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Contract farming and pro-environmental behavior: insights from beef cattle farmers

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Introduction: Facilitating and motivating farmers to adopt standardized pro-environmental production technologies serve as a solution to agricultural surface pollution. Moreover, this approach represents a crucial strategy for promoting low-carbon sustainable development in the farming sector. However, despite the potential of pro-environmental production techniques to facilitate this objective, the adoption rate among Chinese beef farmers remains suboptimal.

Methods: This study empirically examines the influence and mechanisms of contract farming on farmers' pro-environmental behaviors by considering survey data from Chinese beef cattle farmers analyzed using an ordered probit model. To enhance our understanding, we explore the effects of contract farming on various pro-environmental production technologies under different constraints.

Results: The findings reveal that contract farming significantly fosters pro-environmental behaviors among farmers, particularly through enhanced participation in resource-providing contracts. Anticipated economic and ecological benefits and access to information have emerged as critical mediators of the relationship between contract farming and pro-environmental behaviors. Heterogeneity analysis indicates that the impact of contract farming on the adoption of diverse pro-environmental production technologies varies among farmers. Additionally, contract farming exhibits differential effects on the pro-environmental behaviors of various farmer cohorts, influenced by factors such as specific investment, farm size, training frequency, and environmental regulations.

Discussion: This study explores the role of farmers' participation in contract farming in promoting pro-environmental behaviors amidst environmental challenges in the context of beef cattle farming. Due to limitations in data availability and the geographical scope of the study, we have not included a more detailed discussion of the mechanisms or specific implications for other relevant stakeholders. Overall, the findings of this study not only provide new insights into strategies to encourage farmers to engage in pro-environmental behaviors, but also entry points for further research to enhance current environmental policies and promoting the large-scale development of the beef cattle industry. The results of this study indicate that the promotion of pro-environmental behaviors among farmers can be achieved by encouraging them to participate in contract farming. This approach aims to optimize and improve current environmental policies, thereby facilitating the joint promotion of scale and specialization in the beef cattle industry.

KEYWORDS

contract farming, pro-environmental behavior, beef cattle farmers, sustainable development, influence mechanism

1 Introduction

Agriculture is a critical anthropogenic factor that contributes to environmental issues, including greenhouse gas emissions, soil contamination, and deterioration of water quality. Although the rapid advancement of agricultural practices has increased production and enhanced human sustenance, it has resulted in significant surface pollution challenges (Zhang W. et al., 2023; Zhang Y. et al., 2023). Furthermore, agrarian surface pollution threatens the ecological integrity, environmental security, and sustainable development of agriculture on a global scale (Wang X. et al., 2023; Wang Y. et al., 2023; Rosa et al., 2020). There are several concerns among governments, regulatory bodies, enterprises, and stakeholders across multiple nations regarding these environmental impacts, which have led to considerable mitigation initiatives to address these challenges. Over the last four decades, the evolution of rural society in China has significantly advanced agricultural modernization and stimulated economic growth within the farming sector. However, the rapid expansion of agricultural production has resulted in a decline in the ecological integrity of rural environments (Hu et al., 2020). Animal husbandry is a primary contributor to agrarian carbon emissions. Additionally, the waste generated from animal husbandry is a critical factor in surface pollution, with untreated effluents leading to issues such as eutrophication of surface waters, unpleasant odors, and proliferation of pests and diseases (Cheng et al., 2023). Furthermore, as the principal actors in the resource management of livestock waste, farmers represent the foundational elements and are pivotal in implementing pro-environmental technologies. Thus, there is a need to explore solutions to mitigate agricultural pollution while simultaneously preserving or enhancing the quality of livestock products during the sustainable advancement of agricultural output. This can help accelerate the agricultural transformation toward greater quality and efficiency, bolstering the sustainability of the sector.

Scholars from different countries have investigated various programs and practices that may enhance the efficient use of livestock manure resources by agricultural producers. First, the production side perspective. The existing research has examined the impact of farmers' individual attributes, along with their production and management practices, on their pro-environmental behaviors (Gholamrezai et al., 2021; Li et al., 2022; Han et al., 2023). The pro-environmental behavior of farmers can be significantly strengthened by improving their ecological awareness and providing policy subsidies (Jin et al., 2021; Jacobs et al., 2023). As the trend of large-scale farming becomes more apparent, diversified support measures for different scales and enhanced government guidance have become important means to enhance farmers' pro-environmental behaviors (Dróżdż et al., 2020; Li et al., 2021; Yin et al., 2024a, 2024b). Secondly, from the governmental side perspective. Given the public goods nature of pro-environmental behavior, farmers' behavior may be subject to adverse selection and moral hazard (Li et al., 2020; Bist et al., 2024), implying the necessity for governmental environmental regulation to mitigate these issues. The government's current approach involves the implementation of regulatory measures, including command-and-control measures and economic incentives, to modify farmers' behavior (Koul et al., 2022; Vaishnav et al., 2023). Thirdly, the market side perspective. Adhering to the market-oriented operation approach with enterprises as the main body, there is a push to accelerate the development of socialized service organizations for the return of manure to fields. Thereby providing farmers with resource management facilities and technical services through the marketization of outputs and production services, ultimately fostering pro-environmental behaviors among farmers (Milliet et al., 2023; Ahmed et al., 2024).

