Digital Technology’s Influence on Boosting Rice Growers’ Feasible Capacity of Green Production in Sichuan, China

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Abstract. The United Nations Sustainable Development Goals (SDGs) advocate a primary emphasis on environmental protection, the significant levels of pollution and emissions of greenhouse gases stemming from agricultural activities frequently escape notice. It is imperative to expedite the shift towards green agricultural production methods in China. Sichuan Province, being a strategic hub and a prominent rice-producing region, must prioritize the adoption of green farming practices to safeguard food security. To address the sluggish progress in promoting green rice production in Sichuan, amidst the widespread application of digital technology enhancing convenience in production and life, integrating digital technology into green rice production is urgently needed. Such integration is pivotal for driving the transformation and upgrading of the region's agriculture towards sustainable development. Drawing from the group’s 2023 field research data on rice farmers in Sichuan, this paper employs SPSS 25.0 and Stata 17.0 to analyze empirical findings. Building upon existing literature, we utilize OLS regression to delve into the mechanisms underlying digital technology adoption and assess the feasibility of rice farmers’ green production practices. The findings highlight: (1) A marked positive correlation exists between digital technology adoption and rice farmers’ ability to engage in green production. (2) The depth of digital technology application has a notable positive impact on the feasibility of green rice production for farmers. Greater depth in its application amplifies the beneficial effects on transparency, social conditions, and economic well-being of rice farmers. (3) Reliance on production outsourcing services negatively moderates the positive impact of digital technology on feasible capacity of green production among rice farmers. The application of digital technology can significantly bolster rice farmers’ feasible capability for green production. Local governments must prioritize enhancing farmers’ digital literacy and optimizing their operational environments to foster greater green production capacity. This will help diminish disparities in green practices across individuals and regions, thereby promoting sustainable green rice production in Sichuan Province.

Keywords: Digital Technology Applications; Feasible Capacity; Rice Green Production; Outsourcing of Production Services.

1. Introduction

Agricultural production generates substantial pollution and emits significant greenhouse gases, yet these environmental threats are frequently overlooked. The adoption of the United Nations Sustainable Development Goals (SDGs) has heightened the importance countries place on environmental protection, especially concerning agricultural pollution. Countries in Europe have begun to implement their own environmental taxes to mitigate pollution from agricultural production (Miceikiene et al., 2021).China's rapid economic development has led to high natural resource consumption and exacerbated environmental pollution. China’s fundamental agricultural landscape of “large country, small farmers” fosters production focused on quantity over quality, often leading to over exploitation of land resources(Zhang et al., 2015; Zou et al., 2023).This exploitation exacerbates resource depletion and ecological degradation, posing challenges to food security and safety(Huang et al., 2019). As socio-economic instability and environmental challenges continue to escalate, the urgency to expedite the promotion of sustainable agriculture and green production practices within the agricultural sector is increasingly becoming evident(Yu et al., 2022).The Opinions of the Central Committee of the Communist Party of China and the State Council on Doing a Good Job of Comprehensively Promoting the Key Work of Rural Revitalization in 2023 proposes to promote the green development of agriculture and to accelerate the popularization and application of technologies for reducing the quantity and increasing the efficiency of agricultural inputs, which has resulted in outstanding resource and environmental problems and ecosystem degradation, thus affecting food security. The green development of agricultural production, aimed at alleviating ecological issues and enhancing environmental quality, has emerged as a vital path to elevating people's living standards and fulfilling their aspirations for a superior quality of life.

In September 2023, General Secretary Xi Jinping first proposed the development of "new quality productivity" during his investigation in Heilongjiang, and on March 5, 2024, the government work report at the second meeting of the 14th National People's Congress emphasized "accelerating the development of new quality productivity, and solidly pushing forward high-quality development." The essence of "new quality productivity" is to take digital technology innovation as the main hand, using digitalization, greening, technology as the lead, to solve the problems of ecological environment deterioration, rural labor loss and so on. The development of the Chengdu-Chongqing Twin Cities Economic Circle is crucial for advancing the western region. As a strategic national hinterland, Sichuan must prioritize digital technology as a vital lever for growth. To safeguard China's food security, there's a pressing necessity to swiftly integrate rice farming with cutting-edge science and technology(Lin et al., 2022),This will foster "new quality productivity," revolutionize traditional rice production methods, and propel the growth of eco-friendly rice cultivation(Sun et al., 2023).Digital technology, with smartphones as its forefront, commands unparalleled attention in our era, revolutionizing societal advancements and daily life at a breathtaking pace and depth (Kusyanti et al., 2022).Article 24 of Central Document No. 1, 2022, emphasizes "Vigorously Advancing Digital Countryside Construction," advocating smart agriculture, IT-agriculture machinery-agronomy integration, and farmer digital literacy enhancement. This signals an accelerated integration of digital technology into agricultural and rural development. As a strategic national heartland, Sichuan will intensify digital technology's application in agriculture and rural areas, profoundly influencing rural residents' production methods and lifestyles(Yan et al., 2023b).Digitizing agriculture enhances production efficiency by augmenting other production facets, broadening access to pertinent info, (Bhaskara and Bawa, 2021; Zhang and Fan, 2023),and ultimately boosting farmers' profitability(Ma et al., 2020).Digital technology drives agricultural production, management, service, and supervision towards digitization, intelligence, and networking(Gong et al., 2024; Ivanov, 2019).Digital inclusive finance alleviates farmers' financial constraints, while digital e-commerce tackles agricultural product sales challenges(Aker, 2011; Wang, 2023; Xia and Kong, 2024).

