declining trend over the past decades[1]. Statistics show that from 2004 to 2014, China contributed about 19% of global food production while using about 30% of the world's fertilizer resources[2]. The heavy reliance on fertilizers has led to adverse environmental consequences, including global water pollution, eutrophication, and air pollution[3]. At the same time, the marginalization of the countryside in rapid urbanization, the predatory exploitation of rural environmental resources, and the widespread transfer of pollution sources from towns and cities have led to the rapid de-farming of the rural population, land, capital, and other factors. Under this dualistic Structure of urban and rural governance, rural environmental governance has seriously lagged, making "dirty, messy, and poor" almost synonymous with rural areas[4]. A series of problems, such as the loss of rural intellect, the emptying of land, and the defacement of the environment, have arisen[5]. Nowadays, the surface pollution in the countryside and the exogenous pollution transported from the city to the countryside make the sustainable development of agriculture and rural areas face a threat[6], and reducing carbon emissions in agriculture and rural areas is a must.

Nowadays, the importance of reducing carbon emissions in agriculture and rural areas is widely recognized in the academic world. Accelerating the development of eco-agriculture and recycling agriculture, improving the ecological environment in agriculture and rural areas, and increasing the efficiency of agricultural resource utilization will help to form a pattern of comprehensive agricultural development that is compatible with the carrying capacity of resources and the environment, and coordinated with the conditions of production and living, and will promote modernization [7]. Encouraging the resource utilization of agricultural and rural waste and vigorously developing biomass energy and

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other clean energy sources will help improve the human environment and achieve ecological revitalization [8]. Reducing the intensity of greenhouse gas emissions during agricultural production and rural life and improving the capacity of farmland to sequester carbon can enhance the agricultural sector's adaptive capacity to climate change and significantly contribute to global climate governance.

The innovations in this paper are as follows:

On the one hand, this paper focuses on the coordinated promotion of farmers' income improvement and ecological livability. It complements and improves the mechanism of agricultural technological progress on carbon emissions in agriculture and rural areas, elucidates the transmission mechanism of its driving factors, and explores the impact that the carbon emission reduction effect brought about by technological progress will have on the income structure of farmers. This will help to fully use the ecological benefits of technological progress and provide theoretical guidance for achieving sustainable income growth.

On the other hand, this paper considers the endowment differences of different geographical regions. Focusing on the spatial and temporal dimensions, it measures the spatial and temporal characteristics of carbon emissions in agriculture and rural areas and conducts theoretical analyses and empirical tests of the spatial spillover effects of the impacts; this will help to provide constructive suggestions for the achievement of coordinated regional development while promoting the sustainable development of agriculture and rural areas as a whole.

2. Research hypothesis

2.1 Mechanism of agricultural technology Progress affecting agricultural and rural carbon emissions

Marx believes that the change in production technology and production method plays an important role in the development of human history, and the productive forces are the most active and revolutionary factors in social development. China is in a critical period of transformation and upgrading from traditional agriculture to modern agriculture. The traditional extensive high-carbon agriculture has caused a serious negative impact on the rural ecological environment. The technological change brought by technological progress can realize the leap in productivity and solve the problem of backward green production and low-carbon processing technology in the planting and breeding industry. We will promote the transformation of traditional agriculture into modern agriculture characterized by mechanization, industrialization, and informationization. This phenomenon can be explained by the neoclassical theory of technological innovation, the neo-Schumpeterian theory, and the national innovation system theory.

The neoclassical school of technological innovation, represented by R. Solow, introduced the concept of the "Solow black box". At the same time, it is first proposed that economic growth mainly comes from the "growth effect" caused by the accumulation of factors and the "level effect" caused by the improvement of the technical level of factors. And consider the role of government intervention in technological innovation. This theory reveals the important role of technological progress in productivity improvement, and can effectively solve the problem of factor mismatch. At present, China has serious problems such as overcapacity, employment difficulties, and waste of land resources, which reflect the unreasonable allocation structure of different production factors such as capital, labor, and land in our country. With the significant improvement of technical efficiency, the extensive application of modern science and technology can provide support for the full utilization of traditional production factors in rural areas and effectively improve the quality and efficiency of the supply system. The use of modern science and technology and modern equipment to restructure agriculture and build an agricultural ecosystem with rational utilization of resources, effective environmental protection, and a high economic conversion rate can solve the problems of agricultural resource mismatch, high production cost, and low efficiency, and realize energy-saving and low-carbon development in rural areas. At the same time, the application of information technology in different departments and different economic entities can speed up the marketization of factors, eliminate information barriers in the flow of factors, effectively solve the demand-side problem of rural overcapacity, and effectively alleviate the rural non-point source pollution caused by the unmarketable products caused by the expansion of production capacity.