Farmers serve as focal points for interventions to mitigate surface pollution and as both implementers and beneficiaries of pro-environmental behaviors. Initially, pro-environmental behavior was mostly used in sociology and psychology. It is defined as actions undertaken by individuals in their productive endeavors that reduce adverse effects on the ecosystem or enhance ecological conditions, thereby fostering the sustainable development of both the economy and the environment (Kollmuss and Agyeman, 2002; Cheng and Monroe, 2012). Research on pro-environmental behaviors in animal husbandry has primarily focused on the breeding processes, particularly on external conditions such as technical training, external constraints, and environmental regulations (Gholamrezai et al., 2021; He et al., 2025) and psychological factors such as ecological cognition, psychological cognition and risk perception (Evangelista et al., 2024; Vaishnav et al., 2023). Most pro-environmental behaviors of farmers are centered on grassland protection, grass-animal balance, and livestock reduction behaviors (Wang et al., 2025). Accordingly, this study argues that pro-environmental production behavior involves the adoption of scientific reduction, recycling, and environmentally friendly agricultural business models by agricultural production entities. As pro-environmental behavior is an attribute of public goods, challenges such as adverse selection and moral hazard emerge in farmers' actions, which are closely linked to governmental environmental regulations (Kulin and Johansson Sevä, 2021). The government uses various regulatory strategies, including command-and-control measures and economic incentives, to encourage changes in farmers' pro-environmental behavior (Lu et al., 2022; Zeng et al., 2024). Most studies have focused on the effects of regulatory penalties, policy subsidies, and other singular approaches on the pro-environmental behavior of farmers (Barreiro-Hurle et al., 2023; Canessa et al., 2024). While there are studies on pro-environmental behavior among traditional microoperators, studies specifically targeting beef cattle farmers are limited. The trends of scale and intensification in China's animal husbandry have led to increased ecological pressures from the concentrated discharge of agricultural waste. This is in contrast with the pro-environmental behavior mechanisms seen in crop farmers, who primarily use chemical fertilizers, a major source of surface pollution. Therefore, explaining the formation mechanism of farmers' pro-environmental behavior from the perspective of contract farming has theoretical significance and practical value for promoting high-quality development of animal husbandry.

Contract farming exerts exemplary normative pressure on farmers' pro-environmental behavior. Currently, the demand for beef in China is rising annually, while beef production is lagging, exacerbating the supply–demand imbalance. Despite the continuous enhancement of beef cattle production, China's beef cattle breeding remains predominantly characterized by retail operations and small-to-medium-sized farms. This reflects a "small group, large-scale" production paradigm. Consequently, the amount of manure and wastewater generated from these agricultural activities has steadily increased annually (Jing et al., 2023). The substantial farming waste that is either directly discharged or improperly disposed off poses a grave threat to the rural ecological environment and impedes the sustainable development of the agricultural economy (Hu et al., 2017). Conversely, this farm waste represents a significant untapped resource, often called a "misplaced resource," its effective utilization could mitigate the scarcity of agricultural resources in China (Vaishnav et al., 2023). In the beef cattle industry, the "firm+farmer" model of contract farming typically involves a collaborative arrangement between beef cattle producers, processors, and farmers, wherein a legally binding production and marketing contract is established under specified conditions. Farmers are then tasked with raising a predetermined quantity and quality of cattle by contract, adhering to stipulated conditions regarding transaction prices and farming processes (Dubbert et al., 2023). As an institutional framework, contract farming enhances the linkage between farmers and larger markets, facilitating the transition to greener production methods through specialization and resource input advantages, thereby effectively fostering pro-environmental behaviors (Ma et al., 2023). Farmer participation in contract farming promotes the recycling and transformation of agricultural waste to optimize resource utilization and achieve a dual enhancement of economic and environmental outcomes (Vorlaufer et al., 2023). Although contract farming plays a significant role in facilitating green technology adoption, its influence on farmers' adoption of pro-environmental behaviors has received little attention in literature. This study extends the findings of previous studies and explores whether contract farming can facilitate an increase in the adoption of pro-environmental behaviors among farmers, including input reduction, harmless treatment of sick and dead animals, manure resource utilization, farm standardization, and sanitary and epidemiological measures.

This study examined the influence of farmers' participation in contract farming on their pro-environmental behavior. We analyzed 560 data points collected from beef cattle farmers in three Chinese provinces (Jilin, Liaoning, and Hebei). By doing so, we make three contributions to the literature: First, while several studies have primarily conducted comparative analyses between contract and non-contract farmers, few have explicitly differentiated the impacts of various contractual arrangements within contract farming on farmers' pro-environmental behavior. Second, it assesses the direct effects of contract farming on farmers' pro-environmental behavior. Moreover, we evaluated the indirect effects of contract farming on farmers' pro-environmental behaviors through the mediating paths of expected returns and information acquisition. Finally, in addition to estimating the impact of contract farming on the full sample, we investigated the variations in the effects among distinct types of contract farming, diverse pro-environmental behaviors, and the influence of farmers' engagement in contract farming on their pro-environmental behaviors under various constraints, thereby offering enhanced insights to enrich our comprehension.