As resource consumption expands, environmental damage intensifies. China's food production security, crucial for national stability, faces serious over-fertilization, particularly in rice cultivation(Xin et al., 2021).Green agricultural production of rice serves as an effective strategy to address food security concerns and mitigate resource and environmental depletion(Scherer et al., 2018). China has emphasized the need for green agricultural development to prevent resource waste and enhance land productivity. Currently, academic research on green rice production is gaining significant momentum, primarily focusing on the impact of individual factors, production and management modes on green production, as well as its level measurement. According to Zang et al. (2022), the older farm households are, the less likely they are to adopt green production methods. Land inflow fosters environmental awareness, whereas land outflow hinders green production. Yang et al. (2024) contended that rice farmers' green production behavior is primarily driven by costs and benefits, with government regulation serving as a bridge between perceptions and actions. As "boundedly rational economic agents," farmers assess external risks and weigh the costs, benefits, and risk magnitudes to determine their engagement in green production. Modernization in rice production is primarily evident through advanced production techniques and scientific management. Socialized services effectively bridge the gap between traditional and modern agricultural production, significantly boosting the annual income of farming households(Qiu et al., 2024),green productivity, etc. Agricultural socialization services positively impact the development of green agricultural production (Zhou and Chen, 2023). Rice farmers' adoption of service outsourcing fosters green production by reducing chemical fertilizer use, promoting straw incorporation, and increasing organic fertilizer application(Chen et al., 2023; Qing et al., 2023).Rice farmers' membership in cooperatives can facilitate green agricultural production through specific conditions, systems, supervision, and other regulatory frameworks(Li et al., 2021).

As the main rice producing area in China(Liu et al., 2012),ensuring the sustainability of rice production is one of the important tasks in Sichuan Province, which situated in the western region, faces complex terrain, limited plains for cultivation, and a lack of green production knowledge among rice growers, the overall green production of agriculture in Sichuan Province develops slowly(Zou et al., 2023),and there are significant differences in green production behaviors. The green development of rice production in Sichuan Province holds strategic national and agricultural significance, significantly influencing the environment and farmers' future earnings. However, current green rice production promotion relies heavily on policy subsidies, training, and publicity, lacking theoretical foundation for optimal outcomes. Rice farmers' inherent drive for green production remains inadequate. The study reveals that rice farmers' green production behavior is influenced by government policies (Yang et al., 2024),economic conditions(Wang et al., 2024),social opportunities(Gao et al., 2022),information access(Fu et al., 2022), and other constraints, resulting in notable variations among individuals and regions. To foster green agricultural production, exploring strategies to minimize behavioral disparities and enhancing the feasible capacity of green rice production for farmers are crucial to promoting eco-friendly rice cultivation. The feasible capacity theory transcends traditional metrics of individual well-being and capability, highlighting the synergistic effects of diverse factors.

In summary, viable capacity in agricultural green production has been infrequently studied. Nevertheless, significant regional and individual variations in green production behaviors hinder the swift implementation of rice green production due to rice growers' varied viable capacities. Consequently, investigating the factors influencing rice green production feasibility is crucial for promoting its transformation and achieving sustainable rice development. Scholars globally have conducted extensive research on Amartya Sen's feasible capacity theory, encompassing constitutional human rights(Pfister, 2012; Svitych, 2024),social progress(Jacobson, 2016),corporate valuation, urban-rural population well-being, rural poverty, and anti-poverty strategies, among others. Kim Lane Scheppele (2011) and Ragkousis (2024)underscored the significance of individual empowerment within Amartya Sen's theory of viable capacity. Despite limited research on viable capacity's application to agricultural green production, it encapsulates the abilities necessary for realizing "functional activities," fitting our study's purpose. This paper examines how digital technology, deeply integrated with production, influences rice farmers' viable capacity for green production, broadening the research scope. By exploring the feasible capacity of green rice production under this high integration, we contribute to the field and offer policy insights to foster green rice development in Sichuan.

2. Materials and Methods

2.1 Core Concepts

2.1.1 Digital Technology Applications

Digital technology encompasses products and services embedded in ICT, seamlessly integrating information technology. (Li et al., 2022). Digital technology serves as a pivotal tool to cut business costs, eliminate redundant efforts, and boost production through data capture, utilization, and management(Fang and Liu, 2024).This paper builds on existing scholarly research to define digital technology's application, examining whether it entails utilizing modern communication technology in production and daily life, leveraging its associated products and services to enhance production efficiency and quality of life.

2.1.2 Feasible Capacity of Green Production

The term "feasible capacity" was first introduced by Amartya Sen in 1980, who defined it as "an individual's capacity to attain diverse lifestyles or a high quality of life—what an individual can realize or achieve." Amartya Sen's introduction of the concept of "viability" also introduces the interconnected key concept of "functional activities." These activities reflect what a person deems worth doing or achieving. Viability, then, is the constellation of functional activities an individual is likely to attain, conceptualized as a bundle or combination of competencies. It serves as a pivotal factor influencing how an individual realizes their functional activities.This paper defines green production viability as the essential capabilities required by rice farmers to engage in green production behavior.

2.2 Theoretical Mechanisms and Research Hypotheses

As the foremost representative of the historical school, Huang Zongzhi, considering China's "Three Rural Issues," integrated the perspectives of the Organization and Production School and the Rational Small Farmer School, asserting that farmers possessed dual roles as both producers and consumers, with meeting their consumption needs and pursuing market profits being equally significant objectives.The historical school contends that the small farm economy faces a "semi-proletarianization" issue, where excessive labor, unable to be diverted from agriculture, results in extremely low opportunity costs and marginal benefits of labor inputs, leading to agriculture's " involutional development."As "rational economic men," rice farmers' feasible capacity of green production is influenced by multiple factors, primarily categorized into five in this paper: political freedom, economic conditions, social environment, protective safeguards, and transparent guarantees. Consequently, the theory of "rational economic man," in the context of China's "Three Rural Issues," is pertinent to this research.

