frontiers | Frontiers in Sustainable Food Systems

TYPE Original Research
PUBLISHED 28 May 2024
DOI 10.3389/fsufs.2024.1368997

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EDITED BY
Gideon Danso-Abbeam,
University for Development Studies, Ghana

REVIEWED BY
Indira Devi Puthussery,
Kerala Agricultural University, India
Nawab Khan,
Sichuan Agricultural University, China

*CORRESPONDENCE
Qi Li
✉ liqi@qfnu.edu.cn

RECEIVED 11 January 2024
ACCEPTED 14 May 2024
PUBLISHED 28 May 2024

CITATION
Li Q and Wang Z (2024) Impact of contract farming on green technological efficiency of farmers: a comparative study of two contract organizational models.
Front. Sustain. Food Syst. 8:1368997.
doi: 10.3389/fsufs.2024.1368997

Impact of contract farming on green technological efficiency of farmers: a comparative study of two contract organizational models

Qi Li* and Zixuan Wang

School of Economics, Qufu Normal University, Rizhao, China

Introduction: Engaging in contract farming represents a crucial avenue for developing countries to integrate small farmers into modern agricultural practices. Existing research believes that contract farming offers a promising opportunity for fostering sustainable agricultural development. However, insufficient attention has been directed toward investigating the varying impacts of different organizational models within contract farming on farmers' transition to green production practices.

Methods: This study investigates the impact of contract farming on green technological efficiency of farmers using survey data from 719 wheat growers in Shandong Province, China. The propensity score matching method and multiple mediation effects models are employed for empirical analysis.

Results: The organizational model plays a pivotal role in determining whether participation in contract farming can improve the green technological efficiency of farmers. Participation in an integrated model demonstrates a significant effect on improving green technological efficiency, whereas participation in a quasi-integrated model does not show a significant improvement. Integrated contract farming can improve green technological efficiency through expanding the degree of land consolidation and enhancing the level of productive service, whereas quasi-integrated contract farming improves green technological efficiency only by enhancing production intensification. As an economic incentive measure, the effect of contract purchase price on strengthening the enhancement of green technological efficiency in the quasi-integrated model is moderate only when the contract purchase price exceeds the local average selling price of wheat by more than 19.3%. Conversely, the moderate effect of farmers' dividend income in the integrated model remains consistent, with higher dividend incomes correlating with a stronger moderating effect.

Discussion: The impact of contract farming on green technology efficiency correlates significantly with the organizational model. Compared with the quasi-integrated contract farming model, the integrated model distinctly excels in advancing farmers' green technology efficiency, evidenced by its ability to consolidate fragmented land, provide productive services, and offer economic incentives. Therefore, to unlock the latent potential of contract farming in driving agricultural green transformation, a shift toward organizational models with higher levels of integration is essential.

KEYWORDS

contract farming, green technological efficiency, integration model, quasi-integration model, propensity score matching, wheat farmers

1 Introduction

Contract farming, as a significant institutional innovation to achieve the modernization of the agricultural system, has been widely discussed since the 1950s for its potential to address market failures (Wang et al., 2011; Bellemare and Novak, 2017). By the end of the 20th century, contract farming had become a fundamental feature of modern agriculture in developed countries. As a typical mode of agricultural industrialization, contract farming is a production model in which producers (farmers) and buyers (agricultural enterprises) enter into legal agreements specifying yield and quality for a certain period. Enterprises provide agricultural inputs, technical assistance and financial resources to producers, promising to purchase high-value agricultural product from contract farmers (Chen and Chen, 2021). In turn, contract farmers permit agricultural enterprises to control and instruct them on the quality and quantity of agricultural products (Porter and Phillips-Howard, 1997; Bellemare and Bloem, 2018; Isager et al., 2018). Based on this arrangement, farmers can integrate into the modern agricultural value chain by guaranteed markets and guaranteed production factors (Key and Runsten, 1999; Swinnen and Maertens, 2007; Ragasa et al., 2018; Tuyen et al., 2022), cope with market fluctuations (Guo et al., 2007; Soullier and Moustier, 2018; Hong et al., 2023), and meet the market demand for high-quality agricultural products (MacDonald and Korb, 2011; Chen and Zhou, 2023). Therefore, contract farming alleviates three major production difficulties for small farmers regarding what to grow, how to grow, and how to secure profits, thereby improving the agricultural productivity in both developing and developed countries (Miet and Velde, 2017; Bellemare and Bloem, 2018; Islam et al., 2019). Contract farming provides a crucial mechanism for integrating small farmers into modern agriculture (Dubbert et al., 2023), which is particularly prominent in developing countries in Africa and Asia as "small, scattered, and weak" farmers remain their main body of agricultural production (De Haan et al., 2001; Vamuloh et al., 2020; Chen et al., 2023). Recognizing the importance of contract farming, governments in developing countries are actively promoting its development (Ruml and Qaim, 2021; Lin et al., 2022). Compared with developed countries, China's contract farming started relatively late in the southeastern coastal areas in the mid-1980s and rapidly developing, becoming an effective means for China to build agricultural modernization.

Numerous studies have investigated the effects of contract farming on production of farmers. There is a consensus that contract farming can improve agricultural productivity and farmer welfare. Some studies confirm that contract farming has a positive impact on agricultural productivity and efficiency (Champika and Abeywickrama, 2014; Bidzakin et al., 2020; Dubbert et al., 2023) and some other studies find that contract farming can increase farmers' planting profits or household income (Miyata et al., 2009; Kumar et al., 2018; Ogutu et al., 2020; Dagnew et al., 2023). For example, Miet and Velde (2017) find that smallholder participation in the rice sector contract farming program in Benin led to an expansion in rice area, intensification of rice production and increased commercialization of rice, ultimately promoting rice yield growth and income increase. Liang et al. (2023) believe that contract farming significantly increased farmer income, and both marketing contracts and production management contracts significantly improved the income level of farmers.