The rest of the paper is organised as follows. Section 2 introduces the theoretical framework and research hypothesis. Materials and methods are presented in Section 3. Section 4 presents and discusses the empirical results. The final section concludes the paper and proposes the policy implications.

2 Theoretical framework and research hypothesis

The theory of rational behavior of farmers states that beef cattle farmers, as micro-management subjects, have the attributes of, "economic man" (Chatzimichael et al., 2022). Beef cattle farmers decide whether and how to implement pro-environmental behaviors to maximize their profits. Pro-environmental behaviors are characterized by high costs, long action periods, and slow benefits. According to producer decision-making theory, farmers' pro-environmental behaviors result from cost–benefit analysis and weighing and directly affect their behavioral decisions. Currently, animal husbandry in China is transitioning from a labor-intensive to a capital- and technology-intensive model, characterized by lengthy breeding cycles, slow capital turnover, elevated costs, high resource consumption, and substantial pollution levels (Liang et al., 2023). Beef cattle breeding activities are dominated by smallholder farmers and medium-sized agricultural enterprises, which are characterized by part-time, large-scale, specialized, and division of labor. With the continuous development and innovation of China's agrarian management system, contract farming has become the dominant mode of China's industrialized agricultural management, playing an important role in realizing the organic connection between smallholder farmers and modern agricultural development (Zhang W. et al., 2023; Zhang Y. et al., 2023). Contractual types in contract farming present, with significant differences in production services, credit arrangements, transaction methods, and pricing mechanisms. Accordingly, we investigate the impact of three types of contractual arrangements (marketing contract, production-management contract, and resource-providing contract) on the pro-environmental behaviors of beef cattle farmers in the "firm+farmer" type of contract farming (Arouna et al., 2021).

The implementation of pro-environmental behaviors by farmers involved in different types of contract farming may differ markedly. In marketing contracts, beef producers and processors delineate the transaction's price, quantity, timing, and product specifications as farmers' autonomy in production and operational decisions. To safeguard the quality premium and uphold the enterprise's reputation, marketing contracts establish an institutional framework that promotes "high quality and fair price," enhances product quality and safety information transparency, and facilitates quality oversight of livestock products. This approach aims to mitigate moral hazard and adverse selection among farmers, incentivizing pro-environmental behaviors (Mishra et al., 2020). In the production-management contract, beef cattle production and processing firms dictate production methodologies, and farmers raise cattle that conform to established standards, thus reducing technical uncertainty through process optimization. By strictly controlling the inputs of farmers' production factors, this model ensures quality control from the production source, secures the quality premium, and motivates farmers to engage in green production practices to maximize returns (Wang et al., 2014). Concurrently, the "high quality and fair price" operational mechanism generates continuous economic incentives for transitioning production methods, thereby enhancing farmers' pro-environmental behaviors. In resource-providing contracts, beef cattle producers and processors extend credit for essential farming inputs alongside financial and technical assistance to secure a specified quantity and quality of beef cattle. Smallholder farmers often face barriers in acquiring green production machinery and technology owing to financial limitations, size constraints, and technical challenges. However, participation in resource provision contracts can alleviate these endowment constraints and bolster farmers' levels of organization (Ton et al., 2018). Additionally, beef cattle production and processing enterprises offer high-quality production inputs on credit to farmers, thereby minimizing their capital investment, alleviating financial burdens, and facilitating the adoption of pro-environmental behaviors, ultimately leading to enhanced production efficiency and the transformation of production methods (Oyinbo and Hansson, 2024). In general, regardless of the type of contract farming involved, it can provide farmers with a good market environment through the more effective adoption of new technologies, knowledge spillover effects, guaranteed purchase prices, and access to external markets, which is conducive to enhancing their pro-environmental behaviors. Hence, we propose that:

> *H1*: Contract farming positively influences farmers' pro-environmental behavior; however, the effects vary across different types of contract farming arrangements.

Individual behavioral choices under uncertain conditions may be shaped by the anticipated benefits of the outcomes and their likelihood of occurrence. However, the impact of pro-environmental behaviors is hindered by financial constraints, limitations in production scale, technological obstacles, and deficiencies in infrastructure, which complicate farmers' ability to delineate the tangible effects of green technology (Kronrod et al., 2023). Therefore, farmers' subjective assessments of the expected benefits and probability of technological effects play a crucial role in shaping their pro-environmental behaviors. Expected gain pertains to farmers' anticipation of the benefits of adopting pro-environmental behaviors. New institutional economics posits that human motivation is dual-faceted, encompassing both wealth maximization and non-wealth objectives, leading farmers to consider economic and ecological benefits (Jennings and Zandbergen, 1995). Thus, we classify the expected returns into two categories: expected economic benefits and expected ecological benefits. The expected financial benefits are the economic income expectations after farmers implement pro-environmental behaviors. Expected ecological benefits refer to the beneficial and favorable effects on farmers' production and life owing to the improvement of agroecosystems after implementing pro-environmental behaviors.