The neo-Schumpeterian school reveals the inner workings of the "black box". Kaman et al. argue that the more competition there is, the greater the incentive to innovate; The larger the scale of the enterprise, the larger the market opened up in technological innovation, and the more durable the technological innovation. The agricultural product market is a typical perfect competition market, which is characterized by the homogenization of products and distribution channels. Therefore, agricultural enterprises need to obtain super profits through technological innovation, which is reflected in the agricultural pre-production, production, and post-production links. In terms of cost savings, the wide application of new technologies such as smart agriculture can reduce the investment of traditional elements while ensuring the improvement of production capacity, and achieving sound development in line with environmental carrying capacity. Functional agriculture and other biotechnologies can deconstruct and reshape the traditional agricultural production mode, and promote the rational development and effective utilization of rural resources. In addition, the super profits generated by agriculture-related enterprises will encourage their competitors to carry out technological innovation in the development of local resources and the transformation of production and management modes. The attraction of local resources to capital can effectively alleviate the urban-rural dualization pattern, promote the integration construction, provide material support for the improvement of the living environment, and promote pollution prevention, energy conservation, and emission reduction of the whole society.

H1: Agricultural technology progress can curb agricultural and rural carbon emissions

2.2 Mechanism of farmers' income structure regulating agricultural and rural carbon emission reduction

The income structure of farmers can play a regulating role in the process of technological progress driving agricultural and rural carbon emissions, which includes internal driving and external driving. The intrinsic driving factors can be explained by the energy ladder theory, and the extrinsic driving factors can be analyzed by the dry theory.

Smith K.R.[9] proposed the Energy Ladder Hypothesis. The theory points out that household energy consumption will gradually shift from traditional energy sources to more low-carbon and efficient clean energy. Due to the dual constraints of income levels and household energy consumption, economically disadvantaged households have lower rates of household clean energy purchases and fewer green-biased technology applications than wealthier households. As a result, high-income households are more inclined to replace efficient equipment, while low-income households actively reduce energy consumption. Rural households with a high-income level and a reasonable income distribution structure can effectively reduce carbon emissions by investing in efficient equipment, adopting environmentally friendly technologies, and consuming low-carbon and efficient clean energy.

JM.Alam [10] supplemented the energy ladder theory and proposed that the household energy consumption structure would be affected by economic conditions, social structure, government policies, and other macro levels. As a major agricultural country, China's ancient farming culture has resulted in the current urban-rural dual governance pattern, which has led to different views of urban and rural residents on environmental change and the degree of dependence on natural resources. The expansion and extension of farmers' income channels and the provision of fundamental guarantees for rural poverty alleviation is the due meaning of consolidating and expanding the achievements of poverty alleviation and rural revitalization, and effectively alleviating the situation of dual division and governance. With the spillover of knowledge between urban and rural areas, can effectively enhance rural residents' awareness of the importance of energy conservation and emission reduction and lay a prerequisite for villagers to understand and implement energy conservation and emission reduction policies. When the energy policy disseminates information, villagers can use green bias technology to reduce energy costs, save household expenses, control environmental pollution, and transform the policy benefits into actual efficiency of energy conservation and emission reduction according to the policy information.

Extrinsic drive can be explained By the theory of Learning By Doing. In other words, when agricultural employees produce products and provide services, they also accumulate experience and acquire production skills and knowledge from experience, which helps to improve production efficiency and accumulate the total amount of knowledge, to reduce long-term production costs. The diversification and rationalization of farmers' income structure means the extension of income channels. In the process of realizing the expansion of income channels, the accumulation of experience, knowledge, and skills will be generated. Through professional means and innovative thinking, producers improve the level of professional production and scientific and technological innovation ability and promote the progress of green agricultural technology. At the same time, this technological progress will gradually accumulate with the expansion and extension of income channels and the reasonable optimization of income structure, forming cleaner production path dependence, promoting the transformation of traditional technologies to green and clean technologies, reducing environmental pollution, and achieving emission reduction and carbon reduction in agriculture and rural areas.

