sustainability

MDPI

Article

The Impacts and Spatial Characteristics of High-Standard Farmland Construction on Agricultural Carbon Productivity

Xiayire Xiaokaiti [1], Hongli Zhang [1,2,*] and Nan Jia [1]

[1] College of Economics and Management, Shihezi University, Shihezi 832000, China; xiayirexiaokaiti@stu.shzu.edu.cn (X.X.); frankiejia@stu.shzu.edu.cn (N.J.)
[2] Agricultural Modernization Research Center, Shihezi University, Shihezi 832000, China
* Correspondence: zhl8291@shzu.edu.cn

Abstract: Agricultural carbon productivity combines the dual attributes of reducing carbon emissions and stabilizing economic growth, and is a core aspect of the new era of low-carbon agricultural development. The construction of high-standard farmland is an important initiative to promote high-yield and high-efficiency agriculture, as well as environmentally sustainable development through land improvement in China. However, the impact of high-standard farmland construction on agricultural carbon productivity and its mechanisms is still in the process of being determined. In order to fill this gap, this study aims to construct a theoretical, analytical framework for the impact of high-standard farmland construction on agricultural carbon productivity. Based on the current situation of high-standard farmland construction and the characteristics of agricultural carbon productivity in China, this study used the panel data of 31 provinces, from 2003 to 2017 in China, to empirically examine the effects, mediating paths, and spatial characteristics of the construction of high-standard farmland on agricultural carbon productivity using a double fixed-effects regression model, a mediating-effects model, and a spatial econometric model. The results show that: (1) High-standard farmland construction has a positive effect on agricultural carbon productivity, with a direct effect coefficient of 0.139 after adding a series of control variables. (2) Furthermore, heterogeneity analysis shows that the impact of high-standard farmland construction on agricultural carbon productivity will vary greatly depending on the topographic characteristics of the studied area, the level of economic development, and whether it is a main grain-producing area. (3) Mechanism analysis shows that agricultural scale operation, agricultural planting structure, and agricultural technology progress all have partial mediating roles in the impact of high-standard farmland construction on agricultural carbon productivity, with mediating effect coefficients of 0.025, 0.024, and 0.013, respectively. (4) Agricultural carbon productivity has a spatial correlation, and for every 1% increase in the level of high-standard farmland construction, agricultural carbon productivity increases by 0.117%, with a direct effect of 0.074% and a spatial spillover effect of 0.043%. Our study explains the impact effects, mechanisms, and spatial spillover effects of high-standard farmland construction on agricultural carbon productivity from theoretical and empirical perspectives, thus deepening the literature on the relationship between high-standard farmland construction and agricultural carbon productivity, and providing a theoretical basis and practical references for improving agricultural carbon productivity from the perspective of high-standard farmland construction policy.

Keywords: farmland infrastructure; environmentally friendly agricultural production; mediating effect; spatial effect; China

Citation: Xiaokaiti, X.; Zhang, H.; Jia, N. The Impacts and Spatial Characteristics of High-Standard Farmland Construction on Agricultural Carbon Productivity. *Sustainability* **2024**, *16*, 1481. https://doi.org/10.3390/su16041481

Academic Editor: Georgios Koubouris

Received: 27 December 2023
Revised: 6 February 2024
Accepted: 7 February 2024
Published: 9 February 2024

1. Introduction

The traditional "high-input, high-output, high-emission" model of agricultural production has contributed to the rapid growth of the farming economy, yet it seriously threatens the sustainability of the agricultural production system, with agricultural greenhouse gas (GHG) emissions accounting for 23% of total global anthropogenic carbon emissions (<<SPECIAL REPORT: SPECIAL REPORT ON CLIMATE CHANGE AND LAND>>, https://www.ipcc.ch/srccl/chap%E2%80%90, accessed on 30 January 2024). To promote the coordinated development of agricultural economic growth and carbon emission reduction, in recent years, the Chinese government has issued the "14th Five-Year Plan for National Green Agricultural Development", the "Peak Carbon Action Program by 2030", and the "Program for Emission Reduction and Carbon Sequestration in Agriculture and Rural Areas", which systematically determine how agriculture and rural areas can balance the development requirements of increasing production and income with the ecological objectives of emission reduction and carbon sequestration. Agricultural carbon productivity considers the dual goals of reducing carbon emissions and promoting economic growth, which is an essential criterion for measuring the success of climate change mitigation, but is also an inevitable choice for realizing the dual success of modern agricultural development and ecological environmental protection [1].

Scholars have conducted a large number of studies and measurements on agricultural carbon productivity, not only analyzing the development and changes in agricultural carbon productivity over time [2–4], but also conducting a large number of studies on the regional variability and spillover of agricultural carbon productivity from a spatial perspective [5–7]. Scholars generally believe that the natural production conditions of agriculture, as well as the level of agricultural economic development, rural human capital, rural industrial structure, urbanization, agricultural technological progress, the degree of marketization, and so on impact agricultural carbon productivity [8–10]. In addition, policy implementation is widely recognized as a practical pathway for reducing agricultural carbon emissions and promoting agricultural economic growth [11–13]. However, debates are ongoing as to the extent of the impact of policy on agricultural carbon productivity. Some scholars believe that policies can effectively enhance agricultural carbon productivity. For example, Fang, L. et al. found that crop insurance policies can not only promote agricultural economic development, but also promote the use of agricultural green technologies such as deep fertilizer application, deep plowing, and no-tillage, thus reducing carbon emissions and contributing to the promotion of agri-environmental total factor productivity growth [14]. Ramzan, M. et al. argued that implementing environmental protection investments in governmental agricultural sectors is conducive to implementing environmental protection investments without damaging agricultural productivity and while mitigating environmental pollution [15]. Some scholars have argued that policies can inhibit agricultural carbon productivity gains. Wang, S. et al., based on the panel data of 30 provinces in China from 2008 to 2020, found that an agricultural fiscal expenditure policy would promote the growth of the agricultural economy and carbon emissions in the region, which would be detrimental to the improvement of agricultural carbon productivity both therein and in neighboring regions [16]. Ye, D. et al. utilized the panel data of 30 Chinese provinces from 1998 to 2020 and found that, although a policy on grain production areas could enhance agricultural total factor productivity, it would promote the growth of agricultural carbon emissions and thus suppress agricultural carbon productivity [17]. Based on the above analysis, it can be seen that some of China's agricultural policies have been implemented chiefly for economic benefit, but this may not be conducive to the improvement of agricultural carbon productivity. Therefore, it is of great practical significance to comprehensively assess agricultural policies' economic and ecological benefits under the dual objectives of agricultural economic growth and carbon emission reduction.

High-standard farmland construction is the largest single financial expenditure project in China's agriculture-related field [18]. Its main goal is to promote agricultural scaling and specialization through land remediation, strengthening agricultural infrastructure construction, and promoting green and low-carbon production technologies to improve agricultural production efficiency and reduce environmental pollution [19]. Whether high-standard farmland construction can balance economic and ecological benefits is related to improving agricultural carbon productivity. From the perspective of economic benefits, scholars have found that the construction of high-standard farmland can improve returns to economies of scale [20], enhance the efficiency of agricultural mechanization applications [21], improve the total factor productivity of agriculture [22], and increase agricultural output [23]. However, Bradfield, T. et al. found that the construction of high-standard farmland accelerates the substitution of machinery for labor, and this increases the loss of agricultural production [24]. Baráth et al. believe that the improvements to the natural environment that high-standard farmland construction will bring forth will be detrimental to agricultural production, and it may not affect the total factor productivity of agriculture [25]. In terms of ecological benefits, most scholars believe that the construction of high-standard farmland can reduce the efficiency and intensity of the use of high-carbon input factors, such as chemical fertilizers [26]; promote the application and dissemination of advanced low-carbon production technologies [27]; and reduce agricultural carbon emissions [28]. Based on the above studies, it can be found that research results centering on the production benefits and carbon-emission-reduction effects of high-standard farmland construction, respectively, are relatively abundant. However, fewer research results focus on carbon productivity nor consider both agricultural economic growth and carbon reduction. Tang, W. et al. constructed an indicator system covering agricultural resource conservation, agricultural and environmental management, and total agricultural output value to examine the impact of high-standard farmland construction on the development of green agriculture. They found that high-standard farmland construction can improve the efficiency of agricultural production while reducing environmental pollution [29]. However, the study only used data from a single province in China's Hunan Province, which is not conducive to grasping the whole on the macro scale, as well as having only analyzed the mechanism of agricultural scaling operations, leading to the need for more excavation of other potential mechanisms. In addition, constructing high-standard farmland can promote the flow of factors between regions and the diffusion of technology [28]. At the same time, it has a specific demonstrative effect from one region to neighboring regions, making it easy to produce spatial spillover effects. Previous studies have also paid too little attention to this.