Farmers' anticipations of pro-environmental behaviors are influenced by their understanding of green production technologies and available information. Contract farming is a robust risk management strategy that mitigates market risks and uncertainties in returns that farmers encounter, while lowering the costs associated with risk aversion. This mechanism incentivizes farmers to adopt more efficient production methods by ensuring a stable income (Chen and Chen, 2021). Participation in contract farming improves farmers' endowment constraints, bolsters their degree of organization, and enables them to leverage economies of scale, thereby facilitating the reintegration and allocation of capital, labor, and other production factors. This leads to improved contributions from factor inputs and synergistic effects, ultimately enhancing the anticipated economic benefits (Kopp et al., 2024). Furthermore, participation in contract farming alleviates technical and informational barriers faced by farmers. On the one hand, it functions as a conduit for both material and knowledge capital, introducing high-value capital and advanced technologies into the production process. This not only satisfies the technical requirements of farmers but also alleviates the problems of high risk, elevated costs, and inadequate technical management capabilities associated with technology adoption, thereby fostering the dissemination and uptake of innovative practices (Aprile and Fiorillo, 2023). On the other hand, farmers participating in contract farming may learn about various kinds of knowledge, including large-scale farming, the use of feeds and veterinary medicines, understanding of product quality standards, and keeping abreast of market demand. The expertise and experience shared by beef cattle farmers and processors enhance contract farmers' production and management skills, yielding benefits that extend to other business ventures. Consequently, the heightened awareness of responsibility stemming from a deeper understanding of ecological and environmental issues among farmers will likely foster pro-environmental behaviors (Bukchin and Kerret, 2020). In summary, contract farming effectively mitigates farmers' risk and technical and informational constraints while reinforcing their understanding of pro-environmental behavior. Thus, it promotes the formation of pro-environmental behavior of farmers, thereby enhancing the anticipated increases in production, income, and ecological sustainability within the beef cattle sector. Hence, we propose that:

> *H2*: Expected benefits serve as a mediating effect influencing the relationship between contract farming and the pro-environmental behaviors of farmers.
> *H2a*: Expected economic benefits serve as a mediating effect influencing the relationship between contract farming and the pro-environmental behaviors of farmers.
> *H2b*: Expected ecological benefits serve as a mediating effect influencing the relationship between contract farming and the pro-environmental behaviors of farmers.

Information acquisition capacity refers to the ability of farmers to effectively recognize, digest, and apply relevant information in beef cattle farming. This capability can significantly influence farmers' pro-environmental behaviors by enhancing their cognitive abilities and resource allocation skills, which are two critical dimensions. On the one hand, robust information acquisition capacity enables farmers to accumulate knowledge related to agricultural technologies and gain experience in beef cattle breeding, thereby facilitating a comprehensive understanding of the benefits of green farming technologies in boosting beef production and minimizing costs (Liao and Chen, 2017). This understanding fosters the development of pro-environmental behaviors among farmers. On the other hand, farmers with stronger information acquisition skills can integrate resources more efficiently across various contexts, leveraging insights

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gained from green farming technologies to optimize resource allocation in beef cattle farming (Toma et al., 2018). Additionally, enhanced resource allocation capabilities can mitigate the constraints imposed by factor endowments on the adoption of green farming practices, further promoting pro-environmental behaviors. Moreover, technical guidance, training, and sharing of market information provided through contract farming can alleviate farmers' informational constraints and reduce their risk aversion, thereby addressing the challenges of resource allocation failures and uncertainties in technology adoption stemming from insufficient information (Milliet et al., 2023). Consequently, this support enhances the accumulation of technical knowledge and experience among farmers while expanding their information acquisition channels, ultimately leading to a more optimized structure of technological information allocation (Khataza et al., 2018). Overall, contract farming is pivotal in bolstering farmers' information acquisition capabilities, fostering knowledge spillover effects, and encouraging pro-environmental behaviors. Hence, we propose that:

> *H3*: Information acquisition serve as a mediating effect influencing the relationship between contract farming and the pro-environmental behaviors of farmers.

This study incorporates contract farming, expected benefits, information acquisition, and pro-environmental behavior within a unified analytical framework, as illustrated in Figure 1. In particular, we investigate the direct influence of contract farming on farmers' pro-environmental behavior and the indirect effects mediated by expected benefits and information acquisition.

3 Materials and methods

3.1 Data source

The data used in this study were obtained from a household survey conducted in rural China between December 2023 and March 2024. Due to budgetary constraints and other practical reasons, the data were collected from questionnaires by the project team from three provinces: Jilin, Liaoning, and Hebei. The surveyed regions were classified as northeastern and central advantageous national beef cattle production areas. They are characterized by more farmers engaged in beef cattle production with a higher degree of organization, making them more representative and targeted. The survey collected basic information on farmers, beef cattle farming operations, participation in contract farming, and other aspects. A total of 582 questionnaires were obtained in this study, excluding questionnaires with missing data and logical errors, and 560 valid questionnaires were received, with the validity rate of the questionnaires being 96.22%.