Sen (1999), a renowned socio-political scientist, introduced the concept of ‘feasible capacity’ in his seminal works, What Kind of Equality? and Development as Freedom. Sen elaborated on ‘feasible capacity’ as the fundamental freedom an individual possesses to lead a life that is deemed valuable and meaningful. Feasibility is the cornerstone of an individual's aspiration to engage in a functional activity. The sluggish adoption of green production behaviors among rice farmers stems from their varied overall capacity, with most lacking sufficient conditions and motivation to implement green rice production.This paper introduces the viable capacity theory into green rice production, defining it as rice farmers' ability to engage in such activities. This ability is crucial for assessing the realization of green rice production. Rice farmers' production methods are influenced by their costs, incomes, and resources. To enhance green production behaviors among rice farmers, we must study ways to reduce individual and regional disparities, thereby boosting overall green production capacity. Therefore, this paper examines the impact of digital technology application on the feasibility of rice farmers' green production.

2.2.1 The Effect of Digital Technology Application on the Feasible Capacity of Green Production Among Rice Farmers

Sichuan Province has vigorously built digital villages to promote rural development. In recent years, digital infrastructure in rural areas has been robustly constructed, leading to a rapid increase in the level of digital technology application in rural Sichuan. The adoption of digital technology is increasingly becoming a pivotal factor in agricultural production. By leveraging digital technology, rice farmers can minimize economic and social transaction costs (Njihia and Merali, 2013), mitigate information asymmetry issues, and ultimately enhance the feasibility of green production.

Simultaneously, the gap in green production feasibility between rice farmers who use digital technology and those who do not is widening. As "rational economic men," rice farmers exhibit heightened sensitivity to the multifaceted impacts of digital technology adoption. Therefore, to deepen the integration of digital technology in agricultural production and substantially elevate their green production feasibility, the following hypotheses are proposed:

H1:Digital technology applications positively influence the sustainability of green rice production among farmers.

H2:The more profound the digital technology application, the stronger its impact on fostering viable green rice production.

2.2.2 The Moderating Influence of Outsourcing Production Services on Rice Farmers' Adoption of Digital Technology and the Feasible Capacity of Green Production Practices.

Outsourcing agricultural production services effectively addresses labor shortages (Zhang et al., 2017) and land abandonment(Li et al., 2023a), connecting small-scale farmers with green and modern agricultural practices. Outsourcing rice production services encompasses a range of activities, including seedling/seed provision, chemical and organic fertilizer application, nursery management, land preparation, transplanting, irrigation, weeding, pest and disease control, and harvesting (Li and Yu, 2022).The outsourcing of production services employs advanced techniques, minimizing excessive chemical fertilizer use and ensuring appropriate pesticide application, thereby fostering green production and elevating regional rice production sustainability. However, production service outsourcing is mainly through the introduction of external subjects, to achieve the purpose and bring short-term rice green production, rice growers themselves have no direct impact on the green production behavior, individual and regional rice green production can not be sustainable. Rather, it appears that an increase in outsourced services may weaken the positive impact of digital technology on feasible capacity, prompting the following hypothesis:

H3: Outsourcing agricultural production services exerts a negative moderating effect on the feasible capacity of digital technology in facilitating green rice production among farmers.

Drawing upon the 'rational economic man' theory and feasible capacity considerations, this study introduces a model(Fig 1.) exploring the influence of digital technology adoption on the feasible capacity of green rice production among farmers.

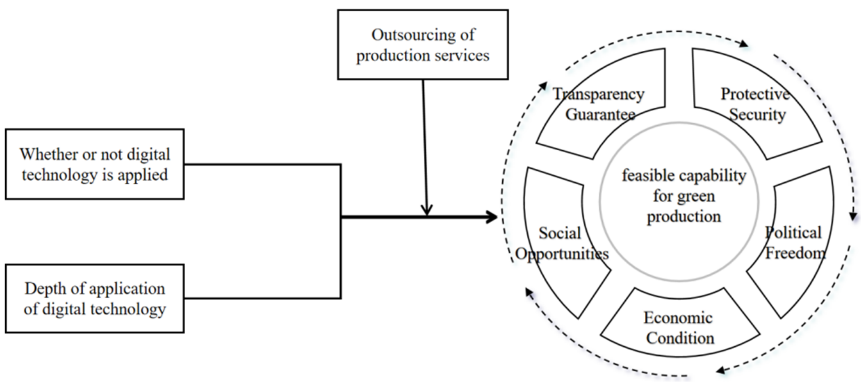

Fig 1. Diagram of the analytical framework

2.3 Sources of Date

The data for this study comes from a survey conducted by the research team in 2023 among rice farmers in rural areas of Chengdu, Deyang, Guangyuan, and other cities in Sichuan Province, To ensure the accuracy and validity of research outcomes, the research team conducted a pre-survey, adjusting the questionnaire accordingly. Researchers were trained before the formal study and their understanding of the questionnaire was verified. To ensure the samples adequately represented rice farmers' current production situation in Sichuan, the team employed stratified random sampling. Initially, stratified sampling was conducted across different terrains in Sichuan,stratified random sampling was employed: 6-7 municipalities were randomly picked from plains, hills, and mountains, within which 1-3 districts/counties were selected. From each district/county, 3-4 townships were chosen, and 15-25 rice farmer per village were surveyed via face-to-face questionnaires. Across 66 villages, 620 households were surveyed, with one adult per household familiar with household conditions participating. Of the 620 questionnaires distributed, 592 were valid, yielding a 95.48% response rate.