This study utilizes China's provincial-level panel data from 2003 to 2017. It adopts double fixed-effects regression models, instrumental variable models, mediated-effects models, and spatial econometric models to analyze the effects, mediated pathways, and spatial characteristics of high-standard farmland construction on agricultural carbon productivity to explore whether and how the structure of high-standard farmland can achieve dual success for both the economy and the environment. Compared with previous studies, the possible contributions of this study are as follows: First, we focus on the carbon emission reduction and economic growth promotion of high-standard farmland construction, providing empirical evidence to support the dual enhancement of agricultural, economic, and environmental benefits. Secondly, we systematically study the influence mechanism of high-standard farmland construction on agricultural carbon productivity. Based on the logical framework of "scale-structure-technology", we utilize an intermediary model to conduct empirical tests on the mechanisms of agricultural scaling operations, agricultural planting structures, and agricultural technological progress, enriching the interpretation of the corresponding mechanisms. Thirdly, this study further examines the spatial spillover effect of high-standard farmland construction on agricultural carbon productivity, which is significant to exploring the "quality" and "quantity" of agricultural carbon emission reduction through the synergy of farming regions.

2. Research Assumptions

2.1. Mechanism of the Impact of High-Standard Farmland Construction on Agricultural Carbon Productivity

According to China's document, "High-standard Basic Farmland Construction Standards", high-standard farmland is defined as "basic farmland that is formed through rural land remediation to be smooth and fertile, concentrated and continuous, with supporting facilities, high and stable yields, ecologically sound, and disaster-resistant, and is compatible with modern agricultural production and operation methods". Since establishing the

Land Development and Construction Fund (LDCF) in 1998, the Chinese government has continued to promote the renovation of low- and medium-yielding fields and the construction of high-standard farmland to improve the quality of arable land. In 2021, the "National High-standard Farmland Construction Plan (2021–2030)", approved and issued by the State Council of China, further refined the content of high-standard farmland construction into eight aspects of comprehensive management, including fields, soil, water, roads, forests, electricity, technology, and management. It emphasizes the need to improve farmland infrastructure, promote the transformation and upgrading of agricultural production methods, and strengthen farmland protection and ecological environmental protection to realize the intensive and economical use of land and water resources, promote the formation of a green and low-carbon production mode, and promote both the protection of farmland biodiversity and the sustainable development of agriculture.

By combing through the literature, we found that the construction of high-standard farmland is conducive to the realization of moderate-scale operations through land leveling and continuous operation [22], the promotion of food crop cultivation [30], and the promotion of low-carbon and high-efficiency technologies in agriculture [31]. These changes in external conditions are bound to impact agricultural economic returns and carbon emission reduction [32–34]. Therefore, drawing on this idea, this study divides the impact pathways of high-standard farmland construction on agricultural carbon productivity into three—scale effects, structural effects, and technology effects—as the foundation of the theoretical analysis framework of this study.

2.1.1. Scale Effects: Promoting Large-Scale Agricultural Operations

The academic community has generally recognized the role of high-standard farmland construction in promoting agricultural scaling operations. Agricultural scaling operations are essential for developing China's agricultural modernization, including farmland and service scaling operations [35]. High-standard farmland construction through the promotion of land leveling and continuous operation effectively alleviates the problem of the dispersion and fragmentation of cultivated land, driving the scale effects of agricultural production. In other words, it can reduce the costs of labor and input factors per unit area, which is conducive to obtaining economies of scale, and at the same time, optimizing the structure of agricultural inputs can effectively improve the efficiency of allocating farming factors, thereby promoting agricultural production [26]. On the other hand, forming a contiguous operation scale is an essential prerequisite for service scaling operations [36]. High-standard farmland construction provides realistic possibilities for the vertical division of labor in agriculture through the improvement of field roads, the expansion of plot size, and the renovation of appropriate mechanization. It can also meet the demand for horizontal labor division in agriculture, which in turn contributes to the capacity to outsource the service market [37], thus promoting the purchase of agricultural production services by large-scale farmers, encouraging the popularization of scientific management modes and low-carbon production technologies among farmers, helping to utilize the positive externalities of service scaling operations and reducing agricultural carbon emissions. Accordingly, this study concludes that constructing high-standard farmland can promote agricultural scaling operations, thereby increasing agricultural income, reducing carbon emissions, and in turn, enhancing agricultural carbon productivity.

2.1.2. Structural Effects: Restructuring Agricultural Cultivation

The construction of high-standard farmland can promote the evolution of the agricultural planting structure "towards grain". High-standard farmland construction can encourage the cultivation of crops that are suitable for large-scale and mechanized operations through measures such as concentrated and contiguous cultivation, supporting facilities, and "changing the land to fit the machine". Grain is a land-intensive product; the expansion of its scale of operation is more likely to bring economies of scale, and compared to cash crops, its production is more likely to be replaced by agricultural machinery.

Therefore, the construction of high-standard farmland will promote the cultivation of food crops [18]. The adjustment of crop planting structures has contributed to the formation of a continuous, specialized production pattern—that is, through the promotion of centralized and large-scale planting varieties, which is conducive to the primary operation to obtain external economies of scale that are specialized and agglomerated. In addition, the cultivation of food crops involves more mature mechanization technology and socialized service technology; operations engaged in food production have a clear "configuration advantage" [38], further improving the degree of agricultural specialization and vigorously promoting the enhancement of agricultural production efficiency, leading to the realization of the incremental effect on the total value of agricultural output. On the other hand, the adjustment of the agricultural planting structure is closely related to the use of inputs of agricultural production factors. It has been shown that, relative to cash crops, food crops have a lower demand for chemical fertilizers and pesticide application. The erosion of food crops in the soil is much lesser, which can better maintain the soil's organic carbon [39], improve the quality of the ground, and further reduce the dependence on fertilizers, pesticides, agricultural films, and other high-carbon input factors, thus reducing agricultural carbon emissions. Therefore, constructing high-standard farmland can promote the adjustment of agricultural planting structures, improving agricultural production efficiency and reducing agricultural carbon emissions, thus enhancing agricultural carbon productivity.

2.1.3. Technology Effects: Promoting Technological Progress in Agriculture

High-standard farmland construction can effectively promote the progression of agricultural technology. The construction of high-standard farmland has realized a mechanization transformation by promoting land remediation, perfecting the farmland's mechanized roads, and "merging small fields with large ones", which significantly improves the efficiency of agricultural machinery application and thus promotes the development of agricultural technology [9]. Improving the application efficiency of agricultural machinery can not only help realize the adequate substitution of machinery for labor in a low-cost way, but can also help to promote the standardization and normalization of agricultural production, which in turn improves the allocation efficiency of factors of production and is conducive to increasing the total value of agricultural output. On the other hand, concentrated and continuous operations after the construction of high-standard farmland provide operating space for low-carbon and high-efficiency technologies, such as mechanical deep-pine turning, increased tillage, straw mulching, and returning to the field, which not only reduces the degree of soil compaction, improves the soil's ability to store and retain water and moisture, and increases the content of organic carbon, but also reduces the consumption of fossil fuels through agricultural machinery compared with traditional farming methods [37]. Furthermore, improving the level of agricultural mechanization can also improve the efficiency and consumption of processes such as mechanical fertilization, irrigation, and harvesting, among others, which is conducive to reducing agricultural carbon emissions. In general, constructing high-standard farmland promotes technical progress in the form of agricultural machinery, enhancing agricultural carbon productivity. Accordingly, the following hypotheses are formulated:

H1. *High-standard farmland construction can enhance agricultural carbon productivity by promoting large-scale operations, adjusting cropping structures, and promoting technological progress.*

2.2. Spatial Spillover Effects of High-Standard Farmland Construction on Agricultural Carbon Productivity

As a policy of supporting and benefiting agriculture, the construction of high-standard farmland can not only enhance the agricultural carbon productivity of the region through land leveling, supporting facilities, and environmental protection, but also rely on its radiating solid power, which can further enable the diffusion and promotion of local, high-quality resources, technology, and experience to the neighboring regions, thus generating positive spatial impact effects on the agricultural carbon productivity from other areas.