3.2 Variable definitions

3.2.1 Dependent variables

The dependent variable in this study was pro-environmental behavior. Combined with related research, this study defines pro-environmental production behavior as the resourcefulness, minimization, and harmlessness behaviors adopted by beef cattle farmers to reduce the pollution of the surrounding agricultural environment, water bodies, and other pollutants caused by their production and to promote the sustainable development of the agricultural ecological economy and society. To assess the pro-environmental behaviors of farmers, the quantity of pro-environmental production technologies implemented during the actual farming process was used as the dependent variable. Specifically, the actual pro-environmental behaviors include input reduction (the implementation of feed additives and the reduction of veterinary pharmaceutical inputs), harmless treatment of sick and dead animals (the implementation of non-detrimental management practices for diseased and deceased livestock), manure resource utilization (the implementation of composting and fermentation processes, the reintegration of manure into the soil, and the generation of organic fertilizers are conducted), farm standardization (availability of standardized farm facilities), and sanitary and epidemiological measures (financial investment in disease prevention and control in beef cattle farming) in five aspects.

3.2.2 Independent variables

The independent variables in this study were contract farming, marketing contract, production-management contract, and resource-providing contract. As this study focuses on the mechanism of contract farming on farmers' pro-environmental behaviors and the

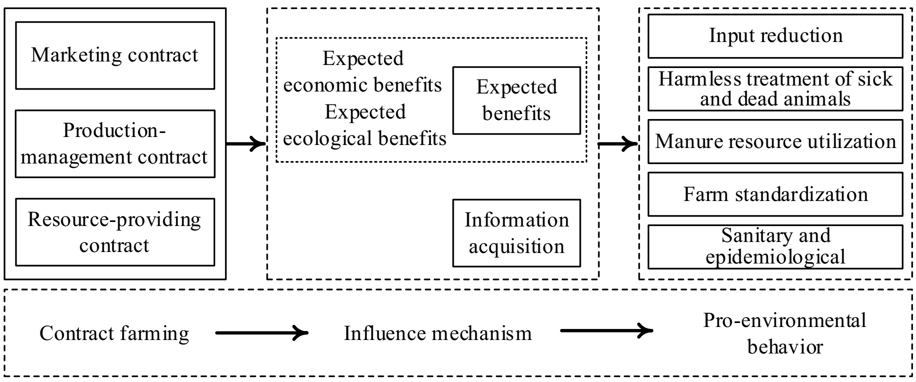

FIGURE 1
Mechanisms of contract farming's influence on farmers' pro-environmental behavior.

effects of participation in different contract farming types on farmers' pro-environmental behaviors, contract farming and the three types of contract farming were set as dummy variables. If the sample farmers participated in contract farming, marketing contract, production-management contracts, and resource-providing contracts, the value was assigned as 1. If the sample farmers did not participate in contract farming, the value was assigned as 0.

3.2.3 Mediating variable

The mediating variables in this study were expected economic benefits, expected ecological benefits, and information acquisition to examine the role of contract farming in promoting farmers' pro-environmental behaviors through expected benefits and information acquisition. Expected economic benefits refer to farmers' expectations of their economic income after implementing pro-environmental behaviors. In the case of more stable beef cattle prices, farmers' income comes mainly from changes in beef cattle production. Therefore, according to the basic situation in rural areas, the question "whether the adoption of pro-environmental production technology is beneficial to your family's production and income, taking into account the costs and benefits" is used to reflect this indicator. The questionnaire is designed using a five-point Likert scale, which categorizes farmers' perceptions into five levels: "very unfavorable, somewhat unfavorable, neutral, somewhat favorable, and very favorable," with corresponding values assigned from 1 to 5.

The expected ecological benefits are mainly expressed in the improvement of agroecological environments and ecosystems as a result of farmers' pro-environmental behaviors. Therefore, based on the rural context, the indicator is reflected in the question "Does the adoption of pro-environmental production technologies contribute to environmental protection and air pollution prevention?." The design of the questionnaire is the same as above.

Information acquisition refers to the ability of farmers to acquire information based on tools that can influence their ecological cognition by reducing information asymmetry and receiving information feedback. For the measurement of information acquisition, this study used the question "How quickly can you adjust the existing production methods according to the new technology and knowledge" to reflect this indicator according to the basic rural situation. The questionnaire is designed using a five-point Likert scale, which categorized the farmers' cognitive situation into five levels of "strongly disagree, disagree, neutral, agree, and strongly agree," with corresponding values assigned from 1 to 5.

3.2.4 Control variables

Drawing on existing research results and considering the actual situation of the sample area and the characteristics of production activities in beef cattle farming, this study selected beef cattle farmers' individual characteristics, household endowment characteristics, and production and business characteristics as control variables. To clarify the mechanism of contract farming's influence on farmers' pro-environmental behavior and the impact of participating in different contract farming types on farmers' pro-environmental behavior. Individual characteristics included age, gender, education, health, and village cadre; household endowment characteristics included breeding number, training time, breeding years, and farm size; and production and business characteristics included specific investments and ease of selling beef cattle. The results of descriptive statistics of specific variables were shown in Table 1.

