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The Impact of the Rural Digital Economy on Agricultural Green Development and Its Mechanism: Empirical Evidence from China

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Abstract: Agricultural green development represents an environmentally friendly and resource-efficient agricultural model, and it is a key way to achieve sustainable agricultural development. With the rapid rise of the digital economy, its influence is gradually spreading from urban to rural areas, and it has played a significant and far-reaching role in promoting the green transformation of agriculture. This paper employs the entropy weight method to measure the level of digital economy and agricultural green development in rural areas in 30 provincial administrative regions in China from 2012 to 2021 and analyzes the relationship between the two and the mechanisms behind it. The research results show that (1) the rural digital economy significantly promotes agricultural green development. (2) With the enhancement of agricultural green development, the impact of the rural digital economy on it initially increases and then declines. (3) The rural digital economy fosters agricultural green development by advancing agricultural technology, easing credit constraints, and promoting agricultural industry agglomeration. (4) Environmental regulation intensifies the positive influence of the rural digital economy on agricultural green development. This research significantly enhances our understanding of the mechanism by which the rural digital economy facilitates agricultural green development. It offers empirical evidence and recommendations for the government to formulate and implement effective policies to advance agricultural green transformation in the context of digital economy trends.

Keywords: rural digital economy; digital technology; agricultural green development; agricultural industry agglomeration; environmental regulation; policy synergy

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1. Introduction

As the green economy continues to evolve, both the public and government are in pursuit of greener development methods [1] and are increasingly integrating the principles of green economic development into various sectors. The concept of green development has also been integrated into agricultural development. Modern agriculture has improved agricultural productivity, but deep-seated challenges accumulated from long-term, extensive operations are gradually becoming evident [2]. On one hand, agricultural development is facing the dual environmental and resource constraints [3], with increasingly tight constraints on water and land resources, intensifying agricultural non-point source pollution [4], and the noticeable degradation of the agricultural ecosystem posing significant challenges to the sustainable development of the agricultural sector. On the other hand, consumer demand for green and premium agricultural products is burgeoning although market supply falls short, leading to a disparity between supply and demand which results in low agricultural economic efficiency. The dual pressures of the environment and the economy necessitate a shift in the approach to agricultural development. The promotion of agricultural green development is an essential approach to addressing the existing predicament in agricultural advancement.

Since the commercialization of the Internet in 1995, digital technology advancements have transformed the structure and form of human economies and societies. Taking China as an example, the 2023 China Digital Economy Development Report released by the China Academy of Information and Communications Technology shows that in 2022, the scale of China's digital economy reached CNY 50.2 trillion, accounting for 41.5% of the GDP [5]. The digital economy has become one of the most active fields in current society. With its new development model, the digital economy has become deeply integrated into all sectors of the economy and society, playing a crucial role in enhancing innovation efficiency [6,7], driving industrial transformation [8,9], and other aspects. The digital economy is the product of the close integration of modern digital technology and various sectors of the national economy. It represents a series of economic activities that are underpinned by digital technology, with digital platforms as the primary media and digital empowerment infrastructure as a vital support [10]. The trajectory of the development of the digital economy is gradually spreading from urban to rural areas. Currently, the level of digital economy development in urban areas is significantly higher than in rural regions, and it is expected to remain so for the foreseeable future. Furthermore, the development of the digital economy will also reinvigorate rural industry by integrating urban and rural areas and through the transfer of various elements [11]. The expansion of the digital economy in rural areas introduces novel prospects for the evolution of conventional agricultural practices. Digital infrastructure is extending to rural areas where digital technology is being integrated into agricultural production, transforming its methods, enhancing the efficiency of factor allocation, and reducing resource inputs in agriculture. Furthermore, the rural digital economy is enhancing agricultural environmental preservation. Digitalization has facilitated environmentally friendly production methods and more efficient regulatory models for the agricultural production environment, improving agro-ecological efficiency and mitigating environmental strain. Consequently, the rural digital economy has the potential to influence the green evolution of agriculture.

At present, there is a dearth of empirical studies in the literature examining the impact of the rural digital economy on agricultural green development. Limited studies have investigated the effects of the digital economy on agricultural green development [12] and its spatial spillover effects [13]. Additionally, several studies have analyzed the effect of the promotion of the digital economy on sustainable agricultural development by assessing its influence on agricultural green total factor productivity [14–16]. The majority of research in this area examines the influence of the digital economy on agricultural green development. However, the digital economy tends to be concentrated in urban areas, potentially creating a "digital divide" in rural or remote locations, further perpetuating digital inequality [17] and resulting in a lower level of the digital economy in rural areas. Therefore, this article assesses the level of digital economy in rural areas and explores its impact on agricultural green development. Moreover, the process of agricultural development may lead to specific environmental implications [18]. Extensive research has been conducted on sustainable agricultural practices, which have gained increasing attention. Following the "Green Revolution'", agriculture has transitioned to a new phase with a focus on achieving sustainable and equitable goals for agricultural development [19]. In addition, agricultural green development, as an extension of sustainable development, necessitates achieving a harmonious integration of economic and environmental factors in ways that align with the fundamental principles of coordination and sustainability [20]. It encompasses both the aspects of "green" and "development" [20], emphasizing an approach to development that pays attention to the conservation of agricultural resources and environmental protection [21,22]. Furthermore, alongside the previously mentioned impact of the digital economy, the scale effect resulting from large-scale farming makes a substantial contribution to the sustainable advancement of agriculture [23], enabling enhanced resource utilization while lowering the carbon footprint [24]. Environmental regulations [25] and agricultural insurance schemes [26] also exert an influence on promoting agricultural green development.

This paper uses data from China to examine the impact of the rural digital economy on agricultural green development. The reason for this is that China is the world's largest emitter of carbon emissions. According to global carbon emissions patterns, China accounts for a significant proportion of global carbon emissions, exceeding the combined total of countries 2–5. According to "The 2023 China Agricultural and Rural Low Carbon Development Report" released by the Chinese Academy of Agricultural Sciences, China's agricultural carbon emissions have reached 0.828 billion tons, accounting for 6.7% of the country's total carbon emissions. During China's rapid agricultural development, there has been a continuous increase in total carbon emissions from agriculture [27], and environmental protection concerns have become more prominent due to fertilizer and pesticide use [28,29]. To enhance sustainable agricultural development and mitigate environmental threats resulting from rapid agricultural growth in China, the Chinese government has incorporated the philosophy of green development into agricultural development [30]. Therefore, exploring the influence of the rural digital economy on agricultural green development in China is of great practical importance for developing countries engaged in rural digital economy construction and for facilitating the transition to green agriculture.

The additional contributions of this paper are as follows: First, this paper assesses the levels of the rural digital economy and agricultural green development. The empirical examination conducted unveils the beneficial impact of the rural digital economy on the transition to greener agricultural practices, effectively filling a void in the existing literature on this subject. Second, this paper delves into the intrinsic mechanism through which the rural digital economy fosters agricultural green development using a mediation effect model. This exploration not only enriches relevant theories but also offers significant guidance for practical applications. Third, this paper examines the moderating role of environmental regulation on the influence of the rural digital economy on agricultural green development, offering empirical evidence for policymakers to refine their agricultural green development policies.

The remainder of this article is structured as follows: Section 2 presents a theoretical analysis of how the rural digital economy impacts agricultural green development. Section 3 outlines the research data, variables, and baseline econometric models. Section 4 comprises empirical analyses, which include benchmark regression tests, robustness checks, heterogeneity analyses, mediation mechanism tests, and moderating effect tests. Section 5 summarizes the research findings and addresses the limitations of this study.

2. Theoretical Mechanism and Research Hypothesis

2.1. The Direct Impact of the Rural Digital Economy on Agricultural Green Development

The expansion of the digital economy is shifting from urban to rural areas, emerging as a fresh impetus for agricultural development. The development of the rural digital economy can promote agricultural economic growth and strengthen agricultural environmental protection, thereby enabling agricultural green development.

The rural digital economy can foster agricultural economic growth. From the perspective of yield, agricultural economic growth is characterized by a consistent rise in agricultural output. From the viewpoint of the agricultural output value, it manifests in the elevation of the total agricultural output value. When analyzed from the standpoint of input–output relationships, it is expressed by an increase in the input–output ratio. From the aforementioned definition, prior to agricultural production, a well-developed digital infrastructure helps increase communication channels among farmers, agricultural business entities, and external sources of information. It speeds up the spread of information and broadens its reach, enhances the verifiability of the information [31], reduces information asymmetry, facilitates the flow of agricultural factors, and promotes efficient resource allocation. Producers can make informed production decisions tailored to their productive endowments, optimize the allocation of agricultural production resources, and enhance the efficiency of allocation. Secondly, in the process of agricultural production, the development of the rural digital economy facilitates the efficient transmission and sharing of agriculture-related information. Agricultural producers can obtain professional knowledge and technology related to agricultural production at a very low cost, thereby improving the output levels of agricultural production sectors. Finally, once agricultural products are harvested, the rural digital economy can facilitate the digital transformation of the agricultural product market, enhance the post-harvest processing efficiency of agricultural products, and promote their sales. Digital platforms, such as agricultural product e-commerce, have expanded sales channels for agricultural products, opened up a larger agricultural product market, and better matched the supply and demand sides of agriculture, thereby creating greater agricultural economic benefits.