H2: The income structure of farmers can regulate the carbon emission reduction efficiency of agricultural technological progress

3. Research design

3.1 Indicator measurement

3.1.1 Technological advances in agriculture

Based on Solow's economic growth model, it is known that technological progress, in a broad sense, is the residual part of economic growth after removing the inputs of factors of production such as labor, capital, and natural resources, which is also known as total factor productivity (TFP). Existing scholars have introduced the DEA-Malmquist index to measure total factor productivity in agriculture, with this indicator reflecting the level of agricultural technology[11]. This paper is modeled on that approach to measure technological progress in agriculture. The methodology focuses on panel data consisting of multiple decision-making units, and the production process is constructed using a distance function. The actual performance of each production decision unit is then compared with the optimal frontier to distinguish between the technological upgrading index and changes in technological efficiency.

$$M_0(x^{t+1}, y^{t+1};\ x^t,\ y^t)$$
$$=\left(\frac{D_0^t(x^{t+1},y^{t+1}|C,S)}{D_0^t(x^t,y^t|C,S)}\times\frac{D_0^{t+1}(x^{t+1},y^{t+1}|C,S)}{D_0^{t+1}(x^t,y^t|C,S)}\right)^{1/2}$$
$$=\frac{D_0^{t+1}(x^{t+1},y^{t+1}|C,S)}{D_0^t(x^t,y^t|C,S)}\times\left(\frac{D_0^t(x^{t+1},y^{t+1}|C,S)}{D_0^{t+1}(x^{t+1},y^t+1|C,S)}\right.$$
$$\left.\mathrm{x}\frac{D_0^t(x^t,y^t|C,S)}{D_0^{t+1}(x^t,y^t|C,S)}\right)^{1/2}$$
$$=TEC(x^{t+1},y^{t+1};x^t,y^t)\times TP(x^{t+1},y^{t+1};x^t,y^t) \quad (1)$$

M denotes the Malmquist index, TEC denotes the technical efficiency change indicator, and TP denotes the technical upgrading indicator. D denotes the directional distance function, C denotes the constant scale payoff;x^t D denotes the directional distance function, and C denotes the constant scale payoff.y^t denotes production at time t. In this paper, the gross output value of agriculture, forestry, animal husbandry, and fishery in a broad sense is chosen as the output indicator. The Number of employees in the primary industry (10,000 people), the total power of agricultural machinery (10,000 kilowatts), the amount of fertilizer applied to agricultural production (10,000 tonnes), the sown area of crops (1,000 hectares), and the scale of input of fixed assets in agriculture (100 million yuan) are chosen as the input indicators. Outputs and inputs use 2012 as the base period.

To compare the relative differences in productivity levels of different economic agents, total factor productivity in agriculture is expressed in relative terms as follows:

$$CML_h = D_h^{12} x_h^{12}, \ y_h^{12} \times \prod_{t=2012}^{T} ML_h^t \quad (2)$$

t denotes the time thatD_h^{12} (x_h^{12}, y_h^{12}) denotes the distance function of the hth province in 2012, andML_h^t denotes the Malmquist index for the hth province in year t. CML denotes total factor productivity.

3.1.2 Structure of farmers' income

Drawing on Yang Shaoxiong et al. (2023)[12], the Structure of farmers' income (FIS) consists of three components: diversification of internal income sources, balance of internal income sources, and balance of external income structure. Diversification of internal income sources is measured by the Herfindahl index of the four major categories of itemized income; the balance of internal income sources is measured by the sum of squared deviations of the proportions of the four major categories of itemized income; and the balance of the external income structure is measured by the ratio of disposable income per capita of urban residents to that of farmers. All three indices are negative indicators and the Structure of farmers' income as measured shows that the lower the value, the more reasonable the Structure, and for simplicity of calculation, the inverse is taken.