Few studies have examined the impact on the environment and sustainable agricultural practices since its emergence. With the recent active advancement of agricultural modernization in developing countries, research on the impact of contract farming on sustainable agricultural development has started to grow traction, primarily focusing on the following two aspects: Firstly, contract farming facilitates the adoption of green agricultural technology (Ruzzante et al., 2021). For example, Chen and Zhou (2023) indicate that contract farming has a significant positive impact on farmers' adoption of green and smart agricultural technologies in China. Secondly, contract farming improves farmers' safety production behaviors (Mao et al., 2022). Ren et al. (2021) reveal that participation in contract farming could increase the probability of manual weeding by 28.2% and the use of organic fertilizers by 31.1% using data of rice farmers in China. Gao et al. (2022) demonstrate that farmers' participation in contract operations increased the probability of applying organic fertilizer by 50.7% using data from vegetable farmers in China.

To summarize, two issues emerge from relevant research: first, the role of contract farming in promoting green development is subject to controversy. While contract farming ideally fosters sustainable agricultural development, some literature studies have drawn heterogeneous conclusions, suggesting that its role in promoting green agricultural development is either negligible or negative (Mwambi et al., 2016; Meemken and Bellemare, 2020; Zhang et al., 2023). This inconsistency necessitates an examination of factors beyonddifferent crops or geographical backgrounds. Since green production behavior in agriculture exhibits obvious external characteristics (Pigou, 1932), and incomplete contracts leads to issues such as information asymmetry (Sun et al., 2022), contract production can result in "regulatory failure," leading to opportunistic behavior by farmers that contravenes product standards (Pouliot and Wang, 2018), such as the illegal use of fertilizers and pesticides. This consideration has prompted our inquiry into the organizational models of contract farming. Due to different contract governance mechanisms stemming from organizational models, there are varying supervisory effects on opportunistic behavior and incentives for green technology behavior of farmers, resulting in differences in green technology efficiency. However, existing research on contract agriculture has overlooked the examination of organizational models. Secondly, there is a lack of research on the impact of contract farming on farmers' green technology efficiency. We believe this is because the green attributes of the production process are difficult to observe, and the changes in green technology efficiency due to contract farming are "hidden" within the production process, making it challenging to directly observe. We believe that farmers' green technology efficiency is a composite representation of production efficiency and quality, deserving scholarly attention.

As a result, this study develops an analytical framework to assess the impact of contract farming on the efficiency of green technology, encompassing both integrated and quasi-integrated organizational models, along with their respective utilities and impact pathways. Empirical testing was conducted in Shandong Province, China. The study aims to achieve two primary objectives:

Firstly, to elucidate the influence of the two most prevalent types of contract farming models on farmers' efficiency in adopting green technology, thereby proposing effective strategies to enhance such efficiency from the perspective of organizational models. Secondly, to delineate the pathways through which organizational models affect the efficiency of green technology adoption, thereby identifying means to optimize contract farming organizational structures. Our goal was not only to leverage the role of contract farming in facilitating the transition to green production in China but also to offer valuable insights to countries and regions grappling with agricultural transformation, particularly those with small-scale and decentralized smallholder operations. This study yields valuable insights for policymakers to devise tools and policies supporting the integrated development of agricultural enterprises and farmers. These policy instruments can enhance agricultural productivity, foster sustainable rural development, and ensure food security in developing nations.

We aim to make two contributions to existing research. Firstly, while previous studies have primarily focuses on the comparative analysis of the production behavior of farmers participating in contract farming vs. those who do not, there has been limited clarity regarding the differential impacts of various types of contract farming on green production behavior. Secondly, in addition to assessing the impact of farmer participation in contract farming on green technological efficiency, we explore the pathways through which contract farming influences green technology efficiency from three dimensions: land contiguity, productive service and economic incentives.

2 Theoretical framework and hypotheses

2.1 Contract farming organizational models

2.1.1 Quasi-integrated model

During the transition from fragmented to industrialized agricultural operations in China, numerous quasi-integrated management organizations have emerged, positioned between dispersed farmers and agricultural enterprises. This model primarily includes "enterprise + farmer" and "enterprise + cooperative + farmer" arrangements. In this model, leading enterprises sign pre-transaction contracts with wheat growers to clarify respective rights and obligations, mainly encompassing wheat transaction prices, quantities, quality, and timing, and purchasing agricultural products at agreed prices. Leading enterprises secure a stable supply of raw materials and provide some pre- and mid-production services to growers. Cooperatives involved in the model negotiate with enterprises as representatives of farmers and are also entrusted by the enterprises to organize production management and provide production supervise to farmers, thus strengthening contract governance (Yang and Liu, 2012). Consequently, farmers, agricultural enterprises, and cooperatives form quasi-integrated operating organizations linked by long-term contracts, which, as a mid-way model between market transactions and full integration, has increasingly developed into a major organizational form of China's industrialized agriculture. As a commodity contract model, the contracting parties in this arrangement maintain strong independence and autonomy (Zhou and Cao, 2001). Market governance mechanisms play a major role in this contract relationship, with price almost being a decisive factor in the establishment, continuation, and termination of transactions, as both farmers and enterprises both passively accepting market prices.

2.1.2 Integrated model

The integrated operation of enterprises integrates production, storage, transportation, and sales within a single company, thereby saving transaction costs (Williamson, 1971). In the industrialization of agriculture in China, an "enterprise + (cooperative +) base + farmer" integrated model has gradually emerged. In this model, enterprises lease land from farmers to establish large-scale production bases, then hire farmers to operate on these bases, with farmers participating in the profits from production based on land shares. Through unified production materials and unified technical standards, companies supervise and guide farmers in standardized production. The model effectively integrates farmers into the vertical integration of enterprise through the use of production bases, transforming external market exchange relations into internal management relations, forming specific transaction relationships up and down the supply chain, enhancing the labor incentives of farmers, and reducing the organizational costs for the enterprise. Factor governance mechanism play a major role in this contract relationship, mainly reflected in the fact that farmers, in addition to receiving land transfer rent and base employment wages, also enjoy dividends by contributing land as shares. As a result, farmers form a semi-closed organization alliance with the enterprise and enterprises can supervise and constrain dispersed opportunistic behavior and achieve effective contract governance.