2.4 Variable Definition and Description

2.4.1 Explanatory Variable

The explanatory variables explored in this paper encompass rice farmers' adoption of digital technology in production and the extent of its application. Drawing from existing research(Huang et al., 2022; Mao et al., 2023),the questionnaire assesses digital technology adoption through a binary question (yes = 1, no = 0), the depth of digital technology adoption is quantified as the aggregate score of nine variables. The contents are as follows: participation in online green production courses and communication training, online procurement of production materials, seeking processing and sales information, learning agricultural management techniques online, selling agricultural products online, utilizing agriculture-related apps, joining agriculture-focused WeChat groups, creating and sharing videos related to agricultural production, and producing and uploading tweets and short videos related to agriculture. As the explanatory variables are composite, they underwent a reliability and validity test using SPSS25. The Kolmogorov-Smirnov Alpha (K-S Alpha) reliability test result was 0.7 (>= 0.7), indicating high consistency. The validity test revealed a KMO value of 0.713 and a P-value of 0.000 (<0.001). Based on these tests, the explanatory variables are deemed credible and useful.

2.4.2 Explained Variable and Measurement

Amartya Sen (1999)defines "feasible capacity" as an individual's capacity to attain diverse lifestyles or a high quality of life, essentially the ability to achieve a specific combination of functional activities. Instrumental freedoms signify the interconnectedness of substantive freedoms, where the expansion of one fosters the growth of others. Integral to the "freedom to view development" approach to feasible capacity, instrumental freedom encompasses five domains: economic conditions, political freedoms, social opportunities, transparency, and protection. This paper adopts this framework to categorize rice farmers' viable capacities for green production into five corresponding categories.

Economic condition refers to an individual's ability to utilize economic resources for consumption, production, and exchange. This study focuses on rice farmers' economic status, assessed through household assets, annual rice cultivation income(Gangwar et al., 2022; Liu et al., 2023; Rajkhowa and Qaim, 2021),and finds that the level of economic conditions significantly influences their production decisions(McCarthy et al., 2021);Political freedom, as defined by Sen, encompasses the broadest sense of liberty, ensuring basic political power and legal rights for workers. In this paper, we examine rice farmers' political background and participation. Study suggesting that political background can motivate green production adoption,(Luo et al., 2022). Sen also emphasizes social opportunity, referring to arrangements in education, healthcare, and other aspects that impact an individual's ability to lead a fulfilling life.(Zhou et al., 2023)found that social environment influences farmers' green production behavior. Hence, this paper explores social opportunities conducive to rice farmers' green production, evaluating factors like green production subsidies and professional service teams. Transparency assurance focuses on individuals' access to effective information and their right to know. This paper examines rice farmers' difficulties in accessing green production and market information. Protective security, the cornerstone and bottom line, rests on individual basic security guarantees. This paper assesses rice farmers' green production feasible capacity by examining medical and pension insurance coverage. Exploratory factor analysis is applied to observe latent variable connections, complemented by Z-score processing for each indicator.

Table 1. Indicators for evaluating the feasible capacity of green production

Type of indicator	Definition of indicators and assignment of values	Variable type
Economic Condition	Total family assets (RMB million)	continuous variable
	Transfer income received in 2022 (RMB million)	continuous variable
	Annual income of rice farmers(RMB million)	continuous variable
Political Freedom	Are you a party member? 1=Yes 0=No	categorical variable
	Have you ever had experience as a village official or civil servant? 1=Yes 0=No	categorical variable
	Have you ever given advice or suggestions to village officials? 0=No 1=Not adopted 2=Adopted and adopted	categorical variable
Social Opportunities	Is there a subsidy for carrying out green production? 1=Yes 0=No	categorical variable
	Participation in green production/technology training? 1=Yes 0=No	categorical variable
	Is there a local professional service team for rice production? 1=Yes 0=No	categorical variable
Transparency Guarantee	Number of consultations with instructors related to green production technologies? (times)	categorical variable
	Difficulty in accessing green rice production technologies/production materials? 1=very difficult 2=difficult 3=average 4=easy 5=very easy	categorical variable
	Difficulty in obtaining information on market prices of green agricultural products? 1=very difficult 2=difficult 3=average 4=easy 5=very easy	categorical variable
Protective Security	Do you have health insurance in 2022? 1=Yes 0=No	categorical variable
	Do you have agricultural insurance in 2022? 1=Yes 0=No	categorical variable

Table 2. Factor analysis results

Ingredient	Initial eigenvalue			Extract the sum of the squares of the loads			Rotational load sum of squares		
	total	Percentage of variance	accumulate %	total	Percentage of variance	accumulate %	total	Percentage of variance	accumulate %
1	2.407	17.196	17.196	2.407	17.196	17.196	2.017	14.405	14.405
2	1.85	13.215	30.411	1.85	13.215	30.411	1.896	13.544	27.948
3	1.457	10.41	40.821	1.457	10.41	40.821	1.615	11.537	39.486
4	1.347	9.619	50.44	1.347	9.619	50.44	1.487	10.624	50.109
5	1.159	8.276	58.716	1.159	8.276	58.716	1.205	8.606	58.716
6	0.888	6.343	65.058						
7	0.811	5.795	70.853						
8	0.756	5.400	76.253						
9	0.742	5.303	81.556						
10	0.697	4.982	86.538						
11	0.643	4.592	91.13						
12	0.54	3.856	94.986						
13	0.368	2.628	97.614						
14	0.334	2.386	100						

This study employed SPSS 25.0 to conduct factor analysis on rice farmers' green production feasible capacity. Validity was tested through KMO (0.623, >0.6) and Bartlett's Sphericity Test (significant at 1%). Results (Table 2) show four factors with eigenvalues >1, explaining 28.716% of the total variance, providing a comprehensive view of the data.