3.1.3 Rural carbon emissions from agriculture

Measurement of Carbon Emissions from Cultivation: The primary carbon source in agricultural production is the consumption of agricultural materials. The actual usage data of pesticides, fertilizers, agricultural plastic films, diesel fuel, and electricity for agricultural irrigation are based on the actual usage of the year; the pesticide, fertilizer, and agricultural film coefficients are shown in Table 1. Agricultural machinery emissions are calculated based on diesel use; diesel is a primary energy source, and its carbon emission formula is of the following form:

$$C \sum FC_i \times NVC_i \times CC_i \times O_i \quad (3)$$

$FC_i$is the physical volume of fossil energy of type I (in tonnes or billion cubic meters); NVC_i is the value of heat per unit of energy of type I (in kilojoules per kilogram or kilojoules per cubic meter); CC_i is the carbon content per unit calorific value of I energy source (unit: kilojoules per gigajoule); O_i is the rate of carbon oxidation during fuel combustion.

Electricity consumed for agricultural irrigation is a secondary energy source, calculated as:

$$\sum C_j \times ELC_j \quad (4)$$

Formula Six: ELC_j is the electricity consumption (unit: billion kWh). C_j is the electricity emission factor, selected as 0.5810tCO2/MWh concerning the "Guidelines for Corporate Greenhouse Gas Emission Accounting Methodology and Reporting for Electricity Generating Facilities (Revised 2022)".

Carbon emissions from livestock: Due to the differences in the growth cycles of different livestock and poultry, it is necessary to discount their data according to the life cycle, which is based on the following formula:

$$T_i = \begin{cases} D_i \times \frac{M_i}{365}, \ D_i < 365 \\ \frac{C_{it} + C_{i(t-1)}}{2}, \ D_i \geq 365 \end{cases} \quad (5)$$

The methane emission factors for enteric and fecal fermentation of livestock selected for this paper are from IPCC (2006), while the nitrous oxide emission factors for fecal fermentation of livestock are based on existing studies.

Carbon emissions from familiar energy sources: Commonly used energy sources in the countryside include coal, oil, natural gas, and electricity. Considering data availability, coal consumption (10,000 tonnes) and electricity consumption (100 million kWh) in the countryside are selected to characterize the carbon emissions from commonly used energy sources. Carbon emissions from rural coal consumption are calculated according to equation (3); carbon emissions from rural electricity consumption are calculated according to equation (4).

Total carbon emissions: Total carbon emissions are characterized by increasing carbon emissions from cultivation, livestock, and typical energy sources.

$$CE_T = CE_P + CE_A + CE_U \quad (6)$$

CE_T denotes total carbon emissions , CE_P denotes carbon emissions from cultivation, CE_A denotes carbon emissions from animal husbandry , and CE_U denotes carbon emissions from commonly used energy sources.

3.1.4 Control variables

Capital flows (cf): using rural fixed asset investment in each province, calculate the capital inflow from towns to villages.

Non-consumer goods flow (ncgf): applying the difference between rural consumption expenditure on subsistence and food consumption expenditure to calculate the inflow of urban non-farm consumer goods to the countryside.

3.2 Modelling

Considering the possible endogeneity between agricultural technological progress, farmers' income structure, and agricultural and rural carbon emissions. A dynamic panel spatial regression model is constructed to analyze spatial spillovers quantitatively.

$$\ln CE_{it} = \alpha + \partial W_{it} \ln CE_{i,t-1} + \gamma W_{it} \ln CE_{it} + \beta X_{it} + \omega_i + v_t + \varepsilon_{it} \quad (7)$$

where α denotes the constant term, and β denotes the regression coefficient, and γ denotes the spatial dependence between explanatory variables in the neighboring region, and $_{it}$ is the spatial weight matrix (the spatial adjacency matrix is chosen to be explored in this paper), and ω_i is the fixed effect, the v_t is the time fixed effect, and ε_{it} is the spatial error term.

$$W_{ij} = \begin{cases} 1, & i = j \\ 0, & i \neq j \end{cases} \quad (8)$$

The existence of a common geographical boundary between two areas is recorded as 1, and the absence of a common geographical boundary is recorded as 0.