The development of the rural digital economy can enhance agricultural environmental protection. First, the integration of the digital economy and agriculture facilitates the incorporation of advanced spatial information technologies such as satellite navigation, remote sensing, and geographic information systems into the current mode of agricultural production. Additionally, this enables precision farming practices [32]. Precision agriculture has revolutionized conventional high-input agricultural production methods by ensuring timely, accurate, and balanced resource allocation through technological intervention. Consequently, this leads to resource-efficient and environmentally sustainable production techniques that enable the precise management of water resources, fertilizers, pesticides, and other agricultural inputs [33], effectively mitigating the damage associated with traditional production approaches [34]. Second, the development of the rural digital economy contributes to enhancing the regulatory mode of the agricultural production environment [35]. As the agricultural economy continues to expand, traditional environmental monitoring models are increasingly exposed to numerous deficiencies. Against this backdrop, innovative applications of digital technology have revolutionized environmental monitoring. By leveraging cutting-edge technologies such as big data and cloud computing, the government can achieve real-time dynamic monitoring of environmental data resources encompassing various aspects including but not limited to air quality, river water quality, and pollution emissions. The application of this technology significantly improves the government's ability to accurately identify and provide timely warnings to pollution sources, thereby effectively enhancing the efficiency and response speed of environmental monitoring. Moreover, techniques such as data visualization provide more intuitive and efficient ways to address concerns regarding environmental pollution, reinforcing public oversight and thus contributing to enhanced agricultural environmental protection.

In summary, we put forward the following research hypothesis:

Hypothesis 1. *The rural digital economy can significantly promote agricultural green development.*

2.2. The Mediating Effect of the Rural Digital Economy on Agricultural Green Development

2.2.1. The Mediating Effect of Agricultural Technological Progress

The integration of digital tools into automation technology, such as drones, intelligent robots, and other intelligent mechanized equipment, can change the methods of agricultural production and enhance agricultural production efficiency [36]. Moreover, intelligent monitoring systems can help manage the agricultural production environment so as to better manage the input of factors and resources, precisely control the input of raw materials and labor resources required in the agricultural production process, improve resource utilization, and achieve the goals of water conservation, saving fertilizer, and energy conservation [37]. Therefore, adopting advanced technologies is crucial as they can significantly enhance the efficiency of resource and energy use and facilitate the recycling of resources and effective pollution control. Such technological innovation can not only achieve energy conservation and reduce emissions in the production process but can also promote the sustainable growth of the agricultural economy while mitigating its ecological burden. In this way, we can facilitate a green transformation in agricultural development and build a more environmentally friendly and sustainable agricultural system. Moreover, against the backdrop of rapidly increasing resource constraints and increasingly stringent environmental regulations, technology itself is continually moving toward more clean and green advancements, making agricultural green innovation an emerging driving force for sustainable development.

However, beneficial agricultural technologies cannot be effectively promoted due to factors such as the agricultural technology promotion system, especially in developing countries [38]. Effective information channels are very important. With the popularization of digital infrastructure in rural areas, the Internet is an important channel for small-scale agricultural producers to receive agricultural technology [39]. For less-educated farmers, online videos comprise an important medium for them to learn about agricultural technology [40]. Concurrently, as the rural digital economy grows, the market's demand for agricultural products will motivate farmers to adopt beneficial agricultural technologies. Consequently, the advancement of the rural digital economy will foster the progress of agricultural technology. Therefore, the following hypothesis is proposed:

Hypothesis 2a. *The rural digital economy drives agricultural technological advancement, thereby fostering agricultural green development.*

2.2.2. The Mediating Effect of Agricultural Credit

The development of the rural digital economy can alleviate constraints in agricultural credit, thereby promoting agricultural green development. Agriculture is inherently vulnerable as crops are exposed to natural disasters during their growth, and they are also exposed to market risks and other uncertainties during the marketing process. Moreover, agricultural entities generally lack effective collateral, and the agricultural financial sector faces challenges including information asymmetry and high transaction costs [41]. The resulting financing constraints limit the inflow of agricultural capital. The development of the rural digital economy alleviates agricultural credit constraints through the following aspects: first, it expands financing channels and enhances financing accessibility. By innovating the credit product supply and providing online financing platforms, it inspires social capital to invest in agricultural and rural development, thereby expanding the modern rural financial system. Second, it reduces transaction costs. By leveraging digital technology, we can precisely identify the demand for effective credit, transcending the spatial and temporal limitations of traditional financial transaction models. We can also streamline the financing approval process, thereby effectively lowering the transaction costs for agricultural financing.

Capital is a crucial input in agricultural production, and easing agricultural credit constraints can effectively boost capital investment, enabling agricultural producers to enhance their agricultural infrastructure and to purchase and adopt production materials such as organic fertilizers, biopesticides, plant-based feed additives, low-toxicity veterinary drugs, and energy-saving and efficient machinery and equipment, thereby improving agricultural production efficiency and resource utilization efficiency [42], meeting the needs of agricultural green development.

Hypothesis 2b. *The rural digital economy alleviates agricultural credit constraints, thereby promoting agricultural green development.*

2.2.3. The Mediating Effect of Agricultural Industrial Agglomeration

Agricultural industrial agglomeration refers to large numbers of agricultural production and operation entities gathering in a specific geographical space, resulting in economies of scale. The concentration of the agricultural sector facilitates the pooling of resources for farming activities, improves the degree of specialization and cooperative efforts among laborers, and diminishes both the costs associated with producing goods and the expenses of transactions. This, in turn, leads to an expansion in the volume of agricultural output, thus realizing the benefits of scaled economic operations [43]. The effect of economies of scale in agriculture can reduce pollution control costs, optimize factor allocation, and enhance resource utilization efficiency, thereby promoting green agricultural development. Agricultural industrial agglomeration will also strengthen competition and mutual learning among agricultural operators, inspiring agricultural operators to continuously improve production technology, adopt green technology, improve the quality of agricultural products as well as their market competitiveness, and promote agricultural green development [44].

In the context of the digital economy, the speed of rapid information dissemination and the cost of information transmission, with the growth of digital technologies in businesses and the expansion of rural e-commerce, have led to a vastly expanded market for agricultural products. By expanding beyond a product's production and surrounding areas, combined with modern logistics, enterprise layout becomes more flexible [45]. Coordinated labor division among different agricultural enterprises effectively reduces transaction costs and boosts economic returns. Furthermore, the application of digital technology provides a foundation for all production stages upstream and downstream to access timely and comprehensive supply and demand information, reducing information asymmetry and promoting agglomeration in the agricultural industry.

Hypothesis 2c. *The rural digital economy facilitates agricultural industry agglomeration, thereby fostering agricultural green development.*

2.3. The Moderating Effect of Environmental Regulation

The development and environmental regulation of the rural digital economy exhibit policy coherence in promoting agricultural green development. Porter's hypothesis posits that appropriate environmental regulation can compensate for potential costs associated with environmental regulation by stimulating corporate innovation [46]. Furthermore, competitiveness varies under different levels of environmental regulation [47]. In the presence of stringent environmental regulations, profit-driven companies can enhance productivity through technological innovation or adopt green production technologies to mitigate pollution emissions [48]. In the agricultural sector, environmental regulation signifies intervening in agricultural production methods to alleviate environmental stress. Specifically, driven by environmental regulations, agricultural producers will actively choose more environmentally friendly production methods. The improved rural digital infrastructure provides a platform for agricultural producers to search for information, reducing search costs. The strengthened rural digital economy's application capabilities have removed geographical restrictions on the circulation of green production materials and equipment. Therefore, under appropriate environmental regulations, agricultural production entities will actively use digital technologies to find production methods that suit their own endowments, thereby improving resource allocation efficiency and reducing pollution emissions in the agricultural sector and thus fully leveraging the role of the rural digital economy in promoting agricultural green development.

Therefore, we propose the following hypothesis:

Hypothesis 3. *Environmental regulation can strengthen the promoting effect of the rural digital economy on agricultural green development.*

In summary, the influence mechanism of the rural digital economy on agricultural green development is shown in Figure 1.