Employing maximum variance orthogonal rotation, a rotated factor greater than 0.5 is considered to satisfy the extraction principle, economic conditions, political freedom, social opportunities, transparency assurance, and protective safeguards were identified. Each category comprises secondary indicators (Table 3). A composite indicator gauges rice farmers' green production feasible capacity, derived from factor scores and variance contributions. It's calculated by:Feasible Capacity for Green Production=(14.405%*Transparency Guarantee+13.%*544Political Freedom+ 11.537% *Social Opportunities+10.624%*Economic Condition+8.606%*Protective Security)/58.716%.

Table 3. Composition table after rotation

	Ingredient1	Ingredient 2	Ingredient 3	Ingredient 4	Ingredient 5
Difficulty in accessing green rice production technologies/production materials	0.872				
Difficulty in obtaining information on market prices of green agricultural products	0.842				
Number of consultations with instructors related to green production technologies	0.623				
Have you ever given advice or suggestions to village officials		0.872			
Are you a party member		0.765			
Have you ever had experience as a village official or civil servan		0.719			
Is there a local professional service team for rice production			0.813		
Is there a subsidy for carrying out green production			0.791		
Participation in green production/technology training			0.517		
Annual income of rice farmers				0.73	
Transfer income received in 2022				0.672	
Total family assets				0.66	
Do you have health insurance in 2022					0.76
Do you have agricultural insurance in 2022					0.712

2.4.3 Moderator Variable

Drawing upon the aforementioned theoretical framework, this paper examines how outsourcing production services moderates the application of digital technology and the feasibility of green rice production practices. Drawing inspiration from prior studies(Lei et al., 2023; Li et al., 2024; Xu et al., 2024) , the questionnaire inquires about the quantity of outsourced agricultural services utilized, ranging from seedlings/seeds to harvesting, with a score of 0-9 representing the number of services.

2.4.4 Other Control Variables

Drawing upon relevant scholarly works(Luo et al., 2022; Sun et al., 2022; Yan et al., 2023a),this paper scrutinizes the effect of digital technology utilization on the sustainability of green rice production, accounting for nine variables, notably the gender of rice farmers. The precise definitions and values attributed to these variables are detailed in Table 4.

2.5 Research Method

2.5.1 Ordinary Least Squares

This article empirically dissects the determinants of green rice production's feasible capacity among farmers, emphasizing the pivotal roles played by digital technology adoption and its depth of application. To achieve this, we employ Ordinary Least Squares (OLS), ensuring adherence to the fundamental assumptions of the classical linear model. The model setup is outlined as follows:

$$\mathrm{greenability_i} = \beta_0 + \beta_1 \mathrm{digital_i} + \beta_3 c_i + \mu_i \quad (1)$$

Table 4. Meaning and value of variables

Type of Variables	Variable name	Variable Definition and Assignment	Average value	Standard deviation
Explained variable	Feasible capacity of green rice production	Calculated by combining factor scores	0.000	1.527
	Economic condition	Calculated by combining factor scores	0.000	1.000
	political Freedom	Calculated by combining factor scores	0.000	1.000
	Social opportunities	Calculated by combining factor scores	0.000	1.000
	Transparency Guarantee	Calculated by combining factor scores	0.000	1.000
	Protective security	Calculated by combining factor scores		
Explanatory variable	Whether or not digital technology is applied(X1)	Positive responses are scored as 1, while negative ones are given a 0. Utilization of digital technology is deemed present if any of the following activities occur: engaging in online green production courses or communication training; procuring production materials/learning about processing & sales info online; acquiring agricultural business management knowledge online; selling agri-products digitally; employing agriculture-focused apps, participating in agri-related WeChat groups; creating & sharing videos promoting agricultural production; posting agri-related tweets/short videos on the internet.	0.789	0.408
	Depth of application of digital technology(X2)	Positive responses are scored as 1, while negative ones are given a 0.The depth of digital technology adoption is determined by summing the values of nine variable as follows, engaging in online green production courses or communication training; procuring production materials/learning about processing & sales info online; acquiring agricultural business management knowledge online; selling agri-products digitally; employing agriculture-focused apps, participating in agri-related WeChat groups; creating & sharing videos promoting agricultural production; posting agri-related tweets/short videos on the internet.	2.456	2.138
Moderator variable	Outsourcing of production services	The questionnaire inquires about the quantity of outsourced agricultural services utilized, ranging from seedlings/seeds to harvesting, with a score of 0-9 representing the number of services.	1.946	2.179
Controlling variable	Genders	1=Male 0=Female	0.728	0.620
	Age	How old are you? (years old)	53.365	10.068
	Educational level	How many years of education do you have? (years)	8.672	3.985
	Scale of land management	Size of your family's land? (acres)	115.225	773.721
	Land fragmentation	Number of land parcels/area of land	1.264	1.555
	Topographical	1=Plains 2=Hills 3=Mountains	1.943	0.359
	Risk appetite	If you had a sum of money to invest, which programme would you prefer?1=High risk, high return 2=Average risk, average return 3=Low risk, low return	2.536	0.657
	Cropland fertility	What do you think about the fertility of the soil on your land? 1=poor 2=poorer 3=average 4=more fertile 5=very fertile	3.416	0.795
	Agricultural population	How many people in your family are engaged in agricultural labor?(per)	2.160	0.945

$$\mathrm{greenability_i} = \beta_0 + \beta_2 \mathrm{depth_i} + \beta_3 c_i + \mu_i \quad (2)$$

$\mathrm{greenability_i}$ indicates feasible capacity of green rice production ;$\mathrm{digital_i}$ indicates the digital technology application for rice growers.$\mathrm{depth_i}$ is the depth of digital technology adoption by rice grower,c_i denotes control variables such as sex and age of rice farmers;μ_i is random interference term ,$\beta_0, \beta_1, \beta_2$ is the parameter to be estimated.