3.3 Data sources

The gross output value of agriculture, forestry, animal husbandry, and fishery, per capita wage income of rural residents, per capita operating income of rural residents, per capita operating income of rural residents, per capita operating income of rural residents, Number of people employed in the primary industry, total power of agricultural machinery, fertilizer use, use of plastic film, use of plastic film, use of diesel oil in agriculture, use of agricultural diesel oil in agriculture, use of agricultural diesel oil in agriculture, use of agricultural diesel oil in agriculture, and Number of livestock stocked at the end of the year, Number of livestock stocked at the end of the year, sown area of crops, the scale of investment in agricultural fixed assets, expenditure on non-farm consumer goods, data from China Rural Statistical Yearbook; rural coal consumption, rural coal consumption data from China Energy Statistical Yearbook.

4. Characteristics of rural carbon emissions from agriculture

4.1 Kernel evolution characteristics of total carbon emissions

The peak value of the Kernel curve generally presents an upward trend, and the right tail extension phenomenon is generally weakened, without an obvious multi-peak phenomenon. This indicates that the spatial difference in carbon emissions from agriculture and rural areas in China is gradually narrowing, and there is no obvious differentiation. It can be shown that the sustainable development of the agricultural sector has achieved remarkable results in recent years, and provinces have controlled carbon emissions by using green bias technology and adopting low-carbon and clean energy.

4.2 Aggregation effect of agricultural and rural carbon emissions

4.2.1 Global Moran's I index

The results show that the spatial spillover effect of inter-provincial agricultural and rural carbon emissions has gradually weakened in recent years, and is generally not significant. On the one hand, it shows that non-point source pollution in rural areas has been alleviated with the further promotion of urban and rural human settlement environment governance; on the other hand, it shows that exogenous pollution transported from cities to rural areas has been weakened with the increasing importance of ecological livability.

4.2.2 Local Moran's I index

The results illustrate that in 2012, Xinjiang, Tibet, Ningxia, Beijing, and Tianjin showed a low aggregation trend. These areas are the primary grain marketing and balance areas; the areas have weak environmental gravity and low agricultural production capacity. Hebei, Henan, Shandong, Jiangsu, and Anhui show a high aggregation trend. These areas are dominated by plains, with favorable conditions for the development of farming and planting, and are the main grain-producing areas. Shanxi and the neighboring Hebei, Henan, and Shandong show a low-high aggregation trend. Compared with 2012, there is a clear trend of high-value agglomeration in Shaanxi Province and the surrounding areas in 2021. This phenomenon can be attributed to the fact that the carbon emissions from animal husbandry and plantations in Shaanxi Province must be effectively managed, and there are limitations in reducing carbon emissions.

5. empirical analyses

Firstly, the LM test is performed. lM lag and Robust LM lag present statistically significant, and LM error and Robust LM error are not significant; thus, it is judged that the spatial lag model is used. Secondly, the Hausman test was conducted. The results show a p-value of 0.000, indicating that the fixed effects model is chosen for further exploration. Finally, the spatial lag model of the dynamic panel is constructed to analyze the impact mechanism.

Table 1 Dynamic panel spatial lag model

	$\ln CE_T$		
	Direct effect	Indirect effect	Total effect
CML	-1.340** (-1.86)	0.736** (1.87)	-0.599** (-1.64)
TP	1.151** (1.91)	0.356** (1.73)	1.658** (2.04)
TEC	1.016* (1.78)	0.315* (1.55)	1.331* (1.86)
FIS*CML	-1.841** (-2.81)	0.079** (0.76)	-1.620** (-2.60)
FIS*TP	-0.562*** (-2.59)	0.134** (2.02	0.428** (2.39)
FIS*TEC	-0.129 (-0.35)	0.037 (0.39)	0.092 (0.32)
Spat. rho		-0.341** (-2.29)	
Time lag		Yes	
Spatial lag		Yes	
Control variable		Yes	
R2		0.395	
Logl		285.371	

Table 1 shows the impact of technological progress on total agricultural and rural carbon emissions considering temporal and spatial factors. As can be seen from the direct effect, the total factor productivity of the province increased by 1 unit, and the total carbon emission of agriculture and rural areas decreased by 1.340 units; When technology upgrading increases by 1 unit, total carbon emissions from agriculture and rural areas increase by 1.151 units; The technical efficiency increased by 1 unit, and the total carbon emission in agriculture and rural areas increased by 1.016 units. This result confirms hypothesis 1 and shows that in the case of considering spatio-temporal factors; The efficiency of technological progress in reducing carbon emissions has not changed.