On the one hand, due to the similar climatic characteristics and geographic environments in neighboring regions, experiences and technologies related to high-standard farmland construction are more likely to flow among neighboring areas [26], thus generating a spatial spillover effect on carbon productivity. On the other hand, as the economic activities of geographically neighboring provinces become closer, the advanced concepts, models, and experiences of high-standard farmland construction will also have demonstration and cohort effects on the neighboring areas; surrounding areas will benefit more greatly by absorbing advanced land improvement technologies and experiences. At the same time, the development of advanced land management concepts and technologies can also enhance the output efficiency and utilization rate of agricultural production factors, as well as reduce agricultural resource consumption and carbon emissions. Accordingly, the following hypotheses are formulated:

H2. *High-standard farmland construction has a significant positive spatial spillover effect on agricultural carbon productivity in neighboring regions.*

3. Methods

3.1. Model

3.1.1. Benchmark Modeling

High-standard farmland construction is continuously promoted and is not a policy shock that occurs suddenly at a specific moment; therefore, referring to existing studies [3,18], this study constructed a fixed-effects panel model and used OLS for regression estimation. The model is shown in Equation (1):

$$\ln CP_{it} = \alpha + \beta_1 HSF_{it} + \beta_n \sum X_{it} + \delta_t + \varphi_i + \varepsilon_{it} \tag{1}$$

In Equation (1), i denotes the province (city, autonomous region); t denotes the year; CP_{it} denotes agricultural carbon productivity; HSF_{it} denotes high-standard farmland construction; $\sum X_{it}$ denotes control variables; α denotes the constant term; β_1 and $\beta_{\rm n}$ denote the coefficient of high-standard farmland construction and the coefficient of each control variable, respectively; δ_t and φ_i denote year fixed effects and province fixed effects, respectively; and $\varepsilon_{\rm it}$ is a random disturbance term.

3.1.2. Mediation Effects Model

In order to further study the effects of high-standard farmland construction on agricultural carbon productivity, three mediating variables (agricultural scale, agricultural cropping structure, and agricultural technology progress) were introduced for stepwise regression, and the following model is constructed on the basis of Equation (1):

$$M_{it} = \alpha_0 + \alpha_1 HSF_{it} + \alpha_2 \sum X_{it} + \delta_t + \varphi_i + \varepsilon_{it} \tag{2}$$

$$\ln CP_{it} = \beta_0 + \beta_1 HSF_{it} + \beta_2 M_{it} + \beta_n \sum X_{it} + \delta_t + \varphi_i + \varepsilon_{it} \tag{3}$$

In Equation (2), $M_{\rm it}$ denotes the three mechanism variables: agricultural scale operation, agricultural cultivation structure, and agricultural technology progress. α_0 denotes the constant term, α_1 denotes the coefficient of high-standard farmland construction, α_2 denotes the coefficient of each control variable, and the others are the same as in Equation (1). In Equation (3), β_0 denotes the constant term, β_1 denotes the coefficient of high-standard farmland construction, β_2 denotes the coefficient of the mediating variable, β_n denotes the coefficient of each control variable, and the others are the same as in Equation (1). Equation (2) verifies the effects of high-standard farmland construction on the above mechanism variables, and Equation (3) demonstrates the impact of high-standard farmland construction and the role of its variables on agricultural carbon productivity.

3.1.3. Partial Measurement Modeling

(1) Global Autocorrelation Model

The relationship between high-standard farmland construction and agricultural carbon productivity needs to be tested for spatial correlation, the most common method of which is Global Moran's Index (Moran's I), which is modeled as shown below:

$$I = \frac{\sum_{i=1}^{n}\sum_{j=1}^{n} W(X_i - \overline{X})(X_j - \overline{X})}{S^2 \cdot \sum_{i=1}^{n}\sum_{j=1}^{n} W_{ij}} \tag{4}$$

In Equation (4), n denotes the total number of regional spatial units; X_i and X_j denote the random variables X attribute values in geographic units, i and j; and $\overline{X}$ is the average of the attribute values of the sample spatial units. $S^2 = \frac{\sum_{i=1}^{n}(X-\overline{X})^2}{n}$ is the sample difference, W_{ij} is the i and j elements of the spatial weight matrix (used to measure the distance between regions), and $\sum_{i=1}^{n}\sum_{j=1}^{n} W_{ij}$ is the sum of the spatial weights. Global Moran's Index values from 0 to 1 are positively correlated, indicating that attributes with similar properties cluster together; values from −1 to 0 are negatively correlated, indicating that attributes with dissimilarities cluster together; and values close to 0 show a random distribution or no spatial autocorrelation. Where the spatial weight matrix is chosen to be the neighbor weight matrix, $W = \begin{cases} 1, i\ is\ adjacent\ to\ j \\ 0, i\ is\ not\ adjacent\ to\ j \end{cases}$, with neighboring areas taking the value of 1 and non-neighboring areas taking the value of 0.

(2) Spatial panel model

The spatial Durbin model incorporates spatially lagged variables for both endogenous and exogenous variables, and focuses on the factors acting on the explanatory variables in different dimensions [40], better capturing different spatial spillovers. Therefore, this constructs a spatial Durbin model to investigate the spatial spillover effect of high-standard farmland construction on agricultural carbon productivity, which takes the following form:

$$\ln CP_{it} = \alpha + \rho \sum_{i=1, j\neq 1}^{n} W_{ij} CP_{it} + \beta_1 HSF_{it} + \beta_{\mathrm{n}} X_{it} + \theta \sum_{i=1, j\neq 1}^{n} W_{ij}(HSF_{it} + X_{it}) + \delta_t + \varphi_i + \varepsilon_{it} \tag{5}$$

where W_{ij} denotes the spatial weight matrix, ρ is the spatial autocorrelation coefficient, θ is the spatially lagged term's elasticity coefficient for the core explanatory and control variables, and the others are the same as in Equation (1).

3.2. Variable Description and Measurement

3.2.1. The Explained Variable

In this study, agricultural carbon productivity is the primary explained variable. Referring to the research of Kaya, Y. et al. [41], this study defines the carbon productivity of agriculture (mainly referring to agriculture in the narrow sense) as the ratio of the total output value of crops in the established growth cycle to the total carbon emissions. The calculation of carbon emissions mainly includes six types of carbon sources—fertilizers, pesticides, agricultural films, diesel fuel, irrigation, and tilling—and their carbon emission coefficients specifically refer to the studies of Wu, G.Y. et al. [42] and Huang, X. et al. [43] (Table 1). The specific calculation formula for agricultural carbon emissions is as follows:

$$E = \sum E_{\mathrm{i}} = \sum T_{\mathrm{i}} \cdot \delta_{\mathrm{i}} \tag{6}$$

In Equation (6), E is the total amount of carbon emissions; T_i and δ_i denote each carbon emission source's original amount and emission coefficient, respectively (Table 1).

Agricultural carbon productivity characterizes the crop output value brought by carbon emissions per unit of agricultural consumption, which is calculated by the specific formula:

$$CP = \frac{\sum P_{Qi} \times Q_i}{\sum C} \quad (7)$$

In Equation (7), CP is the agricultural carbon productivity; P_{Qi} is the market selling price of crop i; Q is the total production of crop i; $\sum P_{Qi}$ is the total output value of the plantation industry; and $\sum C$ is the total carbon dioxide emissions from the plantation industry.

Table 1. Carbon emission sources, factors, and reference sources.

Sources of Carbon Emissions	Carbon Emission Factor	Reference Source
Pesticide	4.9341 kg/kg	ORNL Oak Ridge National Laboratory (USA)
Fertilizer	0.8956 kg/kg	ORNL Oak Ridge National Laboratory (USA)
Agricultural film	5.1800 kg/kg	Institute of Agricultural Resources and Ecological Environment, Nanjing Agricultural University
Agricultural machinery	0.5927 kg/kg	United Nations Intergovernmental Panel on Climate Change (IPCC)
Tillage	312.6 kg/km^2	LABCAU China Agricultural University College of Biology and Technology
Irrigation	19.8575 kg/hm^2	Wu et al. (2020) [42]

Note: Since irrigation generates carbon emissions by consuming electricity, the carbon emission factor for agricultural irrigation was adjusted to 19.8575 kg/hm^2 by referring to the study of Wu et al. [42].