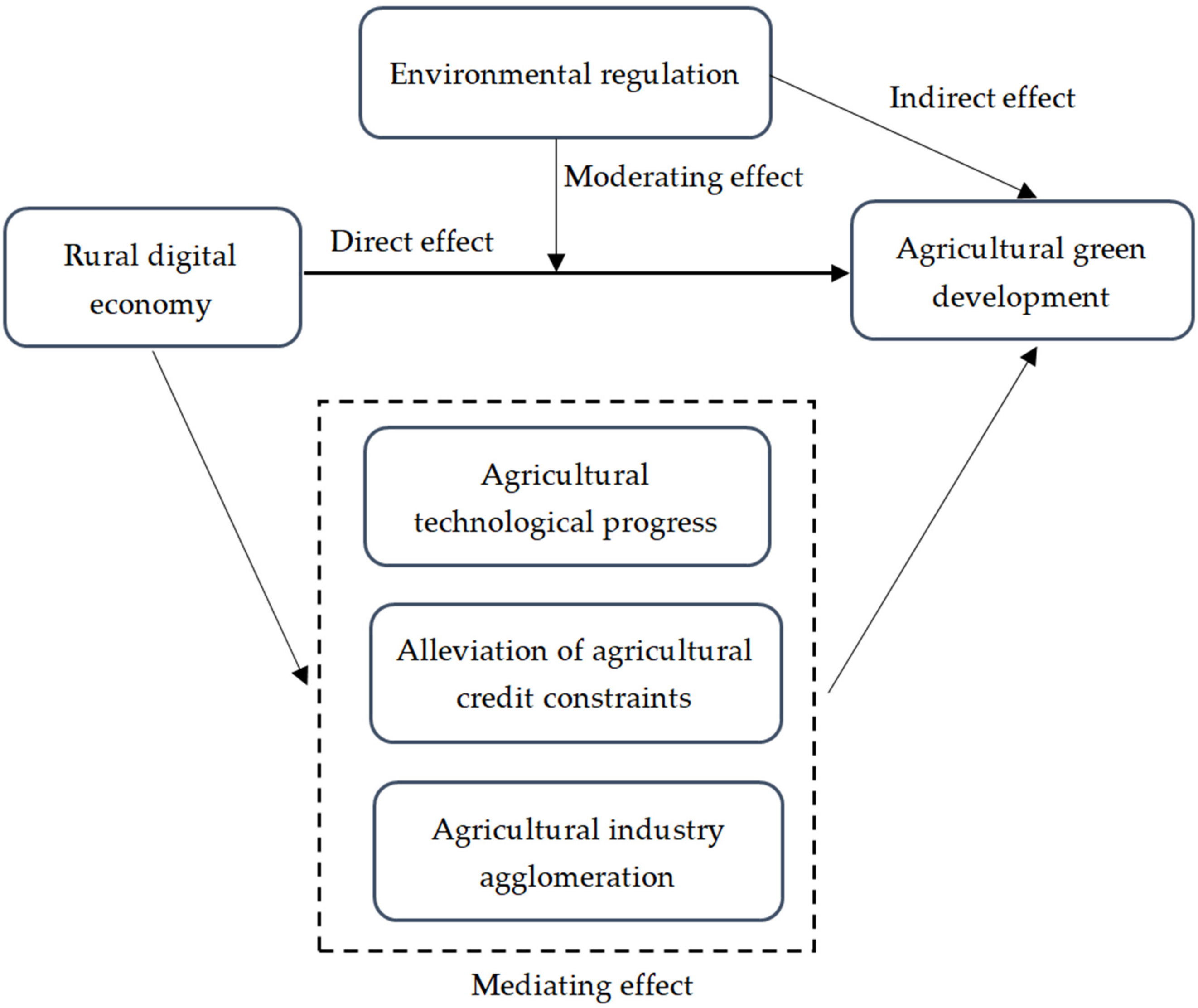

Figure 1. Influence mechanism.

3. Research Design

3.1. Construction and Description of Measurement Model

3.1.1. Benchmark Model

This paper establishes the following econometric model to further test the impact of the development of the rural digital economy on agricultural green development:

$$AGD_{it} = \alpha_0 + \alpha_1 digital_{it} + \sum \alpha_j controls_{jit} + \mu_i + \nu_t + \varepsilon_{it} \quad (1)$$

Here, i denotes provinces, t denotes years, AGD_{it} denotes the level of agricultural green development, and $digital_{it}$ denotes the level of development of the rural digital economy. $controls_{it}$ denotes control variables, which include the contributions of agriculture, urbanization, policy support, and the level of regional economic development. μ_i and ν_t denote provincial fixed effects and year fixed effects, respectively, and ε_{it} is a random error term.

3.1.2. Mediating Effect Model

To further investigate the pathway through which the rural digital economy influences agricultural green development, this study establishes the following mediating effect test model to assess potential mediating effects:

$$Mediate_{it} = \beta_0 + \beta_1 digital_{it} + \sum \beta_j controls_{jit} + \mu_i + \nu_t + \varepsilon_{it} \quad (2)$$

$$AGD_{it} = \gamma_0 + \gamma_1 digital_{it} + \gamma_2 Mediate_{it} + \sum \gamma_j controls_{jit} + \mu_i + \nu_t + \varepsilon_{it} \quad (3)$$

In the above two formulas, Mediate represents the mediating variable. This article selected three mediating variables: agricultural industry agglomeration, agricultural technological progress, and agricultural credit constraints. If the rural digital economy significantly influences agricultural green development, i.e., the significance of α_1 in Equation (1) is evident, then we further investigate whether the rural digital economy influences agricultural green development through this mediating variable. If both β_1 in Equation (2) and γ_2 in Equation (3) are significant, it indicates that the rural digital economy will affect agricultural green development by influencing this mediating variable. At this juncture, if γ_1 remains significant, it suggests that the mediating variable acts as a partial mediating variable. The rural digital economy not only impacts the mediating variable, thus influencing agricultural green development, but also has indirect effects on agricultural green development through various mechanisms. If γ_1 is no longer significant, it suggests that the mediating variable acts as a complete mediating variable. The rural digital economy solely influences agricultural green development by influencing this mediating variable, with no direct or indirect mechanisms of action.

3.1.3. Moderating Effect Model

When fostering agricultural green development trends with the support of environmental regulations and policies, the impact is anticipated to be heightened. Consequently, this study establishes a regression model, as depicted in Equation (4), to investigate whether environmental regulations can amplify the influence of the rural digital economy in advancing agricultural green development.

$$AGD_{it} = \alpha_0 + \alpha_1 digital_{it} + \alpha_2 er_{it} + \alpha_3 digital_{it} \times er_{it} + \sum \alpha_j controls_{jit} + \mu_i + \nu_t + \varepsilon_{it} \quad (4)$$

Based on Equation (1), Equation (4) introduces the environmental regulation variable er_{it} and a term representing the interaction between the rural digital economy and environmental regulation while maintaining all other control variables constant. By examining the results of the estimation of α_3, we can assess whether environmental regulation amplifies the propulsive influence of the rural digital economy on agricultural green development.

3.2. An Evaluation Index System for the Agricultural Green Development Level

There is a fundamental consensus among existing research findings regarding the understanding of green development which suggests integrating its socioeconomic and ecological benefits. The objective of agricultural green development is to coordinate the "development" and "green" aspects of agriculture [20]. Building upon relevant previous studies [49], this article establishes an evaluation system for assessing the level of agricultural green development which encompasses both agricultural ecological benefits and agricultural economic benefits, as depicted in Table 1. Among them, the agricultural ecological benefits include four indicators: the intensity of fertilizer usage, plastic film usage, and pesticide usage and the proportion of agricultural water-saving irrigation. Among these factors, agricultural plastic films, encompassing both mulching and greenhouse films, serve as vital means of production in agricultural production and play a pivotal role in enhancing crop yield and quality. However, the prolonged and widespread use of agricultural plastic films, coupled with the absence of their effective recycling and disposal, resulted in the utilization of 2.358 million tons of agricultural plastic films in China in 2021, thereby giving rise to the so-called "white pollution" issue. The agricultural economic benefits consist of five indicators: agricultural per capita GDP, land productivity, per capita net income of rural residents, grain yield per unit of cultivated land area, and per capita grain consumption.

Table 1. An evaluation index system for the agricultural green development level.

First-Level Indicators	Secondary Indicators	Variable Composition	Indicator Attribute
Agricultural ecological benefits	Fertilizer usage intensity	Agricultural fertilizer usage/agricultural added value	−
	Agricultural film usage intensity	Agricultural film usage/agricultural value added	−
	Pesticide usage intensity	Agricultural pesticide usage/agricultural value added	−
	Proportion of agricultural water-saving irrigation	Water-saving irrigation area/effective irrigation area	+
Agricultural economic benefits	Agricultural per capita GDP	Added value of primary industry/population	+
	Land productivity	Agricultural value added/total sown area of crops	+
	Per capita net income of rural residents	Per capita net income of rural residents (CNY)	+
	Grain yield per unit of cultivated land area	Total grain output/grain sown area	+
	Per capita possession of grain	Total grain output/population	+

Note: "+" denotes indicators that promote agricultural green development; "−" denotes indicators that have inhibitory effects on agricultural green development.

The data are initially standardized to eliminate dimensional effects caused by using different units to measure the indicators' index values. Then, the entropy method is used to determine the weight assigned to each indicator, and finally, the comprehensive evaluation value of the agricultural green development index is calculated.

3.3. Evaluation Index System of the Rural Digital Economic Development Level

Rural digital economic infrastructure serves as a vital foundation for advancing the digital economy. Moreover, once a certain level of digital infrastructure is established, the capability to develop rural digital applications becomes crucial, reflecting the actual state of the digital economy's development. Building on the existing indicator system for digital economy development and considering the unique features of rural digital economic development, this study assesses the level of rural digital economic development across two dimensions: the level of rural digital infrastructure and the capacity for rural digital application development. The selected indicators are detailed in Table 2.

Table 2. Evaluation index system for rural digital economic development level.

First-Level Indicators	Secondary Indicators	Indicator Attribute
Level of rural digital infrastructure	Proportion of rural cable radio and television subscribers	+
	The average number of mobile phones per 100 households in rural households	+
	Rural internet penetration	+
	Number of cell phone service base stations	+
	Average number of deliveries per week in rural areas	+
	The average number of computers per 100 rural households at the end of the year	+

Table 2. *Cont.*

First-Level Indicators	Secondary Indicators	Indicator Attribute
Capacity of rural digital economy application	Electricity consumption per capita in rural areas	+
	Agrometeorological observation operations	+
	Number of Taobao villages	+
	Total farm machinery power	+
	E-commerce sales	+
	E-commerce purchases	+

Note: "+" denotes indicators that promote rural digital economy.

3.4. Variable Description

(1) Dependent and independent variables: The dependent variable studied in this article is the "Agricultural Green Development (AGD)", and the core independent variable is the "Rural Digital Economy (digital)". As mentioned earlier in the index system, we calculate the final assessment result using the entropy method.