Descriptive statistics, as detailed in Table 1, reveal that 63.7% of the surveyed farmers engaged in contract farming. The distribution across contract types indicates that 31.3% participated in marketing contracts, 19.5% in production-management contracts, and 14.5% in resource-providing contracts, highlighting a notable heterogeneity in contractual arrangements. The adoption of pro-environmental production technologies in beef cattle farming, quantified by a mean value of 2.845, suggests variability in the extent of technology adoption among individual farmers. Regarding mediating variables, the mean values for expected economic benefits (3.860) and expected ecological benefits (4.098) demonstrate a general awareness among farmers of the efficiency gains and environmental advantages associated with pro-environmental production technologies. Furthermore, the mean value of information acquisition (3.845) implies that farmers possess the capacity to assimilate new technologies and knowledge. Among the 560 samples that adopted the pro-environmental production technology, nearly 86% were male, with an average age of 46, and most of them had completed junior high school education and were in good health, with fewer farmers having village cadres in their families. In terms of business situation, most of the sample farmers had two family members involved in beef cattle farming; they had longer farming years and rich farming experience; they had larger farming scales, larger differences in the amount of specific investments, and relatively less difficulty in selling their beef cattle.

3.3 Model selection

3.3.1 Ordered probit model

Most existing studies on the environmentally friendly behavior of farmers utilized binary logistic or probit models. However, we selected the number of environmentally friendly production techniques adopted as the dependent variable, with values of 0, 1, 2, 3, 4, and 5, showing a clear progressive relationship. Therefore, we established an ordered probit model, as follows:

$$Y_i^* = \alpha_0 + c_0 X_i + \beta_0 Z_i + \varepsilon_i \quad (1)$$

In Equation 1: Y_i^* denotes the latent variable of pro-environmental behavior of the i farmer, which has a quantitative relationship with Y_i ; X_i denotes the participation of the i farmer in contract farming, marketing contract, production-management contract, and resource-providing contract. Z_i denotes the control variable. α_0 denotes the constant terms; c_0, β_0 denotes the parameter to be estimated; and ε_i denotes the random error terms. Although Y_i^* is unobservable, there exists an observable variable Y_i that corresponds to it, defined as $\delta_0 < \delta_1 < \delta_2 < \delta_3 < \delta_4$, both of which are critical for Y_i^* mutation. Thus, the relationship between both Y_i^* and Y_i, in the form of Equation 2:

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TABLE 1 Variable definitions and descriptive statistics.

Type	Variables	Definition	Mean	SD	Min	Max
Dependent variables	Pro-environmental behavior	Number of actual adoptions of pro-environmental production technologies in the beef cattle breeding process in the year (nos.)	2.845	1.020	0	5
Independent variables	Contract farming	Participation in contract farming: yes = 1, no = 0	0.637	0.481	0	1
	Marketing contract	Participation in marketing contract: yes = 1, no = 0	0.313	0.464	0	1
	Production-management contract	Participation in production-management contract: yes = 1, no = 0	0.195	0.396	0	1
	Resource-providing contract	Participation in resource-providing contract: yes = 1, no = 0	0.145	0.352	0	1
Mediating variable	Expected economic benefits	Whether the adoption of pro-environmental production technologies will benefit your family in terms of increased production and income, taking into account the cost–benefit: very unfavorable = 1, somewhat unfavorable = 2, neutral = 3, somewhat favorable = 4, very favorable = 5	3.860	1.026	1	5
	Expected ecological benefits	Whether the adoption of pro-environmental production technologies is conducive to environmental protection and the prevention of air pollution: very unfavorable = 1, somewhat unfavorable = 2, neutral = 3, somewhat favorable = 4, very favorable = 5	4.098	1.020	1	5
	Information acquisition	You can quickly adapt existing production methods to new technologies and knowledge: strongly disagree = 1, disagree = 2, neutral = 3, agree = 4, and strongly agree = 5	3.845	0.922	1	5
Control variables	Age	Respondent's age (years)	46.632	8.370	21	73
	Gender	Female = 0, male = 1	0.864	0.343	0	1
	Education	Primary or below = 1, junior school = 2, high school = 3, college = 4, master = 5	2.191	0.902	1	4
	Health	Very poor = 1, poor = 2, fair = 3, good = 4, very good = 5	3.991	0.971	1	5
	village cadre	Presence of village cadres in the household, no = 0, yes = 1	0.077	0.266	0	1
	Breeding number	Number of family members involved in beef cattle breeding (persons)	2.320	1.727	1	20
	Training time	Number of times to attend training on beef cattle breeding technology in a year(times)	2.550	2.385	0	25
	Breeding years	Years of beef cattle breeding for farmers (years)	11.561	8.746	1.	38
	Farm size	Annual slaughter of beef cattle (head)	120.137	272.205	2	3,500
	Specific investments	The amount of investment in productive fixed assets is taken as log (yuan)	53.155	83.442	3.000	1,500
	Ease of selling beef cattle	Ease of selling beef cattle: very difficult = 1, difficult = 2, general = 3, easier = 4, very easy = 5	2.277	0.778	1	5