2.1.3 Comparison of the impact of two organizational models on green technology efficiency

Compared to the quasi-integrated model, the integrated model has more advantages in improving green technology efficiency. It facilitates the administration of farmers' land through the establishment of production bases, achieves scaled management, amplifies green technology effects, and efficiently supervises farmers' behavior through "unified" production management. Therefore, it can effectively regulate farmers' green production behaviors. With controlled behavior, the dividend mechanism tightly links farmers' income with the enterprise's product sales, further providing inherent motivation for farmers to produce green and high-quality agricultural products. In the quasi-integrated model, the lack of significant improvement in green technology efficiency may be due to the inherent flaws in contract fragility of the model, leaving a large "public domain" for farmers' opportunistic behaviors such as irregular fertilizer and pesticide use, increasing the cost of monitoring opportunistic behaviors for leading enterprises. Hence, we propose that:

Hypothesis H_1: Farmers' participation in contract farming may promote the enhancement of green technology efficiency.

Compared to the quasi-integrated model, the integrated model has more advantages in improving green technology efficiency.

2.2 Pathways through which contract farming promotes green technology efficiency

Contract farming provides opportunities for environmental management and sustainable agricultural practices. On one hand, contract farming changes the production mode of farmers. Cooperatives or enterprises integrate fragmented land into contiguous land, thereby improving the efficiency of machinery use, expanding the radiating effect of green technology, and forming economies of scale. On the other hand, contract farming transforms the production mode of farmers by providing various types of productive services. Enterprises provide services such as supply of seeds and fertilizers, as well as green production technology support, effectively injecting modern, green, and efficient production elements into the production process of farmers, thus significantly enhancing the intensification level of contract production. For example, services for integrated pest management technologies can reduce the misuse of pesticides (Gao et al., 2017; Yu et al., 2020) and services for organic fertilizers can reduce the excessive use of chemical fertilizers and nutrient loss in agriculture (Ni et al., 2011). Hence, we propose that:

Hypothesis H_2: Contract farming enhances farmers' green technology efficiency through two pathways: increasing the degree of land contiguity and providing various types of productive service.

Farmers' fundamental motive for production is to pursue the maximization of economic benefits, thus economic incentives is an important exogenous force for farmers to achieve a green production transformation. According to theoretical analysis, market mechanisms especially purchase price play a leading role in the contract governance of quasi-integrated model. The logic of premium prices for high-quality products is commonly adopted in contracts, with enterprises purchasing products that meet production standards at prices higher than normal. This price incentive compels farmers to improve production to meet contractual requirements. Factor governance mechanisms dominate in integrated contract farming, where economic incentives are mainly obtained by farmers in the form of profit-sharing dividends. The higher the dividend income, the more it can motivate farmers to produce high-quality agricultural products according to contract requirements. However, farmers are also more likely to engage in opportunistic behavior when faced with high price incentives or dividend incentives. Under the notion that higher application amounts mean higher yields, farmers may choose to replace fertilizer and pesticide varieties or overuse them to obtain higher profits. Therefore, if economic incentives lack production supervision or the risk of opportunistic behavior is low, the efficiency of green technology for farmers may decrease. Hence, we propose that:

Hypothesis H_3: Raising the purchase price or increasing dividend income plays a positive moderating role in the process of enhancing green technology efficiency in both types of contract farming, but it may also inversely stimulate opportunistic behavior in farmers, resulting a decrease in technological efficiency.

3 Materials and methods

3.1 Data sources and descriptive statistics

This study is conducted within the grain production region of Shandong, China, as the sustainability of food production is an important issue related to national security. The sample data were collected through a household survey conducted in Shandong Province between 2021 and 2022. Shandong Province, located in the coastal area of East China, is bordered by the Bohai Sea and the Yellow Sea ($34°22.9'$-$38°24.01'$ N, $114°47.5'$-$122°42.3'$E) and has a warm temperate monsoon climate. As a leading grain-producing province, Shandong develops the "Qilu Grain and Oil" brand and contract farming proactively in propelling the grain industry's transition and strengthening, thus offering good opportunity for examining the impact of contract farming. The study's selected sample areas align with the distribution of primary wheat-growing regions in Shandong Province. These include Xintai and Feicheng City in Tai'an, Bincheng District and Zouping City in Binzhou, Yanzhou District and Jiaxiang County in Jining, and Laixi and Pingdu City in Qingdao. The survey employs a stratified sampling method. Within each sample region, townships were categorized into high, medium, and low groups based on total wheat production to ensure representation across different wheat cultivation levels. This approach captures the regional and hierarchical nuances of wheat cultivation. From each group, one village was selected at random, and within each village, 30–40 wheat growers were chosen randomly for the household surveys. A total of 730 questionnaires were collected, of which 719 were valid.

According to the descriptive analysis of the basic characteristics of sampled farming households (Table 1), the average age of household heads in the sample is 50.17 years old, with an average educational level below junior high school. 81% of household heads have never held any administrative positions, reflecting the prevalent characteristics of aging and low educational attainment among the sampled household heads. On average, they participate in technical training 3.04 times per year, while 46% of farmers exhibit either risk aversion or risk neutrality. In terms of family characteristics, agricultural income accounts for 83% of total household income, and the average number of relatives and friends maintained for social connections is 25.81, indicating that the majority of farmers still rely mainly on farming for income and have a low level of diversification, while also establishing extensive social networks in rural areas. Concerning production characteristics, the average area planted with wheat is 14.89 hm^2, indicating a certain scale of production, but only 44% of farmers consider their own soil quality to be good.