(2) Mediating variables: The degree of agricultural industry agglomeration (LQ) is measured using the location entropy index in this study [50], using the following formula:

$$LQ_{it} = \frac{a_{it}/gdp_{it}}{A_t/GDP_t}$$

In this context, LQ_{it} represents the agricultural industry location quotient index in province i in year t. a_{it} and A_{it} denote the regional and national agricultural production gross values, and gdp_{it} and GDP_{it} stand for the regional and national gross domestic product values. An increase in the agricultural industry location quotient index corresponds to a higher level of agglomeration in the agricultural sector and vice versa. Regarding agricultural technological progress (tec), the number of agricultural technology patents serves as a significant indicator of agricultural technological innovation, reflecting agricultural technological advancement to a certain extent. To better capture the agricultural technological progress of a region, this study employs the ratio of agricultural technology patents to the region's rural population to assess regional agricultural technological progress.

Regarding agricultural credit (cre), the level of agricultural credit can be reflected largely by agriculture-related loans. This paper measures the level of regional agricultural credit by calculating the ratio of the regional GDP to the total agriculture-related loans in the region.

(3) Moderating variables—environmental regulation (er): The literature on environmental regulation primarily focuses on regional or industrial sectors, with limited research dedicated to environmental regulation in the agricultural sector. In this study, we selected four sources of pollution: nitrogen fertilizer, compound fertilizer, pesticides, and plastic film usage. Pollution intensity was assessed by calculating the ratios of these pollution sources to the agricultural value added. The intensity of pollution in an industry frequently exhibits a positive correlation with environmental regulations; therefore, pollution intensity can be used to characterize environmental regulations. Subsequently, every indicator is initially standardized, followed by the calculation of an environmental regulation index using a weighted average approach.

(4) Control variables: Based on existing research, this article selects key factors of agricultural green development to serve as control variables for the model. The specific selection and explanation of the control variables are as follows:

Regarding the contribution of agriculture (agr) [51,52], the steady growth of the agricultural economy supports green development, and the agricultural economy's growth provides the necessary material and financial foundations for green agricultural development. With the steady growth of the agricultural economy, more resources can be invested in researching, developing, and promoting green agricultural technology, fostering a transformation in agricultural production methods and enhancing the environmental friendliness of agricultural production. This article uses the primary industry's GDP as a proportion of the province's GDP in that year to indicate the extent of agriculture's contribution to economic development.

Regarding policy support (gov) [53], government financial support is crucial to the green development of agriculture. By providing financial support and policy incentives, it has promoted agricultural technological innovation, optimized agricultural subsidy policies, enhanced the level of agricultural standardization, and strengthened the prevention and control of agricultural non-point source pollution. These measures have jointly advanced the transformation of agricultural production methods, improved the efficiency and environmental friendliness of agricultural production, promoted the harmonious coexistence of agriculture and the ecological environment, and laid a solid foundation for achieving green development in agriculture. This paper measures government financial support using the ratio of provincial agricultural, forestry, and water fiscal expenditure to the general public budget for the current year.

Urbanization (urb) [54] has strengthened the construction of rural infrastructure, such as water supply, power supply, and communication networks, which provides better material conditions for agricultural production. It promotes the interaction of urban and rural resources and the flow of urban technology and capital to rural areas, supporting the green development of agriculture. Meanwhile, green products and services from rural areas also offer more choices to cities, leading to a situation of mutual complementarity and shared prosperity between urban and rural areas. This article employs the ratio of the urban population to the regional population for measurement.

Regarding he level of regional economic development (lnGDP) [55], economically advanced regions often possess more comprehensive policy support systems and regulatory environments capable of fostering agricultural green development through legislation and policy guidance. Simultaneously, the public's awareness of environmental protection is typically heightened, setting higher standards for environmental protection and sustainable development in agricultural production. This social climate aids in encouraging the government and agricultural producers to adopt more environmentally sustainable production practices, mitigating adverse environmental impacts. The level of regional economic development is measured by taking the logarithm of the year's per capita GDP in a province.

3.5. Data Sources and Descriptive Statistics

This paper is composed of panel data from 30 provincial administrative regions in China from 2012 to 2021. Due to the difficulty of acquiring data, Xizang, Hong Kong, Macao, and Taiwan are not included. The data mainly come from the China Rural Statistical Yearbook (2013–2022), the China Statistical Yearbook on Science and Technology (2013–2022), and the statistical yearbooks of each province from 2013 to 2022.

The descriptive statistics for the variables are presented in Table 3. Differences exist among provinces in terms of the levels of agricultural green development and rural digital economic development. The calculation results indicate that the minimum value of the development level of the rural digital economy is 0.028 and the maximum value is 0.667. The primary factor contributing to this phenomenon may be attributed to disparities in digital economy development across different regions. The rural digital economy is heavily influenced by and reliant on its urban counterpart, thus further widening the existing gap in rural digital economic development within areas characterized by relatively underdeveloped digital economies.

Table 3. Descriptive statistics of variables.

Variable	Mean	Median	SD	Min	Max	N
AGD	0.335	0.306	0.112	0.164	0.701	300
digital	0.184	0.126	0.144	0.028	0.667	300
er	0.127	0.127	0.0480	0.0330	0.294	300
LQ	1.205	1.212	0.648	0.0320	3.274	300
tec	2.305	1.38	2.664	0.137	18.55	300
cre	0.398	0.379	0.181	0.0460	0.897	300
agr	9.592	9.200	5.144	0.200	25.10	300
urb	60.231	58.76	11.81	36.3	89.6	300
gov	0.115	0.115	0.0340	0.0410	0.204	300
lnGDP	4.739	4.717	0.186	4.295	5.265	300

Figure 2 displays the results of the assessment of the rural digital economy and the level of agricultural green development in 30 provinces from 2012 to 2021. During the study period, the level of agricultural green development declined in most provinces, but the pace of decline has slowed in recent years, and in some provinces, it has gradually been on an increasing trend. The rural digital economy has maintained arising increasing trend in most provinces.

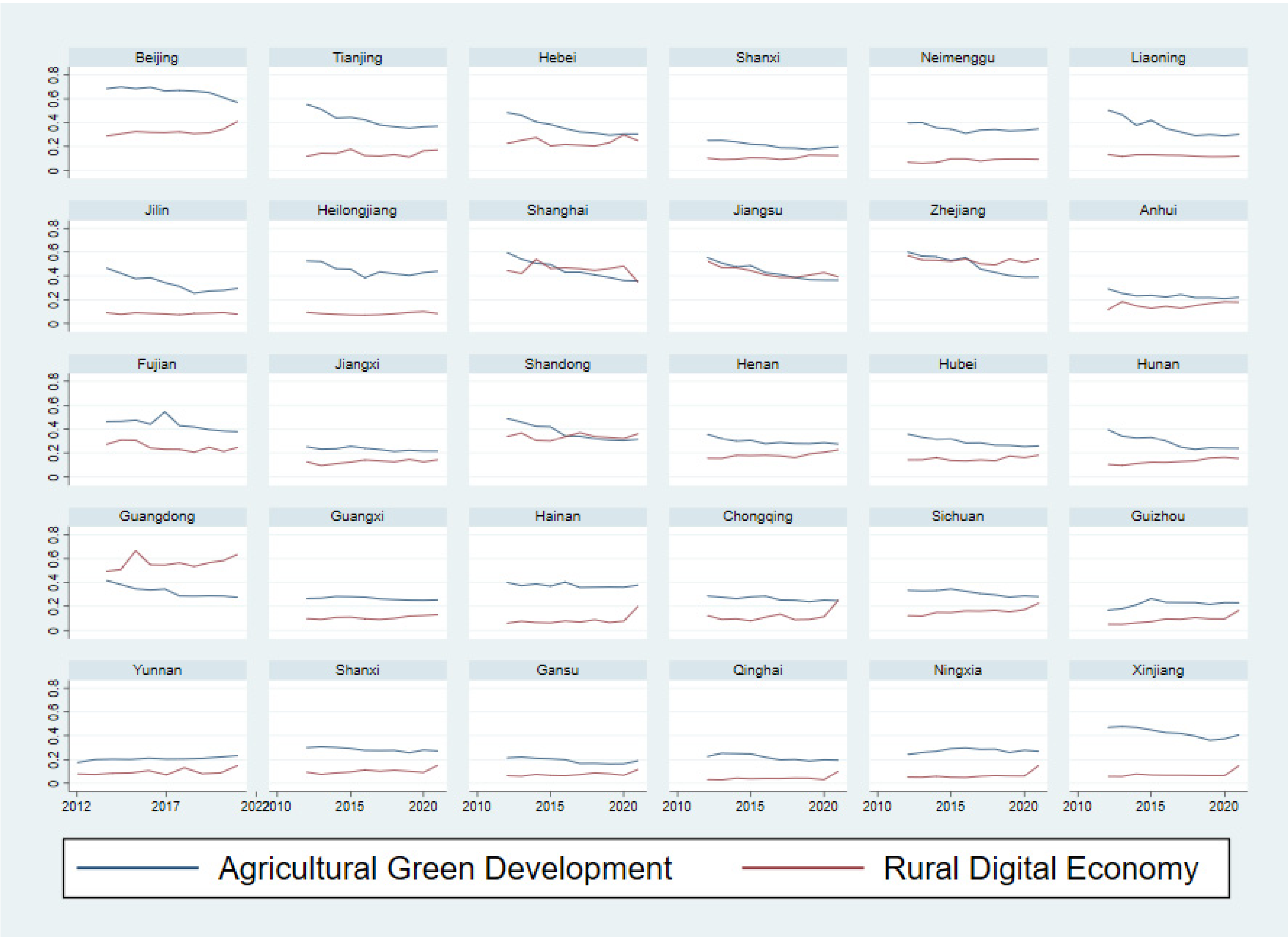

Figure 2. Trend graph of variation in agricultural green development level and rural digital economic development level.