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$$Y = \begin{cases} 0(not\ adopt)\ Y^* \le \delta_0 \\ 1(adopt\ 1\ kind)\ \delta_0 < Y^* \le \delta_1 \\ 2(adopt\ 2\ kinds)\ \delta_1 < Y^* \le \delta_2 \\ 3(adopt\ 3\ kinds)\ \delta_2 < Y^* \le \delta_3 \\ 4(adopt\ 4\ kinds)\ \delta_3 < Y^* \le \delta_4 \\ 5(adopt\ 5\ kinds)\ Y^* > \delta_4 \end{cases} \quad (2)$$

Thus, the probabilities of Y = 0, 1, 2, 3, 4, 5 are as follows:

$$\begin{aligned} &P\left(Y=0\right)=\varphi\left(\delta_0-c_0X_i-\beta_0Z_i\right) \\ &P\left(Y=1\right)=\varphi\left(\delta_1-c_0X_i-\beta_0Z_i\right)-\varphi\left(\delta_0-c_0X_i-\beta_0Z_i\right) \\ &P\left(Y=2\right)=\varphi\left(\delta_2-c_0X_i-\beta_0Z_i\right)-\varphi\left(\delta_1-c_0X_i-\beta_0Z_i\right) \\ &P\left(Y=3\right)=\varphi\left(\delta_3-c_0X_i-\beta_0Z_i\right)-\varphi\left(\delta_2-c_0X_i-\beta_0Z_i\right) \\ &P\left(Y=4\right)=\varphi\left(\delta_4-c_0X_i-\beta_0Z_i\right)-\varphi\left(\delta_3-c_0X_i-\beta_0Z_i\right) \\ &P\left(Y=5\right)=1-\varphi\left(\delta_4-c_0X_i-\beta_0Z_i\right) \end{aligned} \quad (3)$$

In Equation 3: φ denotes the cumulative density function of the standard normal distribution. The ordered probit model parameters are estimated using the maximum likelihood estimation technique. To enhance the measurement and comparison of the impacts of each variable on farmers' pro-environmental behaviors, the estimated coefficients from the ordered probit model in this study are presented as marginal effects. For analytical convenience, this study reports pro-environmental behavior by focusing on the maximum value, specifically the marginal effect associated with farmers' adoption of five pro-environmental production technologies.

3.3.2 Mediating effect model

To explore the effects of contract farming and its three contractual types on farmers' pro-environment behaviors, this study tested whether expected economic benefits, expected ecological benefits, and information acquisition played a mediating role between the two. The specific formulas are as follows:

$$Y_i = \alpha_1 + c_1 X_i + \beta_1 Z_i + \varepsilon_1 \quad (4)$$

$$M_i = \alpha_2 + c_2 X_i + \beta_2 Z_i + \varepsilon_2 \quad (5)$$

$$Y_i = \alpha_3 + c_3 X_i + bM_i + \beta_3 Z_i + \varepsilon_3 \quad (6)$$

In Equations 4–6, Y_i denotes the pro-environmental behavior of the farmer. X_i denotes contract farming; M_i denotes expected economic benefits, expected ecological benefits, and information acquisition; and Z_i denotes the control variable. c1 is the regression coefficient of contract farming, marketing contract, production-management contract, and resource-providing contract on farmers' pro-environmental behavior; c2 is the regression coefficient of contract farming on expected economic benefits, expected ecological benefits, and information acquisition; c3 is the regression coefficient of contract farming on farmers' pro-environmental behavior after introducing the mediating variable; b is the regression coefficient of expected economic benefits, expected ecological benefits, and information acquisition on farmers' pro-environmental behavior; α1, α2, and α3 denotes the constant terms; ε1, ε2, and ε3 denote the random error terms.

4 Empirical results

4.1 Estimated results of contract farming on pro-environmental behavior of beef cattle farmers

This study used Stata 17.0 software to conduct an ordered probit model analysis. Numerous collinearity tests were performed on each variable before the regression analysis to avoid the possibility of multiple collinearities among the variables, leading to imprecise estimation results. The variance inflation factor (VIF) is <10, indicating no multicollinearity among the independent variables; the variables were reasonably selected, and the data were valid. An ordered probit model was used for the regression analysis (Table 2).

Table 2 reports the estimation results of the effect of contract farming and different contract farming types on farmers' pro-environmental behavior. As shown in column (1), the impact of contract farming on pro-environmental behavior passes the 1% positive significance test, and the probability of pro-environmental behavior is enhanced by 7.8% for farmers' participation in contract farming, which validates the hypothesis H1 of this study. This result is similar to the findings of Ma et al. (2023) that the participation of farmers in contract farming promotes the use of pro-environmental production techniques, which in turn enhances pro-environmental behavior formation. On the one hand, beef cattle producers and processors establish contracts with farmers that stipulate production standards, product quality, and purchase orders. To secure price premiums by fulfilling these contractual obligations, farmers are incentivized to implement pro-environmental techniques to improve product quality. On the other hand, participation in contract farming facilitates farmers' access to modern production inputs, including material resources, green technologies, and market intelligence. Meanwhile, beef cattle production and processing enterprises offer farmers educational training and technical support, which helps mitigate the constraints and perceived risks associated with adopting pro-environmental technologies. Consequently, farmers are encouraged to implement pro-environmental technologies such as input reduction, harmless treatment of sick and dead animals, manure resource utilization, farm standardization, and sanitary and epidemiological.