3.2.2. Core Explanatory Variable

The core explanatory variable of this study is high-standard farmland construction. Referring to the study of Gong et al. [37], this study uses the ratio of a land improvement area, which is expressed by the percentage of the sum of the size of renovated low and medium-yield fields and the location of high-standard farmland construction to the area of cultivated land.

3.2.3. Control Variables

Considering the availability and consistency of data, and drawing on existing research results [1,3,6,43], the following control variables were selected: ① Frequent natural disasters will cause some damage to crop output, thus reducing agricultural carbon productivity. The natural disaster rate (DIS) is expressed as the proportion of the affected area of crops to the total sown area of crops. ② The replanting index (MCI): The higher the replanting index, the better the natural conditions of the region, such as good lighting conditions, flat topography, etc., which will be conducive to improving the efficiency of arable land utilization, thus improving the efficiency of agricultural production; however, the increase in replanting brings about an increase in the inputs of agricultural materials and machinery, which will lead to an increase in the amount of carbon emissions from the agriculture industry and thus reduce the agricultural carbon productivity. The replanting index is expressed as the ratio of the cultivated area to the elegant area under crops. ③ Irrigation conditions (IRR): Agricultural irrigation conditions can have a positive or negative impact on agricultural carbon productivity; on the one hand, improved agricultural irrigation conditions are conducive to improving the agricultural production environment and raising the level of agricultural production, thus increasing agricultural carbon productivity. On the other hand, improved agricultural irrigation conditions also promote the large-scale use of agricultural machinery, which increases agricultural carbon emissions and further reduces agricultural carbon productivity. Agricultural irrigation conditions are expressed as the ratio of cultivated area to effectively irrigated area. ④ The agricultural economic development level (AEDL): the better the level of agricultural economic development is, the more favorable it is to enhance agricultural carbon productivity, and the level of agricultural economic development is expressed as the per capita gross plantation output value. ⑤ Agricultural industrial structure (IS): The more significant that the proportion of the output value of the primary industry is, the more capital will be invested in upgrading agricultural infrastructure and technology, thus enhancing agricultural carbon productivity. The structure of the agricultural industry is expressed in terms of the share of GDP accounted for by the output of the primary sector. ⑥ Agricultural financial support (CZ): Financial support for agriculture can have a positive or negative impact on agricultural carbon productivity. On the one hand, it can promote the upgrading of agricultural production conditions by increasing subsidies for rural areas and farmers, and investing in the environmental management of farmland can improve its ecological quality, which in turn improves agricultural carbon productivity. On the other hand, China's long-term financial support policy for agriculture has been more inclined to subsidize agricultural input resources such as pesticides, fertilizers, agricultural machinery, etc., which will increase agricultural carbon emissions and thus reduce agricultural carbon productivity. The strength of financial support for agriculture is expressed as the ratio of local expenditure on agriculture, forestry, and water affairs to the general expenditures of the local finance. ⑦ Rural human capital (EDU): A high-level labor force will inject vitality into agricultural innovation, and rural human capital is expressed in terms of the average number of years of education of the rural population, which is estimated based on the average number of years of education of the rural population aged six and above with a corresponding literacy level in each province. ⑧ The urbanization level (URB): increased urbanization can promote agricultural economic growth and green technological innovation, and is expressed as the proportion of the urban population within the total population. ⑨ Degrees of marketization (MAR), which is measured using the marketization index of Gang, F. et al. [44].

3.2.4. Mechanism Variables

① Agricultural scaling operations: the ratio of the cultivated land area to the number of planting laborers in each province (region); i.e., the natural logarithm of the cultivated land per capita area in agriculture is selected to reflect the agricultural scaling operation. ② Agricultural planting structure: the ratio of the sown area of grain crops to the total sown area of crops is used to indicate the agricultural planting structure [45]. ③ Agricultural technological progress: the total power of agricultural machinery per unit of arable land area indicates the progress of agricultural technology [18].

3.3. Sample Selection and Data Sources

Since data on the construction of high-standard farmland before 2003 and after 2017 in the statistical yearbooks are not available, given the availability and completeness of the data, this study selected the panel data of 31 provinces in China from 2003 to 2017, which came from the China Statistical Yearbook, the China Rural Statistical Yearbook, the China Financial Yearbook, the China Population and Employment Statistics Yearbook, and the China Statistical Yearbook on Science and Technology, as well as the statistical yearbooks of each province (region). The moving average method made up the missing data of individual years. The descriptive statistics of relevant variables are shown in Table 2.

Table 2. Descriptive statistics of variables.

Variables	Abbreviation	Units	N	Mean	S.D.	Min	Max
Agricultural carbon productivity	CP	logarithmic	465	2.750	0.666	1.552	5.854
High-standard farmland construction	HSF	—	465	0.369	0.222	0.068	0.894
Replanting index	MCI	—	465	1.279	0.393	0.566	2.427
Disaster rate	DIS	%	465	22.854	15.114	0.000	93.59
Agricultural irrigation conditions	IRR	%	465	53.626	23.571	14.660	99.701
Agricultural economic development	AEDL	CNY 10,000, logarithmic	465	2.992	2.008	0.279	9.690

Table 2. *Cont.*

Variables	Abbreviation	Units	N	Mean	S.D.	Min	Max
Agricultural financial support	FINA	—	465	0.099	0.034	0.021	0.190
Agricultural industry structure	IS	%	465	20.227	9.949	0.889	54.657
Rural human capital	EDU	logarithmic	465	7.327	0.891	3.240	9.801
Urbanization level	URB	%	465	50.683	14.976	19.928	89.583
Degree of marketization	MAR	logarithmic	465	6.973	2.097	0.106	11.233
Agricultural scale operation	FMS	Acres/person, logarithmic	465	7.986	5.740	2.394	37.608
Agricultural cropping structure	STRU	%	465	66.241	12.988	35.385	96.430
Advances in agricultural technology	AT	Watt/mu, logarithmic	465	509.876	280.017	109.080	1788.119

4. Empirical Results

4.1. Benchmark Regression

Based on the setting of Equation (1) and gradually adding natural, economic, and social control variables in turn, we obtain the effect of high-standard farmland construction on agricultural carbon productivity: see Table 3, Model (1)–Model (3). Hausman's test shows that choosing the fixed-effects model is more reasonable. The results show that the impact coefficient of high-standard farmland construction on agricultural carbon productivity is consistently positive, and all of them are significant at the 5% statistical level, which proves that high-standard farmland construction can significantly enhance agricultural carbon productivity. Taking column (3) as an example, the impact coefficient of high-standard farmland construction on agricultural carbon productivity is 0.139, which is significant at the 1% statistical level, indicating that the effect is significant.

Table 3. Benchmark regression.

Variables	Model (1)	Model (2)	Model (3)
HSF	0.097 **	0.107 ***	0.139 ***
	(0.041)	(0.040)	(0.046)
DIS	−0.097 ***	−0.112 ***	−0.077 **
	(0.038)	(0.039)	(0.037)
IRR	−0.318 ***	−0.254 ***	−0.268 ***
	(0.081)	(0.087)	(0.082)
MCI	−0.004	−0.046	−0.094
	(0.048)	(0.049)	(0.050)
AEDL		0.134 ***	0.135 ***
		(0.023)	(0.030)
FINA		−1.043 ***	−0.927 ***
		(0.288)	(0.291)
IS		0.150 *	0.199 **
		(0.162)	(0.162)
EDU			0.123 *
			(0.147)
URB			0.372 **
			(0.161)
MAR			0.001
			(0.025)
Regional fixed effects	Yes	Yes	Yes
Time fixed effects	Yes	Yes	Yes
Adj-R^2	0.852	0.863	0.864
N	465	465	465

Note: * $p < 0.1$, ** $p < 0.05$, and *** $p < 0.01$.