It can be seen from the indirect effect that the increase of total factor productivity in the province will promote agricultural and rural carbon emissions in the surrounding provinces; When total factor productivity increases by 1 unit, carbon emissions of neighboring provinces increase by 0.736 units. For every 1 unit increase in technological upgrading and technological efficiency of the province, the carbon emissions of the neighboring provinces increased by 0.356 and 0.315 units, respectively. Agricultural technological progress in the province will increase agricultural and rural carbon emissions in neighboring provinces, which can be explained by the "club" effect and the "siphon" effect. According to the calculation results of the above Moran’s I index, China's agricultural and rural carbon emissions show obvious spatial aggregation. Regions with high carbon emission levels are generally major grain-producing areas with weak economic foundations and insufficient supply of human capital. Regions with low carbon emission levels generally have a superior economic foundation, strong independent innovation ability, and vigorous development of green technological progress. However, such technological progress will "siphon" human, material, and financial resources from high-carbon regions, increase competition among high-carbon regions, lead to an insufficient supply of innovative factors, and seriously hinder the process of carbon reduction in agriculture and rural areas.

After adding farmers' income structure as an interactive variable. The technological progress of the province will still promote agricultural and rural carbon emissions in the surrounding provinces, but the promotion effect is significantly weakened. It shows that farmers' income structure can regulate the negative spatial spillover effect of technological progress. This result reveals that with the coordinated promotion of ecological livability and farmers' income and quality improvement, provinces will achieve regional coordinated development of carbon emission reduction in agriculture and rural areas. This result confirms hypothesis 2 and explains the regulating effect of farmer income structure

6. Conclusions

Agricultural and rural carbon emissions have obvious evolutionary characteristics and spatial aggregation. The spatial differences of agricultural and rural carbon emissions in China are gradually narrowing, and there is no obvious differentiation. The negative spatial spillover effect of interprovincial agricultural and rural carbon emissions was gradually weakened. The main grain-selling area and grain balance area generally showed a low-low accumulation trend, and the main grain-producing area generally showed a high-high accumulation trend. In the case of time and space factors, the carbon reduction efficiency of technological progress has not changed significantly. Technological progress has a significant negative spatial spillover effect on carbon emissions, and the increase of total factor productivity in the province will increase agricultural and rural carbon emissions in neighboring provinces. The income structure of farmers can regulate the negative spatial spillover effect of technological progress. The introduction of farmers' income structure as an interactive term weakens the negative effect of the spatial spillover effect.

The advancement of agricultural technology and the improvement of farmers' income structure will play an important role in achieving carbon emission reduction targets in agriculture and rural areas. Therefore, policymakers should pay attention to the promotion and application of agricultural technological advances, while optimizing the income structure of farmers to better promote the carbon reduction work in agriculture and rural areas. This will not only help achieve the country's "peak carbon" and "carbon neutral" goals but also help promote sustainable agricultural development and ecological protection. Specific measures are as follows: to carry out green agricultural practices according to local conditions. Local governments should make effective planning and macro-guidance, establish demonstration models, and ensure adequate financial support and service assistance. Cooperatives, leading enterprises, and other new agricultural business entities should make full use of the progress of green agricultural technology, emphasizing efficient input of factors and scientific matching. Priority should be given to reasonable soil improvement inputs, and large-scale management should be gradually achieved through scientific and sustainable production inputs to enhance the level of industrial development. Actively encourage and support the development of "new farmers" and "modern farmers", train a new generation of agricultural knowledge-based talents proficient in green management methods, promote innovation in the planting industry, method innovation, and product innovation, and provide new momentum for sustainable agricultural development. At the same time, promotes the coordinated flow of cross-provincial production factors, and promotes the cross-border integration and reorganization of agricultural scientific and technological innovation. From the technological innovation of production links to the coupling of whole-factor and whole-chain technological innovation in the whole process, such as planting, breeding, marketing, resources, and environment, to create a full range of whole-chain scientific and technological support, and alleviate inter-provincial carbon pollution.

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