A total of 270 households, accounting for 37.55% of the sample, participated in contract farming. 76 households participated in the quasi-integrated model, accounting for 10.57%, and 194 households participated in the integrated model, accounting for 26.98%. We also provided sample characteristics for three groups: participants in the quasi-integration model, participants in the quasi-integration model, and non-participants in contract farming.

TABLE 1 Basic characteristics of sample farm households.

Variable name		Variable definition	Whole farmers		Farmers participated in contract farming of integrated model		Farmers participated in contract farming of quasi-integrated model		Farmers not participated in contract farming	
			Mean	Standard error	Mean	Standard error	Mean	Standard error	Mean	Standard Error
Individual endowment	Age of head of household	Age of head of household/years	50.17	9.03	49.08	6.40	49.92	8.79	50.44	9.42
	Education of head of household	Elementary school or below = 1; Junior middle school = 2; High school = 3; Above high school = 4	1.99	0.84	2.30	0.78	1.85	0.83	1.99	0.84
	Held administrative position	Yes = 1; No = 0	0.19	0.40	0.34	0.43	0.18	0.39	0.19	0.40
	Risk attitude	Risk-taker = 1; Risk-neutral or risk-averse = 0	0.54	0.50	0.59	0.49	0.61	0.49	0.50	0.50
	Participation in technical training	Average annual participation in agricultural technical training sessions	3.04	1.12	3.43	1.10	2.94	1.07	3.01	1.12
Family endowment	Proportion of agricultural income	Agricultural income/Total family income/%	0.83	0.18	0.83	0.17	0.90	0.12	0.83	0.18
	Size of social network	Number of relatives and friends maintaining contact with the family	25.81	16.17	25.58	16.42	29.30	16.86	25.81	16.17
Production characteristics	Production scale	Wheat cultivation area/hm^2	14.89	59.31	12.89	36.23	10.69	16.54	13.96	55.60
	Soil quality	Good = 1; Poor = 0	0.44	0.50	0.43	0.50	0.41	0.49	0.44	0.50
Participation in contract farming	Participation in contract farming	Yes = 1; No = 0	0.38	0.49	_	_	_	_	_	_
	Participation in quasi-integrated contract farming	Yes = 1; No = 0	0.11	0.31	_	_	_	_	_	_
	Participation in integrated contract farming	Yes = 1; No = 0	0.27	0.44	_	_	_	_	_	_

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TABLE 2 Input–output descriptive statistics.

Variable		Variable description	Whole farmers		Farmers participated in contract farming of integrated model		Farmers participated in contract farming of quasi-integrated model		Farmers not participated in contract farming	
			Mean	Standard error	Mean	Standard error	Mean	Standard error	Mean	Standard Error
Expected output	Output	Yield (Kg/hm^2)	6761.4	1678.05	7451.55	1612.65	7054.2	1419.6	6508.65	1734.9
Unexpected output	Nitrogen	Agricultural non-point source pollution emissions of nitrogen (Kg/hm^2)	106.65	43.65	115.35	45	102.15	43.35	107.4	43.5
	Phosphorus	Agricultural non-point source pollution emissions of phosphorus (Kg/hm^2)	6	2.55	6.6	2.55	5.7	2.4	6	2.4
Input factors	Seed	Seed input quantity (Kg/hm^2)	270.3	104.85	292.35	117	268.65	110.55	269.25	98.4
	Fertilizer	Fertilizer input quantity (Kg/hm^2)	538.2	220.65	567.45	233.85	523.05	219.75	543.15	218.55
	Pesticide	Pesticide input cost (Yuan/hm^2)	590.1	235.5	542.4	208.5	570.45	216.75	606.3	246.75
	Machinery	Total cost of own machinery input and hired machinery input (Yuan/hm^2)	2041.8	1223.85	2329.95	1168.65	1731	1026.15	2147.25	1291.65
	Labor	Hired and family labor input quantity (person-days/hm^2)	68.85	33.9	68.25	33.45	58.5	27.9	73.65	35.25

TABLE 3 Distribution of green technology efficiency among sample households.

Green technology efficiency	(0, 0.2]	(0.2, 0.4]	(0.4, 0.6]	(0.6, 0.8]	(0.8, 1.0]
Frequency	9	179	342	131	58
Percentage (%)	1.25	24.90	47.56	18.22	8.07

From various aspects, the basic characteristics of households in these three groups exhibit consistency in individual endowment, family endowment, and production characteristics. They all demonstrate aging, low educational attainment, low level of diversification, and a certain scale of production. Due to significant space constraints, further detailed descriptions are not provided.

The average expected output of wheat was 6,761.40 kg/hm^2. The unexpected outputs include nitrogen emissions of 106.65 kg/hm^2 and phosphorus emissions of 6 kg/hm^2. The main input factors for wheat production include seeds, chemical fertilizers, pesticides, machinery, and labor, with seed input of 270.30 kg/hm^2, chemical fertilizer input of 538.2 kg/hm^2, pesticide input of 590.10 yuan/hm^2, machinery input of 2,041.80 yuan/hm^2, and labor input of 68.85 person-days/hm^2 (Table 2). From the descriptive analysis results of each group, farmers participating in the integrated model of contract farming have the highest expected and unexpected outputs compared to other groups. However, their inputs in terms of seeds, fertilizers, and machinery are also the highest, while pesticide inputs are the lowest. Farmers participating in the quasi-integrated model of contract farming have significantly lower expected outputs compared to those in the integrated model. Additionally, their unexpected outputs and inputs in terms of seeds, fertilizers, machinery, and labor are also lower. Farmers not participating in contract farming have the lowest expected outputs, but their pesticide and labor inputs are the highest. From a descriptive analysis perspective, there are slight differences in input-output structures among the groups, necessitating the measurement of green technology efficiency levels through modeling.