2.5.2 Moderated Effects Model

To facilitate deeper analysis, this paper incorporates rice growers' perceptions towards green production as a moderating factor within its model, structured as outlined below:

$$\mathrm{greenability_i} = \beta_0 + \beta_1 \mathrm{digital_i} + \beta_4 \mathrm{ouysouring_i} + \beta_5 \mathrm{digital_i} * \mathrm{outsouring_i} + \beta_3 \mathrm{c_i} + \mu_i \quad (3)$$

$$\mathrm{greenability_i} = \beta_0 + \beta_2 \mathrm{depth_i} + \beta_4 \mathrm{outsouring_i} + \beta_6 \mathrm{depth_i} * \mathrm{outsouring_i} + \beta_3 \mathrm{c_i} + \mu_i \quad (4)$$

$\mathrm{outsouring_i}$ is the number of outsourced production services used by rice farmers.;$\mathrm{digital_i} * \mathrm{outsouring_i}$ interaction item between digital technology application and outsourcing of production services for rice growers.$\mathrm{depth_i} * \mathrm{outsouring_i}$ interaction term between depth of digital technology adoption and outsourcing of production services for rice growers.;β_5, $\beta_6$is the focus of the moderating effects regression concern.

3. Empirical Results and Analyses

This study explores the impact of digital technology application and its depth on rice farmers' feasible capacity of green production, alongside their interactive mechanisms. To examine the potential endogeneity due to mutual causality between explanatory and explained variables, the Hausman-test was applied. The outcomes indicated a P-value surpassing 0.1, leading to the rejection of the original hypothesis and confirming the absence of such endogeneity between digital technology application, its depth, and the feasible capacity for green production. Subsequently, a basic regression analysis was performed to assess the influence of digital technology application and its depth on rice farmers' green production feasible capacity. To test moderating effects, additional regressions incorporated interaction terms between these factors and green production perception.

3.1 The Influence of Digital Technology Applications on Feasible Capacity Among Rice Farmers

The variables underwent covariance testing, yielding VIF values below 10, confirming their lack of covariance. Table 5 presents the baseline regression outcomes, examining the impact of digital technology applications on the feasible capacity of rice farmers' green production. The results, adjusted for various other factors, indicate that rice farmers' use of digital technology in production significantly enhances their feasible capacity at the 1% confidence level, with a coefficient of 0.591; The depth of digital technology application exerts a significant positive impact on green production feasible capacity among rice farmers at the 110% confidence level, with a coefficient of 0.0688. This underscores the significant potential to enhance capacity of green production through heightened digital technology utilization, with the impact amplifying as application deepens. Ultimately, Hypotheses H1 and H2 are validated.

An in-depth analysis delves into the influence of digital technology applications and their depth on transparency assurance, political liberties, societal opportunities, economic conditions, and protective measures for bolstering the feasible capacity of rice farmers' green production. Rice farmers' digital technology application significantly enhances transparency assurance at the 1% confidence level, with a coefficient of 0.506. Furthermore, the depth of application also positively impacts transparency assurance (coefficient = 0.0585, 5% confidence), indicating that a deeper application facilitates access to more comprehensive rice green production information, thereby reducing information asymmetry. Digital technology application significantly impacts rice farmers' political freedom at the 10% confidence level, with a coefficient of 0.0.210, empowering them to better comprehend and safeguard their rights. Moreover, the depth of application positively influences their social opportunities at the 1% confidence level (coefficient = 0.105), suggesting that deeper application enhances farmers' utilization of social resources to boost their capabilities. The depth of digital technology application for rice farmers has a significant effect on economic conditions at 5% confidence level, with a coefficient of 0.0452. The deeper the depth of digital technology application, the faster and more conveniently the problems in the whole production process of rice farmers can be solved, and the cost of production can be reduced, thus significantly improving their economic conditions. Digital technology application has a significant effect on the protective security of rice farmers at 5% confidence condition, with a coefficient of 0.291. Digital technology application allows rice farmers to understand how to protect their own rights and interests better, and more conveniently purchase protective services, thus reducing the risks that they may encounter in production and life. In summary, deeper application of digital technology enhances the transparency, social, and economic conditions of rice farmers. It facilitates their access to green production methods, relevant social resources, and economic improvement, creating a positive feedback loop.