As for the control variables, the rate of natural disasters has a significant negative impact on agricultural carbon productivity, indicating that under a specific consumption of agricultural carbon sources, the higher the degree of crop damage, the lower the crop yield, and the lower the value of agricultural output; this leads to a decrease in agricultural carbon productivity. The impact of agricultural irrigation is significantly negative, indicating that although the improvement in irrigation conditions is conducive to the advancement of agricultural production, it also promotes the large-scale use of farm machinery, thus increasing carbon emissions. The impact of the level of agricultural economic development is positive, indicating that the improvement of the level of agricultural economic development can promote economic growth and technological progress, solidifying the capacity of comprehensive agricultural production. This is also achieved through scientific and technological innovation to optimize the efficiency of arable land resource allocation, accelerate the transformation of the agricultural development model, and realize the transformation of agriculture to green and low-carbon production. Financial support for agriculture significantly negatively affects agricultural carbon productivity, likely because China's financial support for agricultural policy has long been more inclined toward pesticides, fertilizers, agricultural machinery, and other agricultural production resources [46]. It is conducive for enhancing the output benefits of agricultural land use, yet simultaneously increases agricultural carbon emissions. The impact of the agricultural industry's structure is significantly positive, indicating that the more significant the proportion of agricultural GDP, the more funds will be invested into upgrading agricultural infrastructure and technology, thus accelerating the transformation of the agricultural development model and acting as a driving force in the enhancement of agricultural carbon productivity. The impact of rural human capital is significantly positive, indicating that the higher the education level of farmers is, the more willing they are to adopt low-carbon production methods, energy-saving and efficient technologies, and advanced agricultural management concepts [47], thus enhancing agricultural carbon productivity. The effect of urbanization is significantly positive; the increase in the urbanization level means that a greater proportion of the agricultural population is transferred to cities and towns, which promotes the transfer of arable land, thus realizing a moderate scale and modern management. At the same time, the increased urbanization level can promote the economic development of agricultural production technology [48], which is conducive to the enhancement of agricultural carbon productivity.

4.2. Heterogeneity Analysis

It has been found that terrain differences cause differences in the utilization efficiency of input factors as well as output effects [6], affecting agricultural carbon productivity. Drawing on the study of Gong et al. [37], this study divides the total sample into plains and mountainous regions. Table 4, Model (1)–Model (2), shows that the construction of high-standard farmland in both plains and mountainous areas has a significant positive effect on enhancing agricultural carbon productivity, and the effect is more pronounced in plains. One possible reason is that the endowment of arable land resources is superior in plains, and the construction of high-standard farmland brings more efficient large-scale land management and greater concentration and specialization within crop cultivation, which helps to improve agricultural carbon productivity.

The primary purpose of constructing high-standard farmland is to guarantee food security and improve the comprehensive production capacity of grain, so the policy tends to favor major grain production areas. Therefore, this study divides the sample into major and minor grain production areas, and from the results of Model (3)–Model (4) in Table 4, it can be seen that the construction of high-standard farmland in both major and minor grain production areas can significantly improve agricultural carbon productivity, the promotion effect of which is more pronounced in major grain production areas. As the core pillar of national food production, central grain-producing regions enjoy more policies, technologies, and funds. Not only do they produce more than 78% of the country's grain, but they also pay more attention to the quality of food and low-carbon production [49]; coupled with their commensurable natural resources and technological and economic conditions, the conditions for and effects of high-standard farmland construction are preferable in these regions, as they are more conducive to improving agricultural carbon productivity.

Table 4. Results of heterogeneity analysis.

Variables	Topographic Features		Production Function Area		Level of Economic Development	
	Plains (1)	Hilly Areas (2)	Major Grain-Producing Areas (3)	Non-Major Grain Producing Areas (4)	East-Central Regions (5)	Western Regions (6)
HSF	0.225 *** (0.067)	0.138 * (0.083)	0.355 ** (0.139)	0.129 ** (0.060)	0.139 *** (0.048)	−0.117 (0.110)
_Cons	Yes	Yes	Yes	Yes	Yes	Yes
Regional fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Time fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Adj-R^2	0.8587	0.8979	0.8182	0.8870	0.8181	0.9185
N	240	225	195	270	330	135

Note: * $p < 0.1$, ** $p < 0.05$, and *** $p < 0.01$.

China is a vast country with wide differences in economic development among regions, which may lead to apparent regional heterogeneity in the impact of high-standard farmland construction on agricultural carbon productivity. Based on this, this study divides the sample into east–central and western regions. The results of Model (5)–Model (6) in Table 4 show that high-standard farmland in the east–central area has a significant positive impact on agricultural carbon productivity and is effective at the 1% level. In contrast, the fitting coefficient is insignificant in the western region. One possible reason is that the eastern and central areas have relatively high levels of economic development, giving them certain advantages in introducing agricultural technology and talent reserves while paying more attention to ecological and environmental issues, which is conducive to enhancing agricultural carbon productivity. The western region is China's traditional farming area, primarily based on agriculture. Still, its agricultural production conditions are poor, the ecological environment is fragile and unstable, and the technological and economic conditions are relatively backward [50], resulting in a non-significant effect of constructing high-standard farmland in the western region on promoting agricultural carbon productivity.

4.3. Robustness Testing

In this study, the results of the benchmark regression are tested for robustness in terms of replacement variables and endogeneity consideration.

4.3.1. Replacement Variable

Drawing on the existing literature [22], this study takes comprehensive agricultural development inputs (AI) as the replacement variable for high-standard farmland construction. It is measured based on the ratio of complete agricultural development funds to the sown area of crops. According to the definition of carbon productivity and concerning existing studies [6,7], this study takes agricultural total factor carbon productivity as a replacement variable for agricultural carbon productivity. It is measured by taking carbon emissions as an input factor based on the Malmquist index of DEA (input variables include fertilizers, pesticides, agricultural films, land, labor, machinery, and carbon emissions, and the output variable is the gross value of plantation production at a constant price in 2003). From the estimation results of Model (1)–Model (3) in Table 5, it can be seen that the coefficients of the core variables are significant at the 1% statistical level whether the core explanatory variables or the explanatory variables are replaced individually, or both variables are replaced at the same time, which proves that the main-effects estimation results are robust.

Table 5. Robustness test.

Variables	Replacement of Core Variables (1)	Replacement of Explanatory Variables (2)	Simultaneous Replacement (3)	System GMM (4)
AI	0.095 *** (0.018)		0.063 *** (0.012)	
HSF		0.073 *** (0.012)		0.145 ** (0.073)
L.CP				0.543 *** (0.140)
_Cons	Yes	Yes	Yes	Yes
Regional fixed effects	Yes	Yes	Yes	Yes
Time fixed effects	Yes	Yes	Yes	Yes
Adj-R^2	0.8173	0.5391	0.6158	
N	465	465	465	434
AR(1)-*p*-value				0.017
AR(2)-*p*-value				0.600
Hansen test *p*-value				0.793

Note: ** $p < 0.05$, and *** $p < 0.01$.

4.3.2. Endogeneity Consideration

Considering the possible endogeneity of the results of the main-effects analysis, this study introduces the lag-one period of agricultural carbon productivity as an instrumental variable in the baseline model. It uses the Generalized Method of Moments (GMM) to estimate the model. From the results of Model (4) in Table 5, it can be seen that the estimated value of the impact coefficient of the construction of high-standard farmland is 0.145, which is significant at the 5% level, and the importance of AR (1) and AR (2) in Model (4) are 0.017 and 0.600, which satisfy the assumption that there is a first-order autocorrelation in the residual term, but no second-order autocorrelation, proving the validity of the estimation results; Hansen's test cannot reject that all the instrumental variables are valid at the 10% level of significance. Therefore, the entire model setup is reasonable and the instrumental variables are valid, reaffirming the research hypothesis.