3.2 Methods

3.2.1 DEA-SBM model

Agricultural green technology efficiency is considered as the production technological efficiency that includes undesirable outputs. Improving agricultural green technology efficiency implies that for a given combination of input factors, resource consumption and environmental pollution are minimized to achieve the maximal beneficial output (Hou and Yao, 2018). The value of green technology efficiency ranges between 0 and 1, with efficiency closer to 1 indicating that a production unit is nearer to the environmental production frontier.

In terms of measurement methods, stochastic frontier analysis (SFA) and data envelopment analysis (DEA) are two mainstream approaches for assessing technical efficiency. However, when stochastic frontier analysis is unable to handle situations with multiple outputs simultaneously, it tends to merge multiple outputs into a composite output for analysis, leading to significant errors. Therefore, when multiple outputs are present, the data envelopment analysis method is typically chosen to evaluate unit efficiency (Wilson, 1995). This study chooses to employ data envelopment analysis to estimate a green technology efficiency model that includes both desirable and undesirable outputs. Data envelopment analysis measures efficiency through linear programming and is a non-parametric method that does not require knowledge of the specific form of the production frontier. It can conveniently handle decision-making units with multiple outputs and avoids the structural bias caused by mis-specification of the production function in stochastic frontier analysis. Among various data envelopment models, we select the non-radial, non-angular DEA-SBM (Slack-Based Measure) model for assessing green technical efficiency. Compared to traditional CCR and BCC models within the DEA framework, the DEA-SBM model effectively addresses the issue of inefficiency measurement lacking slack variables in radial DEA models, as well as the bias stemming from radial and angular selection. It can more accurately identify inefficient decision-making units (DMUs) (Tone, 2003), thereby enhancing the accuracy of green technology efficiency measurement for the sampled farmers in this study.

The DEA-SBM model includes input variables, expected output variables, and unexpected output variables. According to the existing literature, the expected output is commonly measured by the yield of wheat (Qu et al., 2021; Gong et al., 2024). The unexpected output can be measured by agricultural non-point source pollution, primarily due to the fertilizer loss caused by irrational use and residual pollution (Ma and Tan, 2021; Bao et al., 2022). Fertilizer loss mainly contributes to non-point source water pollution through nitrogen and phosphorus emissions. The loss is calculated based on the specific usage, the equivalent pure amount, and the element content of each type of fertilizer[1]. The calculations reveal nitrogen loss at 113.76 kg/hm^2 and phosphorus loss at 6.4 kg/hm^2. With reference to the relevant literature and farmers' practices during the research, the inputs variables for wheat production include seed, chemical fertilizer, pesticide, machinery and labor.

3.2.2 Propensity score matching model

The independent variable of this study is the calculated green technology efficiency of farmers. The dependent variable is whether farmers participate in contract farming. The relationship between them is analyzed utilizing a propensity score matching

1 The loss coefficient of nitrogen is 0.655, and the loss coefficient of phosphorus is 0.326 × 43.66%. Due to the fact that the discount stock of phosphorus fertilizer refers to the amount of phosphorus pentoxide (P_2O_5), the discount stock of phosphorus fertilizer loss needs to be obtained by dividing the phosphorus loss amount by a coefficient of 43.66% (Lai et al., 2004; State Council of China, 2009).

model. Given that farmer' involvement in contract farming is not random, issues of "self-selection" due to personal choices and "endogeneity" resulting from bidirectional causality relationships arise. Therefore, the propensity score matching (PSM) method is utilized to construct a counterfactual scenario. This approach matches individuals in the treatment group with those in the control group based on the closeness of their characteristics. The individual propensity score for a farmer (i.e., the conditional probability fitting value) can be expressed as Equation (1):

$$P(L_i) = p_r[D = 1|L_i] = \frac{exp(\eta L_i)}{1 + exp(\eta L_i)} \tag{1}$$

Where p represents the propensity score to be estimated, indicating the probability of a farmer participating in contract farming; $p_r(.)$ represents the cumulative distribution function; L_i represents covariates; η represents parameters to be estimated; $D = 1$indicates participation in contract farming, and $D = 0$ indicates non-participation in contract farming.

After satisfying the common support domain and balance test, the average treatment effect on the treated (ATT), weighted by the propensity score, can be expressed as Equation (2):

$$\begin{aligned} ATT &= E[(Y_{1i} - Y_{0i})|D_i = 1] = E\{E[(Y_{1i} - Y_{0i})|D_1 = 1], P(L_i)\} \\ &= E\{E[Y_{1i}|D_i = 1, P(L_i)] - E[Y_{0i}|D_i = 0, P(L_i)]\} \end{aligned} \tag{2}$$

Where Y_{1i} is the green technology efficiency of farmers participating in contract farming, and Y_{0i} is the green technology efficiency of farmers not participating in contract farming.

In selecting control variables, primary consideration is given to the individual endowments of the household head, which reflect decision-making abilities and preferences in the contract farming process. These endowments are measured through multiple dimensions including age, educational background, experience in village administrative positions, risk attitude, and the number of training sessions attended. Secondly, the endowed conditions for a family to engage in contract farming are taken into account. Among these, the proportion of agricultural income reflects the family's economic structure and dependence on agriculture, while the size of the social network illustrates the influence of relatives and friends within the rural social context on family decisions. Finally, from the perspective of family agricultural production characteristics, the cultivation area and soil quality are selected to represent the influence of production conditions on decision-making.

4 Results

4.1 Measurement results of green technology efficiency

Based on the selected variables and model, we utilized the Max-DEA software to calculate the green technology efficiency of wheat farming households in the sample area. The calculation reveals that the mean green technology efficiency of wheat farming households is 0.5199, with a variance of 0.1836, indicating an overall low level. The lowest efficiency value is 0.0811, while the highest is 1.0000. The majority of households (47.56%) have efficiency values ranging from 0.4 to 0.6 (Table 3), indicating a generally low level of efficiency. About 26.15% of households have efficiency values below 0.4, while 26.29% have values exceeding 0.6. Only 8.07% have values surpassing 0.8. This suggests that there is significant room for improvement in the green technology efficiency of wheat farming households, indicating potential for enhancement in wheat cultivation practices.