Table 5. Impact of digital technology application on the feasible capacity among rice farmers

Variables	Feasible capacity of green rice production	Transparency Guarantee	Political freedom	Social opportunities	Economic condition	Protective security
X1	0.591***	0.506***	0.210*	0.0865	-0.141	0.291**
	(-3.11)	(-4.16)	(-1.73)	(-0.72)	(-1.24)	(-2.29)
X2	0.0688*	0.0585**	-0.00998	0.105***	0.0452**	0.019
	(-1.83)	(-2.43)	(-0.42)	(-4.45)	(-2)	(-0.76)
Age	0.00179	0.0119***	-0.00522	0.00258	-0.00188	-0.0000585
	(-0.25)	(-2.63)	(-1.16)	(-0.58)	(-0.44)	(-0.01)
Genders	0.0125	-0.00514	-0.107	0.0597	0.0655	0.0101
	(-0.13)	(-0.08)	(-1.69)	(-0.95)	(-1.1)	(-0.15)
Land fragmentation	0.0125	-0.0199	0.0421	-0.0459*	-0.0540**	0.018
	(-0.30)	(-0.76)	(-1.61)	(-1.77)	(-2.19)	(-0.66)
Topographical	0.144	0.0204	0.265**	0.02	-0.257**	0.082
	(-0.82)	(-0.18)	(-2.37)	(0.18)*	(-2.45)	(-0.7)
Risk appetite	-0.0355	-0.00303	0.00605	-0.116	-0.0475	-0.00329
	(-0.38)	(-0.05)	(-0.1)	(-1.94)	(-0.84)	(-0.05)
Cropland fertility	-0.0829	0.166***	0.042	-0.0993**	0.0339	-0.0818
	(-1.07)	(-3.34)	(-0.85)	(-2.04)	(-0.73)	(-1.58)
Educational leve	0.0157	0.0242*	0.0556***	0.0125	0.00961	-0.00493
	(-0.91)	(-2.2)	(-5.08)	(-1.15)	(-0.93)	(-0.43)
Scale of land management	-0.000472	-0.000922	-0.00107	0.000448	-0.00085	0.0000465
	(-0.25)	(-0.76)	(-0.89)	(-0.37)	(-0.74)	(-0.04)
Agricultural population	-0.00813	0.0867**	-0.0603	0.0281	0.0791**	-0.0241
	(-0.12)	(-2.05)	(-1.44)	(-0.68)	(-2)	(-0.55)
_cons	-0.776	-2.109***	-0.810*	-0.0204	0.409	-0.0965
	(-1.10)	(-4.64)	(-1.80)	(-0.05)	(-0.96)	(-0.20)
N	588	588	588	588	588	588
R2	0.061	0.12	0.092	0.107	0.057	0.028
Adj-R^2	0.043	0.103	0.074	0.09	0.039	0.009

Note: * * * and * * indicate the significance levels of 1% and 5%, respectively, and the numbers in parentheses are the robust standard error of the coefficient, and the same is true in the table below.

3.1.1 Robustness Check

There may exist causality and omitted variables between rice farmers' adoption of digital technology and green production viability. High green production viability among farmers could potentially lead to a greater willingness to embrace new knowledge and technology, thereby increasing their adoption of digital technology.Simultaneously, other variables may exert a more significant influence on the viability of green production among rice growers.To address the endogeneity issue, this paper employs a two-stage least squares (2SLS) regression and selects the mean digital technology application of other rice farmers in the same township (IV_X1) as an instrumental variable. This variable fulfills the exogeneity assumption by being directly related to the explanatory variables but not directly to the dependent variables.The findings from the two-stage least squares (2SLS) regression, displayed in Table 6, underscore the substantial impact of digital technology application on the green production viability of rice farmers, even after accounting for endogeneity. The robustness of the benchmark regression results is confirmed. Notably, the first-stage F-value for the instrumental variable surpasses the threshold of 10, and both the Cragg-Donald Wald F statistic and the Anderson-Canon correlation LM test validate the appropriateness of the chosen instrumental variable.

Table 6. Results of endogeneity analysis

VARIABLES	fistX1 X1	second Y
X1		3.2009*** -3.52
IV_X1	0.6184***	
	-4.96	
Control variable	controlled	controlled
Constant	0.7541***	-3.750***
	(-3.65)	(-2.64)
Anderson canon. corr. LM statistic	24.08***	
Cragg-Donald Wald F statistic	24.64(16.380)	
Observations	588	588
R-squared		-0.334

To bolster study reliability, a robustness check was conducted using the Tobit model, replacing the OLS model, as outlined in Table 7. Consistent regression outcomes with Table 5 affirm the stability of our findings.

Table 7. Stability test results

Variables	Feasible capacity of green rice production	Transparency Guarantee	Political freedom	Social opportunities	Economic condition	Protective security
X1	0.591***	0.506***	0.210*	0.0865	-0.141	0.291**
	(3.14)	(4.20)	(1.75)	(0.73)	(-1.25)	(2.32)
X2	0.0688*	0.0585**	-0.00998	0.105***	0.0452**	0.0190
	(1.85)	(2.45)	(-0.42)	(4.49)	(2.02)	(0.76)
Control variable	controlled					
var(e.Y)	2.141***					
	(17.15)					
var(e.y1)		0.880***				
		(17.15)				
var(e.y2)			0.868***			
			(17.15)			
var(e.y3)				0.850***		
				(17.15)		
var(e.y4)					0.770***	
					(17.15)	
var(e.y5)						0.957***
						(17.15)
N	588	588	588	588	588	588
Pseudo-R^2	0.0171	0.0450	0.0345	0.0406	0.0221	0.0100

3.2 Moderating Effects Test

Table 8, Model 1 presents the regression analysis of how the interplay between digital technology adoption and production service outsourcing impacts the feasible capacity of green production. Both factors exhibit a statistically significant negative correlation at the 1% level, with a coefficient of -0.397. This underscores a notable dampening influence of outsourcing production services on rice farmers' ability to leverage digital technology effectively for sustainable production. Model 2 reveals the regression outcomes of the interplay between the extent of digital technology application and production service outsourcing on the practicability of green production. This interaction is significantly negative at 1%, with a coefficient of -0.0516, suggesting that increased outsourcing by rice farmers intensifies the negative influence of digital technology on feasible capacity. Notably, Model 2's coefficient is lower than Model 1's, indicating that a deeper dive into digital technology diminishes the weakening effect of outsourcing. Hence, Hypothesis H3 is supported.