4.4. Analysis of Mechanisms of Action

Table 6 Models (1)–(6) show the results of the test on the mediating mechanisms of high-standard farmland construction on agricultural carbon productivity. According to model (1) of Table 6, it can be seen that the coefficient of the impact of high-standard farmland construction on the scale of agricultural operation is 0.141, which is significant at a 1% statistical level; that is, the construction of high-standard farmland will significantly promote the scale of agricultural operation. From model (2) in Table 6, it can be seen that the impact coefficient of agricultural scaling operations on agricultural carbon productivity is 0.174, which is significant at a 1% statistical level; that is, the increase in the level of agricultural scaling operations can significantly enhance agricultural carbon productivity. Therefore, agricultural scaling operations are an intermediary of high-standard farmland construction affecting agricultural carbon productivity. According to model (3) of Table 6, it can be seen that the impact coefficient of high-standard farmland construction on agricultural planting structure is 0.117, which is significant at a 1% statistical level; that is, the construction of high-standard farmland will significantly promote the adjustment of agricultural planting structures. From model (4) in Table 6, it can be seen that the impact coefficient of agricultural planting structure on agricultural carbon productivity is 0.207, which is significant at a 1% statistical level; that is, the adjustment of agricultural planting structures can significantly enhance agricultural carbon productivity. Therefore, agricultural planting structures mediate high-standard farmland construction, affecting agricultural carbon productivity. According to model (5) of Table 6, it can be seen that the impact coefficient of high-standard farmland construction on agricultural technological progress is 0.115, which is significant at a 1% statistical level; that is, the construction of high-standard farmland will significantly promote agricultural technological progress. From model (6) in Table 6, it can be seen that the impact coefficient of agricultural technological progress on agricultural carbon productivity is 0.117, which is significant at a 1% statistical level; that is, the improvement of agricultural technological progress can significantly enhance agricultural carbon productivity. Therefore, the development of agricultural technology plays a mediating role in high-standard farmland construction, affecting agricultural carbon productivity. In conclusion, high-standard farmland is assumed to enhance agricultural carbon productivity by promoting agricultural scaling operations, adjusting planting structures, and promoting technological progress, and hypothesis 1 is established.

Table 6. Mechanism of action tests.

Variables	Model (1)	Model (2)	Model (3)	Model (4)	Model (5)	Model (6)
HSF	0.141 *** (0.039)	0.157 *** (0.046)	0.117 *** (0.024)	0.080 ** (0.041)	0.115 ** (0.053)	0.099 *** (0.035)
FMS		0.174 *** (0.058)				
STRU				0.207 *** (0.068)		
AT						0.117 *** (0.031)
_Cons	Yes	Yes	Yes	Yes	Yes	Yes
Regional fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Time fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Adj-R^2	0.852	0.866	0.902	0.8589	0.8351	0.8560
N	465	465	465	465	465	465

Note: ** $p < 0.05$, and *** $p < 0.01$.

4.5. Analysis of Spatial Spillover Effects

4.5.1. Spatial Correlation Test

In this study, Moran's I is used to test whether there is a spatial correlation between the construction of high-standard farmland and agricultural carbon productivity, and the results are shown in Table 7. This test failed in 2003–2006 because the concept of high-standard farmland construction was first mentioned in the No. 1 document of the Chinese central government in 2005, 116 counties (cities and districts) were officially identified as the national demonstration zones for the protection of bare farmland in 2006, and the demonstration project of high-standard farmland was gradually carried out to achieve the upgrading of medium- and low-yield fields. Thus, after 2006, the spatial spillover effect of high-standard farmland construction began to appear, and the Moran's index of high-standard farmland construction from 2007 to 2017 passed the test at the 5% significance level with a significant positive spatial correlation. From the Moran's index test results of agricultural carbon productivity, except for 2006 and 2008, which did not pass the test, the rest of the years were significantly positive, indicating that China's agricultural carbon productivity in 2003–2017 had a significant positive spatial correlation as a whole. Therefore, the choice of spatial econometric model analysis to analyze the impact of high-standard farmland construction on agricultural carbon productivity is reasonable.

Table 7. Global Moran's Index of high-standard farmland construction and agricultural carbon productivity.

Year	High-Standard Farmland Construction		Agricultural Carbon Productivity	
	Moran Index	**Z-Value**	**Moran Index**	**Z-Value**
2003	0.027	0.670	0.172 **	2.426
2004	0.040	0.808	0.153 **	1.974
2005	0.051	0.924	0.162 *	1.894
2006	0.135	1.569	0.082	1.216
2007	0.208 **	2.266	0.137 *	1.780
2008	0.195 **	2.151	0.090	1.301
2009	0.228 **	2.466	0.201 **	2.309
2010	0.235 **	2.538	0.210 **	2.351
2011	0.233 **	2.525	0.209 **	2.332
2012	0.236 **	2.558	0.254 ***	2.689
2013	0.234 **	2.545	0.267 ***	2.818
2014	0.232 **	2.536	0.269 ***	2.801
2015	0.230 **	2.512	0.250 ***	2.684
2016	0.235 **	2.552	0.281 ***	2.966
2017	0.238 ***	2.570	0.307 ***	3.142

Note: * $p < 0.1$, ** $p < 0.05$, and *** $p < 0.01$.

4.5.2. Spatial Econometric Model Estimation Results

From the results of the spatial econometric model in Table 8, the LM test and robust LM test are both significant at the 1% confidence level, indicating that the construction of high-standard farmland has a spatial spillover effect on agricultural carbon productivity and that the spatial Durbin model is more appropriate. The results of the Wald and LR tests reject the original hypotheses at the 1% confidence level, indicating that the spatial Durbin model cannot be degraded to a spatial lag model or a spatial error model, which further suggests that the spatial Durbin model can better describe the relationship between the construction of high-standard farmland and agricultural carbon productivity. In addition, the results of the temporal LR test, spatial LR test, and Hausman test all rejected the original hypotheses at the 1% significance level, indicating that it is more reasonable to choose the spatial and temporal double fixed-effects Durbin model.

Table 8. Results of spatial measurement model tests.

Test	Statistic	Test	Statistic
LM spatial lag	325.037 ***	Wald spatial error	37.39 ***
Robust LM spatial error	7.769 ***	LR spatial error	80.85 ***
LM spatial error	366.882 ***	Time LR test	60.34 ***
Robust LM spatial lag	49.614 ***	Spatial LR test	668.51 ***
Wald spatial lag	24.21 ***	Hausman	−49.73 ***
LR spatial lag	82.42 ***		

Note: *** $p < 0.01$.

From the double fixed-effects Durbin model test results (Table 9), the direct and indirect effects of high-standard farmland construction on agricultural carbon productivity are both significantly positive at the 1% level, indicating that the construction of high-standard farmland not only promotes the growth of agricultural carbon productivity in the region, but also produces a specific effect on neighboring regions, guides adjacent areas to emulate the advanced management mode, introduces professional technology and knowledge, and thus produces a spatial spillover effect on agricultural carbon productivity in neighboring regions. Therefore, hypothesis 2 is valid.

Table 9. Spatial Durbin regression results.

Variables	(1)	(2)
HSF	0.071 *** (0.020)	
W× HSF	0.025 ** (0.029)	
Direct effect		0.074 *** (0.020)
Indirect effect		0.043 *** (0.012)
Total effect		0.117 *** (0.031)
_Cons	Yes	Yes
Regional fixed effects	Yes	Yes
Time fixed effects	Yes	Yes
ρ	0.394 *** (0.050)	0.394 *** (0.050)
R^2	0.4021	0.4021

Note: ** $p < 0.05$, and *** $p < 0.01$.

5. Discussion

The above discussion and analysis show that high-standard farmland construction can effectively enhance agricultural carbon productivity. Most researchers believe that high-standard farmland construction can promote economic growth and reduce agricultural carbon emissions through land leveling, improving agricultural infrastructure, and protecting the ecological environment [19,22,26]. However, some scholars have found that pursuing high-standard farmland construction of "fields into squares" and "canals connected" will change the natural layout of the land, and the improvement of the natural environment through high-standard farmland construction is not conducive to agricultural production [4]. Moreover, our study explains the positive impact of high-standard farmland construction on agricultural carbon productivity from both theoretical and empirical perspectives, providing a theoretical reference for the synergistic economic and environmental effects of high-standard farmland construction, and seeking a feasible path to improve agricultural carbon productivity. This study finds that the scale of agricultural operation, the agricultural planting structure, and agricultural technological progress are essential pathways for high-standard farmland construction to enhance agricultural carbon productivity, thus broadening the interpretation of the effects of high-standard farmland construction policy. In addition, this study confirms that high-standard farmland construction has spatial spillover effects on agricultural carbon productivity, which provides new perspectives and methodological guidance in studying the mechanisms of both.