TABLE 4 Number of lost samples in the common support domain.

Group	Common support domain		Total
	Outside common value range	Inside common value range	
Treatment group	12	437	449
Control group	2	268	270
Total	14	705	719

4.2 The impact of contract farming on green technology efficiency

Before executing propensity score matching, it is imperative to first conduct a common support domain test and a balance test. 705 observations fall within the common value range, with only 14 samples lost using nearest neighbor matching method (1-to-4 matching) (Table 4), satisfying the common support domain condition. The results (Table 5) indicate that the Pseudo R^2 is close to 0, and the LR value after matching is not rejected in four matching methods, indicating that the propensity score matching has appreciably decreased the disparities between the treatment and control groups. Following the matching process, the two sample groups (Treatment group: farmers participating in contract farming; Control group: farmers not participating in contract farming) exhibit substantial similarity across all characteristic dimensions, thereby satisfying the balance test requirements.

The estimated results of the four matching methods are consistent (Table 6). Taking the nearest neighbor matching method as an example, if farmers who have not participated in contract farming participate in contract farming, the green technology efficiency would rise from 0.4859 to 0.5863. This increase of 0.1004, or 20.66%, is statistically significant at the 1% level. Therefore, participation in contract farming has a significant enhancing effect on green technology efficiency of farmers. In comparison to independent farming, contract farming imposes specific requirements on the quantity, quality, and process of farmers' production. Additionally, it offers guidance and assistance, aiding small farmers in transitioning toward green production and addressing certain challenges encountered during this transition.

Theoretical analyses suggest that the impact of contract farming on green technology efficiency might be influenced by

TABLE 5 Balance test results.

Matching method	Pseudo R^2	*LR* value	*P*-value	Mean variance	Median variance
Before matching	0.032	30.92	0.001	8.7	8.4
Nearest neighbor matching	0.005	3.41	0.970	4.5	4.8
Kernel matching	0.001	0.64	1.000	1.6	1.6
Local linear regression matching	0.011	8.92	0.601	4.9	2.6
Radius matching	0.001	0.96	1.000	2.0	2.2

the organizational model of the contract. Consequently, this study further segregates the sub-samples based on two types of contract models and employs nearest neighbor matching method (1-to-4 matching) to compute the average treatment effect. According to the *ATT* value results of sub-samples 1 and 2 (Table 7), for farmers who did not participate in contract farming, transitioning to the quasi-integrated contract farming model would result in a green technology efficiency increase of 0.0331, though not statistically significant; conversely, transitioning to the integrated contract farming model would yield a significant increase of 0.1075 at the 1% level. The results clarify the role of organizational model evolution in promoting green production in contract farming, showing that: first, whether contract farming can improve green technology efficiency is closely related to organizational models. Participation in integrated contract farming significantly enhances green technology efficiency, whereas participation in quasi-integrated contract farming does not show a significant enhancement effect. The results indicate that the significant improvement in farmers' green technology efficiency across the entire sample (Table 6) primarily stems from the involvement of contract farming under the integrated organizational mode, rather than from contract farming under the quasi-integrated organizational mode.

TABLE 6 Average treatment effect on green technology efficiency of sample farmers.

Matching method	Treatment group	Control group	ATT
Nearest neighbor matching	0.5863	0.4859	0.1004***
Kernel matching	0.5856	0.4930	0.0926***
Local linear regression matching	0.5971	0.5007	0.0864***
Radius matching	0.5856	0.4908	0.9483***

***indicate significance at the 1% levels.

TABLE 7 Average treatment effects of different contract models on green technology efficiency of sample households.

Sample group (number of samples)		Custodial features	Mean	*ATT*
Subsample 1	Treatment Group (194)	Participating in quasi-integrated contract farming	0.5636	0.0331
	Control Group (447)	Not participating in contract farming	0.5305	
Subsample 2	Treatment Group (76)	Participating in integrated contract farming	0.5939	0.1075***
	Control Group (449)	Not participating in contract farming	0.4864	

***indicate significance at the 1% levels.

4.3 Robustness test

Since the green technology efficiency of farmers are strictly bounded between 0 and 1, they are considered censored variables. Therefore, the IV-Tobit regression model is used to examine the robustness of the impact of farmers' participation in contract farming on green technology efficiency. To address the endogeneity problem of participating in contract farming, the "proportion of other farmers in the same village participating in contract farming" is chosen as an instrumental variable (IV) which is correlation and exogeneity.

The Wald values for the weak instrumental variable test in the three IV-Tobit models are 5.62, 5.76, and 17.87, respectively, each surpassing the threshold critical value required to reject the weak IV hypothesis at the 5% significance level. Furthermore, in the first stage regression, the instrumental variables are significant at the 1% level, indicating the absence of weak IV issues. The IV-Tobit regression results (Table 8) reveal that participation in contract farming and integrated contract farming has a positive impact and is significant at the 5% level, while participation in quasi-integrated contract farming has a positive impact but is not significant. The results suggest that contract farming, overall, has a positive impact on the green technology efficiency of farmers. However, the enhancement effects vary between the two contract farming models; specifically, the promotion effect of the integrated mode is significant, whereas the promotion effect of the quasi-integrated mode is not. Collectively, these results align with the findings derived from the propensity score matching analysis.

TABLE 8 IV-Tobit model estimation results.