4. Empirical Results and Analysis

4.1. Benchmark Regression

This paper employed both fixed-effects and random-effects models to estimate the regression equation. The Hausman test yielded a value of 292.03, significant at the 1% level. The fixed-effects model's estimates were superior to those of the random-effects model. The regression findings, as presented in Table 4, reveal that both columns (3) and (4) show the coefficients for the rural digital economy variables to be significant at the 1% level. Column (4), after the inclusion of control variables, saw a decrease in the coefficient from 0.306 to 0.180, suggesting the presence of additional factors influencing agricultural green development. In this case, both the primary explanatory variables and control variables were significant at the 5% level, underscoring the efficacy of the control variables as influential factors in agricultural green development. The extent of agricultural contribution, urbanization, policy support measures, and the level of regional economic development all positively influence agricultural green development. The extent of agricultural contribution reflects the relative importance of agriculture in the overall economy and serves as an indicator of its development level, thereby promoting green agricultural development. A higher degree of urbanization enables rural areas surrounding cities to access advanced technologies and adopt improved management practices that drive green agriculture advancements forward accordingly. Regional economic development represents the overall progress made within a region's economy, and more developed regions generally exhibit greater focus on environmental governance. The greater the government's support for agriculture, the more investment can be allocated to agricultural environment management.

Table 4. Benchmark regression results.

	(1) (RE)	(2) (RE)	(3) (FE)	(4) (FE)
	AGD	AGD	AGD	AGD
dgital	0.135 *	0.381 ***	0.306 ***	0.180 ***
	(0.075)	(0.070)	(0.073)	(0.061)
urb		−0.000		0.008 ***
		(0.001)		(0.001)
lnGDP		−0.204 ***		0.301 ***
		(0.056)		(0.043)
gov		−0.462 **		0.284 **
		(0.209)		(0.143)
arg		0.002		0.010 ***
		(0.002)		(0.002)
_cons	0.310 ***	1.291 ***	0.620 ***	−1.540 ***
	(0.022)	(0.220)	(0.026)	(0.216)
Province	N	N	Y	Y
Year	N	N	Y	Y
N	300	300	300	300
R^2	0.225	0.289	0.569	0.717
Provinces	30	30	30	30

Note: *** $p < 0.01$, ** $p < 0.05$, and * $p < 0.1$; standard errors are in parentheses.

4.2. Robustness Test

4.2.1. Changing the Measurement Index of the Explained Variable

To validate the effectiveness of the benchmark regression, the measurement indicators for agricultural green development are changed. Agricultural economic benefits encompass various aspects, but the most straightforward representation is the value added by the primary industry. Therefore, this study employs the value added by the primary industry as an indicator of agricultural economic benefit, replacing the indicators previously used in the existing measurement system. The indicators of agricultural ecological benefits remain unchanged. After changing the measurement indicators, when using the entropy method to re-evaluate the level of agricultural green development, the agricultural green development is represented as AGD *. The regression results presented in Table 5, column (1), remain consistent with the baseline regression findings mentioned earlier, even after altering the indicators used to measure agricultural green development. The positive coefficients indicate that rural digital economic development significantly promotes agricultural green development, which is in line with previous research.

Table 5. Results of the robustness test.

	(1)	(2)	(3)	(4)	(5)
	AGD *	**AGD**	**AGD ***	**AGD ****	**AGD ****
digital	0.287 *** (0.083)			−0.097 ** (0.099)	
digital_{t-1}		0.146 ** (0.069)	0.202 ** (0.086)		−1.706 *** (0.589)
Control	Y	Y	Y	Y	Y
Province	Y	Y	Y	Y	Y
Year	Y	Y	Y	Y	Y
_cons	−1.861 *** (0.292)	−1.217 *** (0.213)	−1.311 *** (0.263)	0.153 *** (0.199)	0.162 *** (0.214)
N	300	270	270	300	270
R^2	0.652	0.703	0.658	0.920	0.925
Provinces	30	30	30	30	30

Note: *** $p < 0.01$, ** $p < 0.05$; standard errors are in parentheses.

4.2.2. Lagging the Explanatory and Control Variables by One Period

Whether it is through influencing agricultural economic growth or impacting environmental protection in agriculture, the development of the digital economy will have a delayed impact on the green development of agriculture. This is because despite the accelerated circulation of information brought about by the development of the digital economy, a certain amount of time is still needed for this information to be disseminated from the market to agricultural producers. Subsequently, time must be allowed for agricultural producers to make necessary adjustments in their production practices and for agricultural products to be ultimately delivered. Additionally, time is needed for the relevant regulatory authorities to respond and implement necessary adjustments after the identification and monitoring of issues within the agricultural domain. Therefore, considering the potential time lag in the impact of the rural digital economy on agricultural green development, a regression analysis is conducted on both the explanatory and control variables with a one-period lag. The findings are presented in columns (2) and (3) of Table 5. Column (2) shows the regression results with a lag of one period, and the coefficient is positive. Column (3) shows the regression result obtained by replacing the measure indicator of the explained variable in the previous text with a positive and significant coefficient. This is consistent with the aforementioned results.

4.2.3. Altering the Criteria for Measuring the Dependent Variable

A significant portion of the environmental pollution from agricultural activities stems from carbon emissions generated during production processes. In this study, agricultural carbon emissions are adopted as a proxy variable for sustainable agricultural development. Agricultural carbon emissions refer to the CO_2 emitted during agricultural production activities, and the specific calculation method is as follows [56]:

$$E = \sum E_i = \sum T_i \times \varepsilon_i$$

In this context, E represents the total agricultural carbon emissions in a region, and T_i denotes the input of the ith carbon source. There are primarily six types of carbon sources including fertilizers, pesticides, agricultural films, diesel consumption by agricultural machinery, and agricultural irrigation areas. The carbon emission coefficients for these sources were determined based on existing research [37,56,57], as detailed in Table 6.

Table 6. Carbon emission coefficient.

Carbon Source	Carbon Emission Coefficient	Unit
Chemical fertilizer	0.89	kg/kg
Pesticide	4.93	kg/kg
Agricultural film	5.18	kg/kg
Diesel oil	0.59	kg/kg
Irrigation	266.48	kg/hm^2

Upon calculating the total agricultural carbon emissions, to better measure the regional intensity of agricultural carbon emissions, we characterize the intensity of agricultural carbon emissions by the ratio of agricultural carbon emissions to the regional agricultural GDP, denoted by AGD **. An empirical test was conducted, and the specific results are presented in columns (4) and (5) of Table 5. Column (5) shows the regression results with the explanatory variable lagged by one period. The results show that the coefficients for the rural digital economy variables are significant at the 1% level and the signs of the coefficients are negative, indicating a suppressive effect on agricultural carbon emissions. Additionally, the coefficient of the rural digital economy variable lagging one period is significantly larger than that of the current period, indicating that the impact of the rural digital economy on agricultural carbon emissions has a significant time lag. These results further support the robustness of the baseline regression findings.

4.2.4. Test for Endogeneity

In the field of agriculture, the application of digital technology has become an important cornerstone in the construction of the rural digital economy. Amidst the pursuit of agricultural green development, regional needs will spur the active adoption of digital technologies tailored for agriculture. This process encompasses not only technological innovation and application but also the enhancement and refinement of digital infrastructure, thereby influencing the overall state of the rural digital economy. Therefore, this development model may lead to a reverse causality; that is, the demand for agricultural green development could also foster the growth of the rural digital economy at the same time. In this paper, we employ a two-stage least squares approach and instrumental variable methods to address potential endogenous issues. We utilize the average number of mobile phones per 100 rural households and a lagged rural digital economy variable as instrumental variables for the level of rural digital economic development. The empirical analysis is conducted using the 2SLS method. The findings, as presented in Table 7, indicate a significant positive correlation consistent with the baseline regression results. To validate the endogeneity of the explanatory variables, we first used the Husman test, which yielded a p value of 0.000, indicating a rejection of the null hypothesis that all explanatory variables are exogenous at a significance level of 1%, thereby concluding that the variable "digital" is an endogenous variable. The p value from the overidentification test was 0.307; therefore, the null hypothesis is accepted, concluding that the instrumental variable is exogenous and not correlated with the error term. Furthermore, upon further examination of the correlation between the instrumental variable and endogenous variables, the first-stage F statistic is 4.028 and its p value is 0.019, which means that the instrumental variable selected in this study is not a weak one. Therefore, the results are robust.

Table 7. 2SLS results.

	(First-Stage)		(Second-Stage)
	Digital		AGD
digital			0.180 * (0.102)
IV	0.078 * (0.043)		
L.digital	0.141 * (0.077)		
Control	Y		Y
Year	Y		Y
Province	Y		Y
First-stage F-statistic (P)		F = 4.028 (0.019)	
N	270		270
R^2	0.975		0.948
Provinces	30		30

Note: * $p < 0.1$; standard errors are in parentheses.