While this study reveals some important findings, there are some limitations. First, limited by data availability, our study data are only updated to 2017, and future data updates are needed for further research. Second, we only explored the impact of high-standard farmland construction on agricultural carbon productivity at the macro level, which can be further expanded to the farmer level in the future. Historically, the problem of ecological security has been more reflected in the government's behavior. The related policies and measures are macroscopic and mandatory. However, regardless of policies and measures, the ultimate implementer is the individual on the micro-scale; therefore, in the future, it is necessary to further explore the micro-mechanisms of high-standard farmland construction policy in order to promote the coordinated development of farmers, increase production and income, and lower carbon production. Finally, this study is based on rural agricultural production areas in China, and whether the findings apply to rural areas in other countries remains to be further tested.

6. Conclusions and Recommendations

This study empirically examines the impact and spatial characteristics of high-standard farmland construction on agricultural carbon productivity based on panel data from 31 provinces in China from 2003 to 2017. The main findings include the following: (1) high-standard farmland construction can enhance agricultural carbon productivity and has a more pronounced effect on its enhancement in plains, major grain-producing areas, and east–central areas; (2) high-standard farmland construction enhances agricultural carbon productivity by expanding the scale of farming operations, adjusting the structure of agricultural cultivation, and promoting the advancement of agricultural technology; and (3) high-standard farmland construction not only enhances agricultural carbon productivity within the region of interest, but also has a significant positive effect on the agricultural carbon productivity of neighboring regions.

Based on this study's findings, the following recommendations are made: First, a national plan should be implemented for the construction of high-standard farmland to help the country achieve a win–win situation in terms of increased production and income, as well as the goal of "double carbon". The construction of high-standard farmland is a crucial initiative for China to "hide food in the ground and food in technology". It is also a meaningful way to promote low-carbon agricultural development. Through the orderly transformation of low- and medium-yield fields and the effective management of the ecological environment, we can not only increase the operational efficiency of farmland, but also help to promote agricultural carbon sequestration and emission reduction to realize the dual success of increased income and decreased carbon emissions in China. Secondly, we should focus on the differentiation of impact effects and the precision of policy measures. For areas with more appropriate natural conditions, major grain-producing provinces, and more economically developed regions, the sound ecological and economic effects of high-standard farmland construction should be further stabilized and brought into play to promote sustainable and high-quality agricultural development. For areas with relatively poor terrain conditions, minor grain-producing areas, and economically underdeveloped regions, the policy on high-standard farmland should be strengthened. Practical high-standard farmland construction plans, models, and management systems should be actively innovated and popularized to broaden the space for constructing high-standard farmland. Thirdly, to improve agricultural carbon productivity, special attention should be paid to the critical impacts of large-scale farming operations, the adjustment of planting structures, and the advancement of agricultural technology, which are also crucial mechanisms through which the construction of high-standard farmland affects agricultural carbon productivity. Therefore, in the subsequent construction process, special attention should be paid to promoting land transfer and accelerating the promotion of appropriate scaling operations through land leveling and concentrated and continuous operations. A particular focus should be on adjusting and optimizing the agricultural planting structure and promoting the application of advanced and environmentally friendly agricultural technology and equipment. Finally, the positive spatial spillover effects of high-standard farmland construction on agricultural carbon productivity should be brought into full play; inter-regional agricultural economic ties should be strengthened; and advanced land remediation technologies and modes should be popularized to create positive, synergistic economic growth and carbon emission reduction in the region.

Author Contributions: X.X. contributed to the paper's data collection, data processing, and drafting; H.Z. provided the research direction and conception for the study.; N.J. provided advice and checked the manuscript. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by the National Natural Science Foundation of China (72063028) and the Social Science Foundation of the Corps (22YB13).

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Publicly available datasets were analyzed in this study. These data can be found at: https://data.stats.gov.cn/ (accessed on 29 December 2023) and https://data.cnki.net/yearBook?type=type&code=A (29 December 2023).

Conflicts of Interest: The authors declare no conflicts of interest.

References

1. McKinsey Global Institute. *The Carbon Productivity Challenge: Curbing Climate Change and Sustaining Economic Growth*; McKinsey & Company, McKinsey Global Institute: Washington, DC, USA, 2008.
2. Geffersa, A.G.; Agbola, F.W.; Mahmood, A. Technical efficiency in crop production across agro-ecological zones in Ethiopia: A meta-analysis of Frontier studies. *Outlook Agric.* **2019**, *48*, 5–15. [CrossRef]
3. Liao, X.; Qin, S.; Wang, Y.; Zhu, H.; Qi, X. Effects of Land Transfer on Agricultural Carbon Productivity and Its Regional Differentiation in China. *Land* **2023**, *12*, 1358. [CrossRef]
4. Baráth, L.; Bakucs, Z.; Benedek, Z.; Fertő, I.; Nagy, Z.; Vígh, E.; Debrenti, E.; Fogarasi, J. Does participation in agri-environmental schemes increase eco-efficiency? *Sci. Total Environ.* **2024**, *906*, 167518. [CrossRef] [PubMed]
5. Adetutu, M.O.; Ajayi, V. The impact of domestic and foreign R&D on agricultural productivity in sub-Saharan Africa. *World Dev.* **2020**, *125*, 104690.
6. Xiong, C.; Wang, G.; Xu, L. Spatial differentiation identification of influencing factors of agricultural carbon productivity at city level in Taihu lake basin, China. *Sci. Total Environ.* **2021**, *800*, 149610. [CrossRef]
7. Coderoni, S.; Vanino, S. The farm-by-farm relationship among carbon productivity and economic performance of agriculture. *Sci. Total Environ.* **2022**, *819*, 153103. [CrossRef] [PubMed]
8. Gornall, J.; Betts, R.; Burke, E.; Clark, R.; Camp, J.; Willett, K.; Wiltshire, A. Implications of climate change for agricultural productivity in the early twenty-first century. *Philos. Trans. R. Soc. B Biol. Sci.* **2010**, *365*, 2973–2989. [CrossRef]
9. Akbar, U.; Li, Q.L.; Akmal, M.A.; Shakib, M.; Iqbal, W. Nexus between agro-ecological efficiency and carbon emission transfer: Evidence from China. *Environ. Sci. Pollut. Res.* **2021**, *28*, 18995–19007. [CrossRef]
10. Chopra, R.; Magazzino, C.; Shah, M.I.; Sharma, G.D.; Rao, A.; Shahzad, U. The role of renewable energy and natural resources for sustainable agriculture in ASEAN countries: Do carbon emissions and deforestation affect agriculture productivity? *Resour. Policy* **2022**, *76*, 102578. [CrossRef]
11. Olesen, J.E.; Bindi, M. Consequences of climate change for European agricultural productivity, land use and policy. *Eur. J. Agron.* **2002**, *16*, 239–262. [CrossRef]
12. Rehman, A.; Alam, M.M.; Alvarado, R.; Işık, C.; Ahmad, F.; Cismas, L.M.; Pupazan, M.C.M. Carbonization and agricultural productivity in Bhutan: Investigating the impact of crops production, fertilizer usage, and employment on CO_2 emissions. *J. Clean. Prod.* **2022**, *375*, 134178. [CrossRef]
13. Khurshid, A.; Rauf, A.; Qayyum, S.; Calin, A.C.; Duan, W. Green innovation and carbon emissions: The role of carbon pricing and environmental policies in attaining sustainable development targets of carbon mitigation—Evidence from Central-Eastern Europe. *Environ. Dev. Sustain.* **2023**, *25*, 8777–8798. [CrossRef]
14. Fang, L.; Hu, R.; Mao, H.; Chen, S. How crop insurance influences agricultural green total factor productivity: Evidence from Chinese farmers. *J. Clean. Prod.* **2021**, *321*, 128977. [CrossRef]
15. Ramzan, M.; Iqbal, H.A.; Usman, M.; Ozturk, I. Environmental pollution and agricultural productivity in Pakistan: New insights from ARDL and wavelet coherence approaches. *Environ. Sci. Pollut. Res.* **2022**, *29*, 28749–28768. [CrossRef] [PubMed]
16. Wang, S.; Zhu, J.; Wang, L.; Zhong, S. The inhibitory effect of agricultural fiscal expenditure on agricultural green total factor productivity. *Sci. Rep.* **2022**, *12*, 20933. [CrossRef] [PubMed]
17. Ye, D.; Zhen, S.; Wang, W.; Liu, Y. Spatial double dividend from China's main grain-producing areas policy: Total factor productivity and the net carbon effect. *Humanit. Soc. Sci. Commun.* **2023**, *10*, 459. [CrossRef]
18. Qian, L.; Liu, C.; Zheng, L.; Qian, W. How does high-standard farmland construction affect farmland transfer. *China Land Sci.* **2023**, *37*, 62–70.
19. Hao, S.; Wang, G.; Yang, Y.; Zhao, S.; Huang, S.; Liu, L.; Zhang, H. Promoting grain production through high-standard farmland construction: Evidence in China. *J. Integr. Agric.* **2024**, *23*, 324–335. [CrossRef]
20. Martyn, A.; Koshel, A.; Hunko, L.; Kolosa, L. Land consolidation in Ukraine after land reform: Voluntary and forced mechanisms. *Acta Sci. Pol. Adm. Locorum* **2022**, *21*, 223–229. [CrossRef]
21. Nguyen, H.Q.; Warr, P. Land consolidation as technical change: Economic impacts in rural Vietnam. *World Dev.* **2020**, *127*, 104750. [CrossRef]
22. Ye, F.; Wang, L.; Razzaq, A.; Tong, T.; Zhang, Q.; Abbas, A. Policy Impacts of High-Standard Farmland Construction on Agricultural Sustainability: Total Factor Productivity-Based Analysis. *Land* **2023**, *12*, 283. [CrossRef]
23. Pašakarnis, G.; Maliene, V. Towards sustainable rural development in Central and Eastern Europe: Applying land consolidation. *Land Use Policy* **2010**, *27*, 545–549. [CrossRef]
24. Bradfield, T.; Butler, R.; Dillon, E.; Hennessy, T.; Kilgarriff, P. The effect of land fragmentation on the technical inefficiency of dairy farms. *J. Agric. Econ.* **2021**, *72*, 486–499. [CrossRef]