Variable	First stage regression		Second stage regression	
	Standard error	Coefficient	Standard error	Coefficient
Participation in contract farming			0.2657***	0.0713
Proportion of other farmers in the village participating in contract farming	0.3316***	0.0567		
Control variables	Controlled	Controlled	Controlled	Controlled
Participation in quasi-integrated contract farming			0.7050*	0.3655
Proportion of other farmers in the village participating in quasi-integrated contract farming	0.0890**	0.0343		
Control variables	Controlled	Controlled	Controlled	Controlled
Participation in integrated contract farming			0.2107***	0.0296
Proportion of other farmers in the village participating in integrated contract farming	0.6638***	0.0387		
Control variables	Controlled	Controlled	Controlled	Controlled

*, **, ***indicate significance at the 10%, 5%, and 1% levels, respectively.

TABLE 9 Multiple-mediation model results.

Mediating effect		Coefficient	Confidence Interval	
Quasi-integrated contract farming				
Direct effect		0.0331	0.0028	0.0913
Parallel indirect effects	Level of productive service	0.0077	0.0011	0.0171
	Degree of land consolidation	0.0037	−0.0051	0.0229
Total effect		0.0445	0.0252	0.1038
Integrated contract farming				
Direct effect		0.0566	−0.0021	0.0852
Parallel indirect effects	Level of productive service	0.0154	0.0092	0.0266
	Degree of land consolidation	0.0322	0.0236	0.0485
Total effect		0.1042	0.0507	0.1373

TABLE 10 Moderation-effect model results considering endogeneity.

Variable	Coefficient	Standard Error	Z-Value
Quasi-integrated contract farming			
Quasi-integrated contract farming	0.0537	0.0605	0.8900
Quasi-integrated contract farming ×percentage above local average selling price	−0.0004	0.0004	−1.0900
Percentage above local average selling price	0.0003**	0.0001	2.1500
Control variables	Controlled	Controlled	Controlled
Integrated contract farming			
Integrated contract farming	0.0819	0.0950	0.86
Integrated contract farming ×average dividend income	0.8221***	0.3144	2.61
Average dividend income	3.0611**	1.4470	2.12
Control variables	Controlled	Controlled	Controlled

**, ***indicate significance at the 5% and 1% levels, respectively.

TABLE 11 Threshold model regression results.

Contract farming model	Coefficient 1	Standard error	Coefficient 2	Standard error
Quasi-integrated contract farming	−0.0107	−0.44	0.2230***	3.72
Integrated contract farming	0.0837***	5.41	0.2410***	6.98

***indicate significance at the 1% levels.

4.4 Mediation path analysis of the impact of participation in contract farming on green technology efficiency

According to theoretical analysis, the variable "level of productive service" measured by the number of productive service items provided by contract farming is used to measure the intensification level of farmers' production[2]. The variable "degree of land consolidation" measured by average contiguous operation area of land (in hm^2) is used as a variable to measure the degree of land consolidation of farmers. With the coexistence of these two mediating variables, a parallel multiple mediation model is devised for the analysis. Compared to the standard mediation model, the multiple mediation model offers the benefit of ameliorating biases in parameter estimation due to the concurrent influence of multiple variables.

The average number of productive service items provided by the integrated contract farming model is 2.72, while the average number in the quasi-integrated model is 3.98. The integrated model's average contiguous operational land area measures 0.0947 hm^2, while for the quasi-integrated model, it spans 0.2573 hm^2. The Bootstrapping method (5,000 iterations) is employed to evaluate the mediating effects (Preacher and Hayes, 2008), which provides a 95% confidence interval estimate. The interval estimate includes 0 indicating that the mediating effect is not significant; otherwise, the mediating effect is significant. The results (Table 9) show that in the quasi-integrated model, the mediating value of the productive service level is 0.0077 and is significant at the 5% level, while the mediating value of the degree of land consolidation is 0.0037 but not significant. In the integrated model, the mediating value of the productive service level is 0.0154 and is significant at the 5% level, while the mediating value of the degree of land consolidation is 0.0322 and is significant at the 5% level.

The results suggest that the "level of productive service" and the "degree of land contiguity" serve as mediating variables in the impact of contract farming on farmers' green technology efficiency, exhibiting distinct mediating effects in integrated and quasi-integrated models. In the integrated model, farmers' green technology efficiency is enhanced through two mediating pathways: the formation of contiguous production scales and the provision of productive services. Conversely, the quasi-integrated model improves green technology efficiency solely through the pathway of providing productive services.

4.5 The moderating effect of economic incentives on the pathway through which contract farming affects green technology efficiency

To measure the moderating effect of the purchase price in the quasi-integrated contract farming model on the enhancement of green technology efficiency by contract farming, the "percentage above local average selling price" is employed as a moderating variable. The average purchase price for farmers in the sample last year was 5.11% higher than the local average selling price of wheat. A two-stage least squares (2SLS) method with IV is used for the moderation effect analysis. The LM value is 25.433, which strongly rejects the null hypothesis of unidentifiability at the 1% significance level. The Cragg-Donald Wald F statistic is 12.95, which exceeds the critical value for 10% bias and rejects the null hypothesis, suggesting no weak instrumental variable problem. The interaction term is negative and not significant in the results (Table 10), implying that economic incentives do not strengthen the promotional effect of contract farming on green technology efficiency of farmers.

To evaluate the impact of dividend income in the integrated contract farming model on enhancing green technology efficiency, "average dividend income" is employed as a moderating variable. The average dividend income for sample farmers last year was 1019.25 Yuan/hm^2. The LM value is 28.305, which strongly rejects the null hypothesis of unidentifiability at the 1% significance level. The Cragg-Donald Wald F statistic is 14.560, which exceeds the critical value for 10% bias and rejects the null hypothesis, suggesting no weak instrumental variable problem. The results (Table 10) demonstrate that the interaction term in the moderation model is positive and significant at the 5% level, indicating that dividend income significantly enhances the positive impact of contract farming on green technology efficiency.