4.3. Heterogeneity Analysis under Different Levels of Agricultural Green Development

Given the varying levels of agricultural green development across provinces, the impact of the rural digital economy on promoting agricultural green transformation may also differ. In provinces where the level of agricultural green development remains at a relatively low level, agricultural production activities often result in high emissions of pollutants. In such regions, it may be advisable to adopt energy-saving and emission-reduction measures, as well as reduce the use of fertilizers and pesticides, to mitigate the environmental impact of agricultural production. Under these circumstances, the influence of the rural digital economy in driving agricultural green development may be relatively modest, with its potential role yet to be fully realized. Conversely, provinces with advanced agricultural green development typically exhibit less usage of production factors like fertilizers and pesticides that might cause environmental pollution. These areas tend to prioritize leveraging the digital economy, intensifying the use of digital technology in agricultural production to achieve agricultural green development. Consequently, in these provinces, the rural digital economy's role in fostering agricultural green development may prove to be more pronounced and effective. To examine the differentiated impact characteristics of the rural digital economy on agricultural green development across different levels of agricultural green development, a panel quantile regression model is established, as depicted in Equation (5):

$$AGD_{q,it} = \alpha_{q,0} + \alpha_{q,1}digital_{q,it} + \sum \alpha_{q,j}controls_{q,jit} + \mu_{q,i} + \nu_{q,t} + \varepsilon_{q,it} \quad (5)$$

In this study, we select five quantile points (10%, 25%, 50%, 75%, and 90%) to estimate the quantile regression model presented in Equation (5). Table 8 presents the quantile regression results. Figure 3 shows the trend in the marginal effect of the rural digital economy on agricultural green development as the level of such development increases. The estimated coefficients for the rural digital economic development level variable are significantly positive across all five quantiles, indicating that as the level of agricultural green development increases, the rural digital economy can effectively promote agricultural green development, which confirms the aforementioned conclusion. At the 10% quantile, when the level of agricultural green development is relatively low, the estimated coefficient value is 0.184. As the quantiles increase to 50%, the coefficient of the variable representing the level of rural digital economic development rises to 0.34. However, it decreases to 0.268 at the 75% quantile and further decreases to 0.243 at the 90% percentile. As the level of agricultural green development gradually increases, the promoting effect of the rural digital economy on it also gradually strengthens. Once it reaches a certain high level, the marginal contribution of the rural digital economy to agricultural green development diminishes, thereby causing its promotional role to begin to weaken. Therefore, it becomes apparent that there are variations in the extent to which the rural digital economy enhances the green development of agriculture at different stages of agricultural green development.

Table 8. Quantile regression results.

	q10	q25	q50	q75	q90
	AGD	ADG	ADG	ADG	ADG
digital	0.184 *** (0.041)	0.244 ** (0.110)	0.340 *** (0.126)	0.268 *** (0.093)	0.243 *** (0.064)
Control	Y	Y	Y	Y	Y
Province	Y	Y	Y	Y	Y
Year	Y	Y	Y	Y	Y
N	300	300	300	300	300
Pseudo R^2	0.811	0.812	0.843	0.869	0.890
Provinces	30	30	30	30	30

Note: *** $p < 0.01$, ** $p < 0.05$; standard errors are in parentheses.

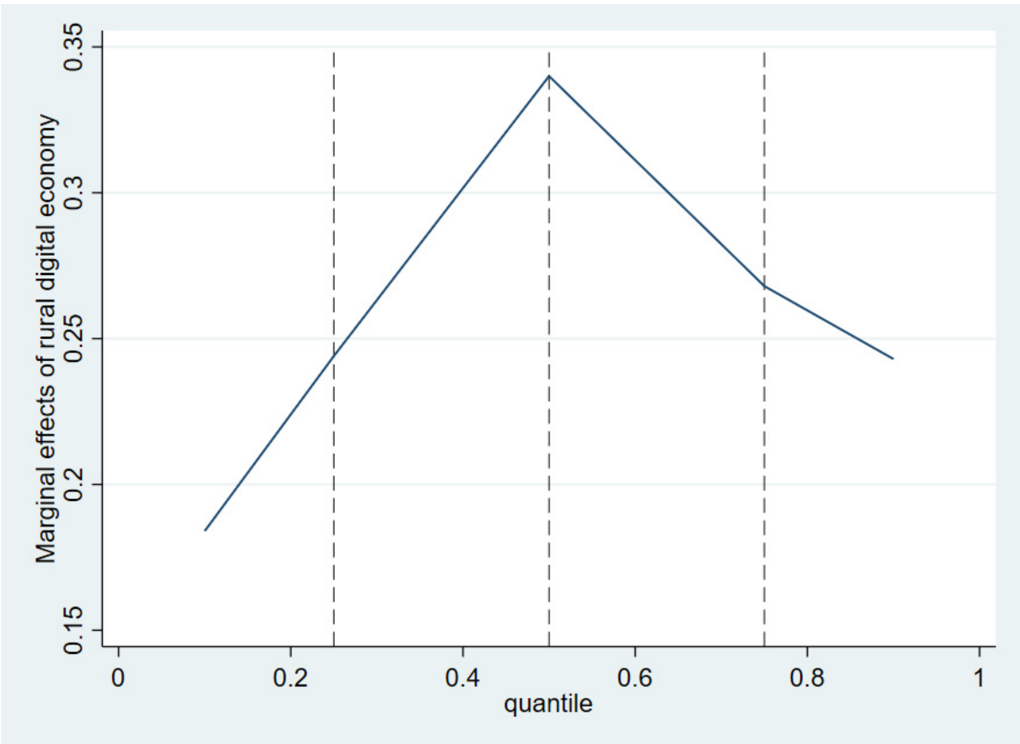

Figure 3. The marginal effect of the rural digital economy.

4.4. Analysis of the Mediating Mechanism

This study employs the mediating effect model consisting of Formulas (1)–(3) for estimation, and the results are shown in columns (1), (2), and (3) of Table 9. Column (2) shows that the rural digital economy has a significant facilitating effect on agricultural technological progress. Additionally, column (3) demonstrates that agricultural technological progress also has a significant promoting effect on agricultural green development. Consequently, the rural digital economy can promote agricultural technological progress, thereby facilitating agricultural green development and thus supporting Hypothesis 2a. Columns (1), (4), and (5) present the test results for the mediating effect, which suggests that the rural digital economy can alleviate the constraints of agricultural credit and thus promote agricultural green development, and Hypothesis 2b has been confirmed. Columns (1), (6), and (7) present the outcomes of the mediating effect test for agricultural industry agglomeration. These findings suggest that the rural digital economy can promote agricultural industry agglomeration, thereby fostering agricultural green development, and Hypothesis 2c is supported. To validate the robustness of the findings, Sobel and Bootstrap tests were applied to the mediating variables, as shown in Table 9, supporting the aforementioned conclusion.

Table 9. Test results for the mediating effect of agricultural industrial agglomeration.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
	AGD	**tec**	**AGD**	**cre**	**AGD**	**LQ**	**AGD**
digital	0.180 *** (0.061)	4.565 ** (1.979)	0.176 *** (0.64)	0.298 *** (0.116)	0.242 *** (0.065)	0.374 *** (0.143)	0.184 *** (0.0618)
tec			0.005 *** (0.002)				
cre					0.125 *** (0.035)		
LQ							0.183 *** (0.0266)
Control	Y	Y	Y	Y	Y	Y	Y
Year	Y	Y	Y	Y	Y	Y	Y
Province	Y	Y	Y	Y	Y	Y	Y
Sobel test	0.0249 (z = 1.762, p = 0.781)			0.0372 (z = 2.092, p = 0.364)		0.0686 (z = 2.44, p = 0.015)	
Bootstrap test(ind_eff)	0.0249 (z = 1.98, p = 0.048)			0.0372 (z = 1.87, p = 0.061)		0.0686 (z = 2.32, p = 0.020)	
Bootstrap test(dir_eff)	0.176 (z = 2.29, p = 0.022)			0.242 (z = 3.06, p = 0.002)		0.184 (z = 2.83, p = 0.005)	
N	300	300	300	300	300	300	300
R^2	0.717	0.659	0.693	0.419	0.671	0.849	0.733
Provinces	30	30	30	30	30	30	30

Note: *** p < 0.01, ** p < 0.05; standard errors are in parentheses.

4.5. Moderating Effects of Environmental Regulation

The moderating effect model, which was constructed for Equation (4), has been used for an estimation, and the results are presented in Table 10. The estimation results indicate that both the estimated coefficients of rural digital economic variables and environmental regulatory variables are positive at the 5% significance level. Furthermore, the interaction term between the two variables is also significantly positive at the 1% level of significance. Environmental regulations will bolster the role of the rural digital economy in fostering agricultural green development, thereby corroborating Hypothesis 3. To test the robustness, we use AGD * as a proxy variable. The findings are as shown in column (2). Government funding for environmental protection can partially indicate its environmental regulation efforts. Here, we use the ratio of fiscal expenditure on environmental protection to the regional GDP to reflect the level of environmental regulation, denoted as er*, substituting for the original environmental regulation variable. The results are presented in columns (3) and (4), with both yielding a consistent positive and significant correlation, underscoring the reliability of the findings. Therefore, when formulating policies, the government should fully consider the diversity and efficiency of agricultural green development and focus on the coordination between environmental regulation policies and the rural digital economy so as to give full play to the role of the rural digital economy in promoting agricultural green development.

Table 10. Test results of the moderating effect of environmental regulation.

	(1)	(2)	(3)	(4)
	AGD	AGD *	AGD	AGD *
digital	0.159 ***	0.255 ***	0.199 ***	0.324 ***
	(0.059)	(0.081)	(0.062)	(0.083)
er	0.641 ***	0.662 ***		
	(0.13)	(0.18)		
Digital × er	2.154 ***	2.907 ***		
	(0.752)	(1.039)		
er *			0.066	0.585 **
			(0.214)	(0.287)
Digital × er *			3.608 **	4.285 *
			(1.719)	(2.304)
Control	Y	Y	Y	Y
Year	Y	Y	Y	Y
Province	Y	Y	Y	Y
_cons	−1.734 ***	−2.07 ***	−1.532 ***	−1.933 ***
	(0.204)	(0.282)	(0.218)	(0.292)
N	300	300	300	300
R^2	0.755	0.684	0.722	0.663
Provinces	30	30	30	30

Note: *** $p < 0.01$, ** $p < 0.05$, and * $p < 0.1$; standard errors are in parentheses.