Table 8. Moderating effects test

Variables	Model 1	Model 2
X1	0.504**	
	(3.02)	
X2		0.136***
		(4.30)
Outsourcing	0.0889**	0.0719*
	(2.85)	(2.28)
X1* Outsourcing	-0.397***	
	(-4.17)	
X2 * Outsourcing		-0.0516***
		(-3.77)
control variable	controlled	controlled
N	588	588
R^2	0.087	0.071
adj.-R^2	0.068	0.051

4. Discussion

4.1 Similarities and Differences with Existing Research

The Chinese government has consistently fortified digital infrastructure in rural areas, leading to marked enhancements in the productivity and living standards of rural residents. Consequently, digital technology has progressively emerged as a pivotal force shaping both rural production and lifestyles(Chen et al., 2022).As posited by Weng et al. (2023) and Li et al. (2023b), digital technology application can transform rice farmers' production challenges, enhancing their market information comprehension, mitigating market-farmer information asymmetry, and fostering awareness of their rights. This, in turn, bolsters the feasible capacity of green rice production, thereby upgrading rice farmers' capacity for environmentally sustainable production. Concurrently, Sichuan Province, being a pivotal national strategic region, underscores the equal significance of rural digital development and green rice production. The more extensive farmers' adoption of digital technology in rice production fosters a deeper comprehension and utilization of societal resources conducive to production, thereby elevating the feasible capacity of green rice production and fueling the momentum for environmentally sustainable rice cultivation in the area.

Distinct from existing research, including that of Li and Yu (2022) and Shi et al. (2023), this paper transcends the mere analysis of influencing factors in green production. It acknowledges the overlooked disparity in green production behaviors among individuals within the same region and across different regions. The crux lies in addressing the long-standing challenge of sluggish feasible capacity of green production green production, emphasizing that enhancing the overall practicality for rice farmers is pivotal to effectively propel the development of environmentally sustainable rice production. Both Qing et al. (2023) and Yang et al. (2023) concurred that outsourcing production services fosters green rice production, aligning with our study. While we zoom in on individual farmers' green production potential, outsourcing leverages external resources to elevate green production standards, a valuable approach. However, in Sichuan's rugged terrain, outsourcing effects may be limited, emphasizing the need for sustained efforts to bolster rice farmers' green production capabilities as a cornerstone of green development.

4.2 Policy Recommendations

In the dual backdrop of Sichuan Province's role as a national strategic hinterland and the ongoing 'Tianfu Granary' construction, bolstering the feasible capacity of green rice production among farmers is crucial for ensuring food security. Active promotion of digital technology application in agriculture serves as a vital safeguard for achieving this goal. However, current policies still exhibit shortcomings. Despite ongoing improvements in rural digital infrastructure, rice farmers' adoption of digital technology remains limited, largely confined to browsing short videos and answering phone calls. Their ability to proactively harness production-related information and resources via digital means is inadequate. Constrained by local government resources and cognitive limitations, policies pertaining to digital villages have predominantly focused on infrastructure development, overlooking the critical need for farmer training and upskilling. This has stymied the rapid advancement of rural digital technology. Furthermore, the absence of a robust green product monitoring and sales platform has led to a significant gap in information between producers and sellers of green agricultural goods. This has in turn fueled issues like elevated production costs for green rice and hindered the ability to sell it profitably.

Drawing from the insights gained through literature review and empirical analyses, this paper offers the following policy recommendations: Firstly, bolster digital technology training in rural areas by leveraging regional resources and fostering long-term partnerships with local universities and experts. Tailor publicity and training efforts to address varying learning needs, especially for those with lower educational backgrounds, older ages, or facing difficulties, to empower them in enhancing their green rice production capabilities. Secondly, to enhance the promotion of green rice production, utilize both online and offline channels simultaneously. Engage rice farmers through enjoyable methods to deepen their understanding and cognition of green production practices.Lastly, by prioritizing the promotion of rural digital technology application, targeted agricultural outsourcing services can be fostered. The focus should be on enhancing the green production feasibility of rice growers in various regions, which necessitates accelerating the adoption of rural digital technology in production. While outsourcing services can temporarily reduce pollution in rice production, they do not constitute a sustainable path for green rice production.

5. Conclusion

As the primary grain-producing region in China, maintaining stable and high-quality grain output in Sichuan Province is paramount. Hence, expediting green rice production is imperative. Central to fostering green rice production practices is exploring strategies to diminish disparities in farming methods and enhancing the practicality of eco-friendly production for rice farmers. In the digital age, examining digital tech's role and feasible capacity of green rice production will boost its development in Sichuan. Hence, this paper aims to review pertinent literature and offer insights into the implications and underlying mechanisms by conducting one-on-one questionnaire surveys with rice farmers and empirical analyses. The findings reveal: (1) Digital technology application significantly enhances rice farmers' feasible capacity of green production. (2) The extent of digital technology application significantly influences the viability of green rice production. Greater depth in its application leads to more pronounced positive effects on the transparency, security, social conditions, and economic status of rice farmers. (3) The adoption of production service outsourcing by rice farmers exhibits a notable negative moderating influence on digital technology application and green production viability. Production outsourcing fails to enhance the green production viability of rice farmers; it merely boosts rice green production temporarily without improving farmers' long-term green production sustainability.

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