25. Baráth, L.; Fertő, I.; Bojnec, Š. The effect of investment, LFA and agri-environmental subsidies on the components of total factor productivity: The case of Slovenian farms. *J. Agric. Econ.* **2020**, *71*, 853–876. [CrossRef]
26. Liu, Y.; Liao, W.; Zhang, X.; Qiu, H. Impact of high-standard farmland construction policy on chemical fertilizer reduction: A case study of China. *Front. Environ. Sci.* **2023**. [CrossRef]
27. Asimeh, M.; Nooripoor, M.; Azadi, H.; Van Eetvelde, V.; Sklenička, P.; Witlox, F. Agricultural land use sustainability in Southwest Iran: Improving land leveling using consolidation plans. *Land Use Policy* **2020**, *94*, 104555. [CrossRef]
28. Yang, N.; Sun, X.; Qi, Q. Impact of factor quality improvement on agricultural carbon emissions: Evidence from China's high-standard farmland. *Front. Environ. Sci.* **2022**, *10*, 1722. [CrossRef]
29. Tang, W.; Huang, K.; Zhou, F. Can High-Standard Farmland Construction Policy Promote Agricultural Green Development? Evidence from Quasi Natural Experiments in Hunan, China. *Pol. J. Environ. Stud.* **2023**, *32*, 5333–5346. [CrossRef] [PubMed]
30. Ntihinyurwa, P.D.; de Vries, W.T. Farmland fragmentation, farmland consolidation and food security: Relationships, research lapses and future perspectives. *Land* **2021**, *10*, 129. [CrossRef]
31. Wang, Y.; Li, G.; Wang, S.; Zhang, Y.; Li, D.; Zhou, H.; Yu, W.; Xu, S. A Comprehensive Evaluation of Benefit of High-Standard Farmland Development in China. *Sustainability* **2022**, *14*, 10361. [CrossRef]
32. Long, R.; Shao, T.; Chen, H. Spatial econometric analysis of China's province-level industrial carbon productivity and its influencing factors. *Appl. Energy* **2016**, *166*, 210–219. [CrossRef]
33. Koondhar, M.A.; Aziz, N.; Tan, Z.; Tang, S.; Abbasi, K.R.; Kong, R. Green growth of cereal food production under the constraints of agricultural carbon emissions: A new insights from ARDL and VECM models. *Sustain. Energy Technol. Assess.* **2021**, *47*, 101452. [CrossRef]
34. Ismael, M.; Srouji, F.; Boutabba, M.A. Agricultural technologies and carbon emissions: Evidence from Jordanian economy. *Environ. Sci. Pollut. Res.* **2018**, *25*, 10867–10877. [CrossRef] [PubMed]
35. Houssou, N.; Diao, X.; Cossar, F.; Kolavalli, S.; Jimah, K.; Aboagye, P. *Agricultural Mechanization in Ghana: Is Specialization in Agricultural Mechanization a Viable Business Model?* International Food Policy Research Institute: Washington, DC, USA, 2013.
36. Li, C.; Shi, Y.; Khan, S.U.; Zhao, M. Research on the impact of agricultural green production on farmers' technical efficiency: Evidence from China. *Environ. Sci. Pollut. Res.* **2021**, *28*, 38535–38551. [CrossRef] [PubMed]
37. Gong, Y.; Zhang, Y.; Chen, Y. The Impact of High-Standard Farmland Construction Policy on Grain Quality from the Perspectives of Technology Adoption and Cultivated Land Quality. *Agriculture* **2023**, *13*, 1702. [CrossRef]
38. Takeshima, H.; Hatzenbuehler, P.L.; Edeh, H.O. Effects of agricultural mechanization on economies of scope in crop production in Nigeria. *Agric. Syst.* **2020**, *177*, 102691. [CrossRef]
39. Mathew, I.; Shimelis, H.; Mutema, M.; Minasny, B.; Chaplot, V. Crops for increasing soil organic carbon stocks—A global meta analysis. *Geoderma* **2020**, *367*, 114230. [CrossRef]
40. Tientao, A.; Legros, D.; Pichery, M.C. Technology spillover and TFP growth: A spatial Durbin model. *Int. Econ.* **2016**, *145*, 21–31. [CrossRef]
41. Kaya, Y.; Yolobori, K. *Energy and Economy: Strategies for Sustainability*; Bookwell Publications: Delhi, India, 1999; pp. 1–69.
42. Wu, G.Y.; Sun, X.J.; Yu, F.B.; Yang, L.S. Analysis of the spatial correlation pattern of carbon productivity in China's plantation industry and the factors affecting it. *China Popul. Resour. Environ.* **2020**, *30*, 46–57.
43. Huang, X.; Feng, C.; Qin, J.; Wang, X.; Zhang, T. Measuring China's agricultural green total factor productivity and its drivers during 1998–2019. *Sci. Total Environ.* **2022**, *829*, 154477. [CrossRef] [PubMed]
44. Gang, F.; Xiaolu, W.; Guangrong, M. The Contribution of Marketization to China's Economic Growth. *China Econ.* **2012**, *7*, 4.
45. Liu, L.; Wang, X.; Meng, X.; Cai, Y. The coupling and coordination between food production security and agricultural ecological protection in main food-producing areas of China. *Ecol. Indic.* **2023**, *154*, 110785. [CrossRef]
46. Zhang, F.; Wang, F.; Hao, R.; Wu, L. Agricultural science and technology innovation, spatial spillover and agricultural green development—Taking 30 provinces in China as the research object. *Appl. Sci.* **2022**, *12*, 845. [CrossRef]
47. Kurosaki, T.; Khan, H. Human capital, productivity, and stratification in rural Pakistan. *Rev. Dev. Econ.* **2006**, *10*, 116–134. [CrossRef]
48. Oueslati, W.; Salanié, J.; Wu, J.J. Urbanization and agricultural productivity: Some lessons from European cities. *J. Econ. Geogr.* **2019**, *19*, 225–249. [CrossRef]
49. Tian, P.; Lu, H.; Heijungs, R.; Li, D.; Xue, Y.; Yang, Y. Patterns of carbon footprints of main grains production in China: A comparison between main and non-main producing areas. *Environ. Sci. Pollut. Res.* **2022**, *29*, 23595–23606. [CrossRef] [PubMed]
50. Zhang, Q.; Zhang, F.; Wu, G.; Mai, Q. Spatial spillover effects of grain production efficiency in China: Measurement and scope. *J. Clean. Prod.* **2021**, *278*, 121062. [CrossRef]