5. Conclusions and Policy Recommendations

As a key emerging force in the economic growth of developing countries, the digital economy's influence extends beyond urban areas, with focus on its impact on rural regions growing. The development of rural areas encompasses not only economic progress but also a balanced approach to environmental conservation and the well-being of residents [58]. Rural areas can seize the opportunity for digital transformation to enhance social welfare for residents [59]. In terms of rural residents' income, the development of digital agricultural technology has displaced some labor force, but it has also created new employment opportunities [60]. The use of digital technology can increase non-agricultural employment opportunities, thus increasing farmers' income [61]. In terms of the environment, the construction of digital villages can improve the living environment in rural areas [62] and reduce carbon emissions generated by agricultural activities [57]. However, for reasons of geography and infrastructure, the digital economy primarily emerges in urban areas and gradually spreads from them to rural regions. In this process, a significant risk of a "digital divide" emerging exists, particularly among older and less-educated residents whose application capabilities are low even with the digital infrastructure available. Thus, examining the impact of the digital economy in rural areas holds practical significance.

We believe that the rapid development of the rural digital economy represents a significant opportunity for achieving green agricultural development. Based on panel data from 30 provincial-level administrative regions in China from 2012 to 2021, this article constructs evaluation index systems to measure the levels of rural digital economic development and agricultural green development and analyzes the impact effect, heterogeneity, and action mechanism of the rural digital economy on agricultural green development. The research findings suggest that first, the rural digital economy plays a significant role in promoting agricultural green development. This conclusion remains valid after conducting robustness tests by altering the measurement indicators for agricultural green development, considering lag effects, substituting variables for agricultural green development, and employing instrumental variable methods. Second, heterogeneity analysis results indicate that as agricultural green development continuously improves, the overall trend in the promotion effect of rural digital economy on agricultural green development initially rises and then declines. Third, an analysis of influencing mechanisms revealed that the rural digital economy can enhance agricultural green development by advancing agricultural technological advancement, alleviating agricultural credit constraints, and stimulating agricultural industry agglomeration. Fourth, a test for moderating effects indicates that environmental regulatory policies can enhance the facilitative role of the rural digital economy in promoting agricultural green development.

Therefore, we offer the following policy recommendations:

First, we should strengthen support and investment in the rural digital economy. As a key driver of rural development, the rural digital economy plays a vital role in promoting rural economic growth and agricultural green development. To further unleash its potential, it is essential to increase investment in the infrastructure required for the rural digital economy, including but not limited to financial support in areas such as network coverage and information technology equipment. Through these measures, we can effectively promote the application of digital technology in agricultural production, thereby significantly improving the efficiency of agricultural production and resource utilization while reducing production costs and environmental pollution. This not only helps build an efficient and sustainable agricultural production system but also is a key step in realizing an agricultural green development model.

Second, policymaking should consider regional distinctiveness and adopt tailored strategies to cater to the varying realities of agricultural green development across regions. For areas that have made notable strides in green agricultural development, local governments should fully foster the growth of the rural digital economy and harness its potential to hasten the transition to a greener agriculture. In areas where agricultural green development is still in its infancy, the government should prioritize the deep integration of the digital economy into agriculture. By promoting the effective application of digital technology in agricultural production, it can enhance the positive impact of the rural digital economy on promoting agricultural green development.

Third, it is necessary to build an agricultural industry agglomeration platform. The government should play a pivotal role in fostering a favorable business environment, which involves actively establishing an agricultural industry agglomeration platform and further expanding the agricultural industry value chain to facilitate agricultural industry agglomeration. Thereby, the government will exploit the external economies of scale resulting from agricultural industry agglomeration. Then, this will advance the green transformation of agriculture while enhancing the efficiency of agricultural green development and comprehensively promoting sustainable agriculture.

Fourth, it is necessary to enhance the integration of environmental regulatory policies and the growth of the rural digital economy to fully leverage the role of environmental policy tools in guiding both the digital economy and sustainable agricultural development, amplify policy coherence, and enhance the facilitating impact of the rural digital economy on agricultural green growth.

This paper primarily presents the following research limitations: First, while this article primarily examines the direct influence of the rural digital economy on agricultural green development and its mechanisms, it only explores three potential mediating mechanisms and one moderating mechanism. For instance, in terms of the primary factors influencing agricultural economic growth, this article only considers technology and capital, without analyzing land and labor inputs. This is because data on land input and labor input are not readily available, and measuring land changes and human capital is relatively challenging. Therefore, regarding all influencing mechanisms, there may exist other mechanisms beyond those explored in this article, leading to a lack of comprehensiveness in our research. Second, the data used for empirical testing in this paper are provincial data with a limited sample size. Using city-level or micro-data might enhance the persuasiveness of the results.

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References

1. Li, Z.; Hou, Y.; Cao, J.; Ding, Y.; Yuan, X. What Drives Green Development in China: Public Pressure or the Willingness of Local Government? *Environ. Sci. Pollut. Res.* **2022**, *29*, 5454–5468. [CrossRef] [PubMed]
2. Jun, H.; Xiang, H. Development of circular economy is a fundamental way to achieve agriculture sustainable development in China. *Energy Procedia* **2011**, *5*, 1530–1534. [CrossRef]
3. Dethier, J.J.; Effenberger, A. Agriculture and development: A brief review of the literature. *Econ. Syst.* **2012**, *36*, 175–205. [CrossRef]
4. Zhao, Z.; Liu, K.; Yu, B.; Liu, G.; Wang, Y.; Wu, C. Modeling of Agricultural Nonpoint-Source Pollution Quantitative Assessment: A Case Study in the Mun River Basin, Thailand. *Sustainability* **2023**, *15*, 10325. [CrossRef]
5. China Academy of Information and Communications Technology. Available online: http://www.caict.ac.cn/kxyj/qwfb/bps/202304/t20230427_419051.htm (accessed on 14 April 2024).
6. Aniqoh, N.A.F.A. The role of digital economy to enhancing sustainable economic development. *Int. J. Soc. Sci. Bus.* **2020**, *4*, 519–527. [CrossRef]
7. Si, S.; Hall, J.; Suddaby, R.; Ahlstrom, D.; Wei, J. Technology, entrepreneurship, innovation and social change in digital economics. *Technovation* **2023**, *119*, 102484. [CrossRef]
8. Frank, A.G.; Mendes, G.H.; Ayala, N.F.; Ghezzi, A. Servitization and Industry 4.0 convergence in the digital transformation of product firms: A business model innovation perspective. *Technol. Forecast. Soc. Chang.* **2019**, *141*, 341–351. [CrossRef]
9. Ng, I.C. New business and economic models in the connected digital economy. *J. Revenue Pricing Manag.* **2014**, *13*, 149–155. [CrossRef]
10. Bukht, R.; Heeks, R. Defining, conceptualising and measuring the digital economy. *Int. Organ. Res. J.* **2018**, *13*, 143–172. [CrossRef]
11. Tiwasing, P.; Clark, B.; Gkartzios, M. How can rural businesses thrive in the digital economy? A UK perspective. *Heliyon* **2020**, *8*, e10745. [CrossRef]
12. Jiang, Q.; Li, J.; Si, H.; Su, Y. The impact of the digital economy on agricultural green development: Evidence from China. *Agriculture* **2022**, *12*, 1107. [CrossRef]
13. Hong, M.; Tian, M.; Wang, J. The impact of digital economy on green development of agriculture and its spatial spillover effect. *China Agric. Econ. Rev.* **2023**, *15*, 708–726. [CrossRef]
14. Zhang, Y.F.; Ji, M.X.; Zheng, X.Z. Digital Economy, Agricultural Technology Innovation, and Agricultural Green Total Factor Productivity. *SAGE Open* **2023**, *13*, 1–13. [CrossRef]
15. Zhao, S.; Peng, D.; Wen, H.; Wu, Y. Nonlinear and spatial spillover effects of the digital economy on green total factor energy efficiency: Evidence from 281 cities in China. *Environ. Sci. Pollut. Res.* **2023**, *30*, 81896–81916. [CrossRef] [PubMed]
16. Zhou, X.; Chen, T.; Zhang, B. Research on the impact of digital agriculture development on agricultural green total factor productivity. *Land* **2023**, *12*, 195. [CrossRef]
17. Philip, L.; Williams, F. Remote rural home based businesses and digital inequalities: Understanding needs and expectations in a digitally underserved community. *J. Rural Stud.* **2019**, *68*, 306–318. [CrossRef]
18. Singh, R.B. Environmental consequences of agricultural development: A case study from the Green Revolution state of Haryana, India. *Agric. Ecosyst. Environ.* **2000**, *82*, 97–103. [CrossRef]
19. Fischer, G.; Kotu, B.; Mutungi, C. Sustainable and equitable agricultural mechanization? A gendered perspective on maize shelling. *Renew. Agric. Food Syst.* **2021**, *36*, 396–404. [CrossRef]
20. Shen, J.; Zhu, Q.; Jiao, X.; Ying, H.; Wang, H.; Wen, X.; Xu, W.; Li, T.; Cong, W.; Liu, X.; et al. Agriculture green development: A model for China and the world. *Front. Agric. Sci. Eng.* **2020**, *7*, 5–13. [CrossRef]
21. Rezaei-Moghaddam, K.; Karami, E. A multiple criteria evaluation of sustainable agricultural development models using AHP. *Environ. Dev. Sustain.* **2008**, *10*, 407–426. [CrossRef]
22. Struik, P.C.; Kuyper, T.W. Sustainable intensification in agriculture: The richer shade of green. A review. *Agron. Sustain. Dev.* **2017**, *37*, 39. [CrossRef]
23. Ren, C.; Liu, S.; Van Grinsven, H.; Reis, S.; Jin, S.; Liu, H.; Gu, B. The impact of farm size on agricultural sustainability. *J. Clean. Prod.* **2019**, *220*, 357–367. [CrossRef]