To further clarify the role of purchase price and dividend income in the impact of contract farming on green technology efficiency, a threshold model is employed to separately analyze the incentive effects in the two contract models. The results (Table 11) show that in the quasi-integrated model, the single threshold model F value is 13.983. The estimated threshold value is 0.193, indicating that when the purchase price increase is below 19.3%, the coefficient of the impact of participation in contract farming on green technology efficiency is−0.0107 and not significant; however, when the purchase price increase exceeds 19.3%, the coefficient becomes 0.2230. This implies that an insufficient price increase does not promote the improvement of green technology efficiency

2 Production service related to green technology efficiency production include: (1) Free provision of seeds, chemical fertilizers and pesticides; (2) Green prevention and control technology services; (3) Standardized fertilization services; (4) Unified land preparation services; (5) Unified harvesting services; (6) Systematized drip irrigation services; (7) Technical consultation services.

and may even provoke opportunistic behavior among farmers. In the integrated model, the single threshold model F value is 19.160. The estimated threshold value is 8208Yuan/hm^2. When the dividend income is below this threshold, the coefficient is 0.0837 and significant at the 1% level; when the dividend income exceeds this threshold, the coefficient amplifies to 0.2410, indicating that the higher the dividend income, the stronger the incentive effect on improving green technology efficiency.

The results indicate that in quasi-integrated contract farming, only a contract purchase price exceeding the local average wheat selling price by more than 19.3% strengthens the enhancement of green technology efficiency. In integrated contract farming, farmers' dividend income intensifies the enhancement of green technology efficiency, with greater dividends correlating with a stronger moderating effect.

5 Discussions and conclusions

Since the organizational model of contract farming relates to the control over the farmers' production process, this study employs propensity score matching method to investigate the impact effects of two types of contract farming on the green technology efficiency of farmers based on survey data of 719 wheat growers in Shandong Province in China. The mediation pathway of two types of contract farming on the green technology efficiency is further analyzed using a mediation model from two dimensions of land contiguity and productive service. The moderating role of economic incentives in the process of enhancing green technology efficiency in both types of contract farming is analyzed using multiple mediation model.

While previous studies generally recognize that farmer participation in contract farming can enhance levels of green production, they often overlook the role of organizational structure in this process. By examining the distinctions between integrated and quasi-integrated models in contract farming, this study contributes additional insights to the existing literature. The findings indicate that not all forms of contract farming lead to improvements in farmers' green technology efficiency. Specifically, the integrated industrialized organizational model demonstrates a significant enhancement in the level of farmers' green technology efficiency, whereas the effect of the quasi-integrated model is not statistically significant. This conclusion prompts a discussion on the relationship between industrialized organizational models of contract farming and farmers' engagement in green production. Drawing from the results of the impact pathway analysis, it is inferred that the integrated organizational model enhances farmers' green technology efficiency through several mechanisms, including the establishment of contiguous large-scale production bases, provision of productive services, and offering competitive procurement prices. Under this model, there is effective control over farmers' input-output and field management practices. Conversely, farmers' green technology efficiency remains unaffected in the quasi-integrated model. Even when collaborating with industrialized organizations, farmers may not actively pursue green production if they retain decision-making authority. In situations where farmers lack control, providing economic incentives may inadvertently encourage opportunistic behavior, leading farmers to prioritize high yields over product quality.

It can be inferred that the potential for contract farming to enhance farmers' green technology efficiency hinges on the establishment of a closely integrated organizational model. Consequently, the primary entity and its organizational framework that facilitate contract farming play a pivotal role. Beyond merely signing production contracts with farmers, it is imperative for these entities to possess the capacity to organize farmers and implement integrated management of production and operations. Therefore, in the promotion of contract farming, attention should not only be directed toward the willingness of both parties to participate but also toward the organizational model underpinning contract farming.

To harness the potential of contract farming in promoting green production among farmers in developing countries, active promotion of the integration of organizational models is imperative. The policy recommendations outlined in this study are as follows: Firstly, agricultural enterprises must be empowered to spearhead the development of industrialized integrated models. Therefore, it is essential to provide support for the growth and expansion of agricultural enterprises. Governments should offer loans for the construction of contract production bases, addressing issues such as the difficulty in obtaining loans and the inadequate loan amounts available to agricultural enterprises. This support will enable more enterprises or cooperatives to expand their scale and engage in integrated operations, thereby becoming leaders in contract farming. Secondly, to facilitate the implementation of integrated contract farming by enterprises, it is crucial to establish a platform that facilitates land transfer and enables the creation of contiguous land bases to realize scale effects effectively. Thirdly, governments need to aid in optimizing the cooperation mechanism between enterprises and farmers for contract farming. Acting as a third party, the government can monitor the fulfillment of commitments such as dividends. Meanwhile, enterprises should prioritize technological advancement and efficiency enhancement in the development of productive services. This approach will drive the green transformation and advancement of farmers' production by providing services related to green technology, industrial systems, and material equipment.

Despite its theoretical and practical contributions, the study also has some limitations. First, the differentiation of organizational models is dichotomized into only two primary types, which may oversimplify the complexities of organizational structures in contract farming. Secondly, the study is based on a cross-sectional design, limiting the ability to establish causal relationships and potentially overlooking temporal dynamics. Future studies may use longitudinal designs to enhance the generalizability of the empirical findings and capture changes over time.

Building upon the insights provided in this article, future studies aiming to delve deeper into the relationship between industrialized organizational models in contract farming and farmers' green technology efficiency should consider exploring differences among various models. In practical terms, organizational models can be further categorized based on factors such as the presence of intermediary organizations, shareholding structures, and other pertinent variables for conducting heterogeneity analysis. Equally worthy of future research is the exploration of how, within the quasi-integrated model, the introduction of incentives or controls can enhance the model's efficacy in driving farmers' green transformation.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.

Author contributions

QL: Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Software, Resources, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization. ZW: Writing – review & editing, Investigation.

Funding

The author(s) declare that financial support was received for the research, authorship, and/or publication of this article. This study was supported by the National Social Science Foundation Project of China (No. 23BGL207).

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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