24. Zhu, Y.; Waqas, M.A.; Zou, X.; Jiang, D.; Wilkes, A.; Qin, X.; Gao, Q.Z.; Wan, Y.F.; Hasbagan, G. Large-scale farming operations are win-win for grain production, soil carbon storage and mitigation of greenhouse gases. *J. Clean. Prod.* **2018**, *172*, 2143–2152. [CrossRef]
25. Li, B.; Wu, S. Effects of local and civil environmental regulation on green total factor productivity in China: A spatial Durbin econometric analysis. *J. Clean. Prod.* **2017**, *153*, 342–353. [CrossRef]
26. 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]
27. Liu, D.; Zhu, X.; Wang, Y. China's agricultural green total factor productivity based on carbon emission: An analysis of evolution trend and influencing factors. *J. Clean. Prod.* **2021**, *278*, 123692. [CrossRef]
28. Liu, Y.; Sun, D.; Wang, H.; Wang, X.; Yu, G.; Zhao, X. An evaluation of China's agricultural green production: 1978–2017. *J. Clean. Prod.* **2020**, *243*, 118483. [CrossRef]
29. Zou, L.; Liu, Y.; Wang, Y.; Hu, X. Assessment and analysis of agricultural non-point source pollution loads in China: 1978–2017. *J. Environ. Manag.* **2020**, *263*, 110400. [CrossRef]
30. The Ministry of Agriculture and Rural Affairs of China. Available online: http://www.moa.gov.cn/govpublic/FZJHS/202109/t20210907_6375844.htm (accessed on 14 April 2024).
31. Deichmann, U.; Goyal, A.; Mishra, D. Will digital technologies transform agriculture in developing countries? *Agric. Econ.* **2016**, *47*, 21–33. [CrossRef]
32. Barnes, A.P.; Soto, I.; Eory, V.; Beck, B.; Balafoutis, A.; Sánchez, B.; Vangeyte, J.; Fountas, S.; van der Wal, T.; Gómez-Barbero, M. Exploring the adoption of precision agricultural technologies: A cross regional study of EU farmers. *Land Use Policy* **2019**, *80*, 163–174. [CrossRef]
33. Zhou, Z.; Liu, W.; Wang, H.; Yang, J. The impact of environmental regulation on agricultural productivity: From the perspective of digital transformation. *Int. J. Environ. Res. Public Health* **2022**, *19*, 10794. [CrossRef] [PubMed]
34. Paudel, K.P.; Mishra, A.K.; Pandit, M.; Larkin, S.; Rejesus, R.; Velandia, M. Modeling multiple reasons for adopting precision technologies: Evidence from US cotton producers. *Comput. Electron. Agric.* **2020**, *175*, 105625. [CrossRef]
35. Forney, J.; Epiney, L. Governing Farmers through data? Digitization and the Question of Autonomy in Agri-environmental governance. *J. Rural Stud.* **2022**, *95*, 173–182. [CrossRef]
36. Sishodia, R.P.; Ray, R.L.; Singh, S.K. Applications of Remote Sensing in Precision Agriculture: A Review. *Remote Sens.* **2020**, *12*, 3136. [CrossRef]
37. Klerkx, L.; Jakku, E.; Labarthe, P. A review of social science on digital agriculture, smart farming and agriculture 4.0: New contributions and a future research agenda. *NJAS—Wagening. J. Life Sci.* **2019**, *90–91*, 100315. [CrossRef]
38. Takahashi, K.; Muraoka, R.; Otsuka, K. Technology Adoption, Impact, and Extension in Developing Countries' Agriculture: A Review of the Recent Literature. *Agric. Econ.* **2020**, *51*, 31–45. [CrossRef]
39. Zheng, Y.; Zhu, T.; Jia, W. Does Internet use promote the adoption of agricultural technology? Evidence from 1449 farm households in 14 Chinese provinces. *J. Integr. Agric.* **2022**, *21*, 282–292. [CrossRef]
40. Abate, G.T.; Bernard, T.; Makhija, S.; Spielman, D.J. Accelerating technical change through ICT: Evidence from a video-mediated extension experiment in Ethiopia. *World Dev.* **2023**, *161*, 106089. [CrossRef] [PubMed]
41. Lopez, T.; Winkler, A. The challenge of rural financial inclusion—Evidence from microfinance. *Appl. Econ.* **2018**, *50*, 1555–1577. [CrossRef]
42. Wang, F.; Du, L.; Tian, M. Does Agricultural Credit Input Promote Agricultural Green Total Factor Productivity? Evidence from Spatial Panel Data of 30 Provinces in China. *Int. J. Environ. Res. Public Health* **2023**, *20*, 529. [CrossRef]
43. Picard, P.M.; Zeng, D. Agricultural sector and industrial agglomeration. *J. Dev. Econ.* **2005**, *77*, 75–106. [CrossRef]
44. Wang, Z.; Zhang, X.; Lu, H.; Kang, X.; Liu, B. The effect of industrial agglomeration on agricultural green production efficiency: Evidence from China. *Sustainability* **2023**, *15*, 12215. [CrossRef]
45. Remondino, M.; Zanin, A. Logistics and agri-food: Digitization to increase competitive advantage and sustainability. Literature review and the case of Italy. *Sustainability* **2022**, *14*, 787. [CrossRef]
46. Porter, M.E.; Linde, C.V.D. Toward a new conception of the environment-competitiveness relationship. *J. Econ. Perspect.* **1995**, *9*, 97–118. [CrossRef]
47. Iraldo, F.; Testa, F.; Melis, M.; Frey, M. A literature review on the links between environmental regulation and competitiveness. *Environ. Policy Gov.* **2011**, *21*, 210–222. [CrossRef]
48. Shao, S.; Hu, Z.; Cao, J.; Yang, L.; Guan, D. Environmental regulation and enterprise innovation: A review. *Bus. Strategy Environ.* **2020**, *29*, 1465–1478. [CrossRef]
49. Chen, Z.; Sarkar, A.; Rahman, A.; Li, X.; Xia, X. Exploring the drivers of green agricultural development (GAD) in China: A spatial association network structure approaches. *Land Use Policy* **2022**, *112*, 105827. [CrossRef]
50. Billings, S.B.; Johnson, E.B. The location quotient as an estimator of industrial concentration. *Reg. Sci. Urban Econ.* **2012**, *42*, 642–647. [CrossRef]
51. Du, Y.; Liu, H.; Huang, H.; Li, X. The carbon emission reduction effect of agricultural policy—Evidence from China. *J. Clean. Prod.* **2023**, *406*, 137005. [CrossRef]
52. Zhang, H.; Zhang, J.; Song, J. Analysis of the threshold effect of agricultural industrial agglomeration and industrial structure upgrading on sustainable agricultural development in China. *J. Clean. Prod.* **2022**, *341*, 130818. [CrossRef]

53. Deng, H.; Zheng, W.; Shen, Z.; Štreimikienė, D. Does fiscal expenditure promote green agricultural productivity gains: An investigation on corn production. *Appl. Energy* **2023**, *334*, 120666. [CrossRef]
54. Ge, P.; Liu, T.; Wu, X.; Huang, X. Heterogenous Urbanization and Agricultural Green Development Efficiency: Evidence from China. *Sustainability* **2023**, *15*, 5682. [CrossRef]
55. Liu, H.; Liu, H. Study on the influence mechanism and level measurement of agricultural green development—A case study of China. *Front. Environ. Econ* **2023**, *2*, 1179399. [CrossRef]
56. Guo, L.; Zhao, S.; Song, Y.; Tang, M.; Li, H. Green Finance, Chemical Fertilizer Use and Carbon Emissions from Agricultural Production. *Agriculture* **2022**, *12*, 313. [CrossRef]
57. Hao, A.; Hou, Y.; Tan, J. How Does Digital Village Construction Influences Carbon Emission? The Case of China. *PLoS ONE* **2022**, *17*, e0278533. [CrossRef]
58. Noack, E.M.; Schüler, S. Rural development and human well-being: Do pillar-II-programmes take into account ecosystem services? A study in Lower Saxony, Germany. *Environ. Sci. Policy* **2020**, *106*, 191–200. [CrossRef]
59. Marino, D.; Tebala, D. Rural Areas and Well-Being in EU Countries + UK: A Taxonomy and a Cluster Analysis. *Sustainability* **2020**, *14*, 15213. [CrossRef]
60. Li, F.; Zhang, W. Research on the Effect of Digital Economy on Agricultural Labor Force Employment and Its Relationship Using SEM and fsQCA Methods. *Agriculture* **2023**, *13*, 566. [CrossRef]
61. Han, J.; Wang, J.; Zhang, W. Digital Adoption levels and income generation in rural households in China. *Heliyon* **2023**, *9*, e21045. [CrossRef]
62. Liu, B.; Zhan, J.; Zhang, A. Aoxiang Zhang. Empowering rural human Settlement:Digital Economy's path to progress. *J. Clean. Prod.* **2023**, *427*, 139243. [CrossRef]