Furthermore, this explored the estimated outcomes regarding the influence of farmers' engagement in various forms of contract farming on their pro-environmental practices. Columns (2–4) show that participation in marketing, production management, and resource-providing contracts significantly promoted farmers' pro-environmental behaviors, with probabilities of 0.8, 4.0, and 4.3%, respectively. All three contractual types of contract farming can significantly promote farmers'

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pro-environmental behaviors, with resource-providing contract having a greater degree of enhancement. This study found that participation in marketing contracts is beneficial for mitigating the impact of market price risk on farmers. When the market price fluctuates greatly, the contracted enterprise fulfills the contract and buys the farmers' products at a protected price, which ensures that the farmers make a profit, greatly reducing the production and marketing risks of the contracted households, thereby enabling them to adopt a higher level of pro-environmental technologies. Farmers in production-management contracts act as "production workshops" for contracted enterprises. On the one hand, the contracted enterprise provides labor, land, and fixed assets; on the other hand, the contracted enterprise provides farmers with technical training, market information, financing and loans, and other services that can effectively help farmers complete the order contract. Consequently, with the production resources and factors provided by contracted enterprises and the technical guidance and training provided, farmers will be able to grasp the technical information and operating principles more quickly. They can adopt pro-environmental technologies more easily. Farmers with resource-providing contracts have established a closer interest linkage mechanism between beef cattle production and processing enterprises. The contractual pact can reduce the productive expenditures of beef cattle farmers by providing production materials on credit and providing farmers with production materials, such as high-quality breeds of racked cattle, feeds, and veterinary medicines, which, to a certain extent, reduce the mobility and production constraints of contractual households. Farmers generally participate in contract farming as if in an environment protected by a "safety net." When making decisions on adopting pro-environmental technologies, they believe that if they fail, they may still be able to receive assistance from contracted enterprises. As a result, farmers' expectations of compensatory losses reduce their aversion to the risk of adopting pro-environmental technologies; thus, they are more inclined to develop pro-environmental behaviors.

TABLE 2 Estimates of the impact of contract farming and three contractual types on pro-environmental behavior.

Variables	Pro-environmental behavior			
	(1)	(2)	(3)	(4)
Contract farming	0.078***			
	(0.017)			
Marketing contract		0.008*		
		(0.005)		
Production-management contract			0.040***	
			(0.009)	
Resource-providing contract				0.043***
				(0.011)
Age	−0.000	0.000	0.000	0.000
	(0.000)	(0.000)	(0.000)	(0.000)
Gender	0.013	0.008	0.009	0.009
	(0.011)	(0.010)	(0.010)	(0.010)
Education	0.002	0.001	0.000	−0.000
	(0.004)	(0.004)	(0.004)	(0.004)
Health	0.008**	0.007*	0.006*	0.007*
	(0.004)	(0.004)	(0.004)	(0.004)
Village cadre	0.012	0.019*	0.012	0.023**
	(0.011)	(0.010)	(0.010)	(0.010)
Breeding number	0.001	0.002	0.001	0.002
	(0.001)	(0.001)	(0.001)	(0.001)
Training time	0.003*	0.004**	0.004**	0.003**
	(0.002)	(0.001)	(0.001)	(0.001)
Breeding years	0.000	−0.000	−0.000	−0.000
	(0.000)	(0.000)	(0.000)	(0.000)
Farm size	0.000**	0.000***	0.000***	0.000***
	(0.000)	(0.000)	(0.000)	(0.000)
Specific investments	0.017***	0.027***	0.024***	0.025***
	(0.004)	(0.005)	(0.005)	(0.005)
Ease of selling beef cattle	−0.001	−0.009**	−0.004	−0.004
	(0.004)	(0.004)	(0.004)	(0.004)
N	560	560	560	560
Pseudo R^2	0.1423	0.0876	0.0980	0.0973

Standard errors are reported in parentheses. *, **, and *** represent statistical significance at the 10, 5, and 1% levels, respectively.

4.2 Robustness check

4.2.1 Replacement model

To verify the robustness of the above regression results, we use the replacement model to replace the ordered probit model with the ordered logit model and the OLS model for the robustness test. As can be seen from the test results in Table 3, both the significance of the variables and the sign of the coefficients are consistent with the results of the benchmark regression, indicating that the research results are robust.

4.2.2 PSM method

To address concerns about possible observable self-selection bias in our sample, we re-estimate Equation 1 using a sample after PSM. First, contract farming is used as the treatment variable, and the control variables in the baseline regression model are used as covariates. Second, the treatment and control group samples are matched using the 1:1 nearest neighbor matching method. Finally, we regress Equation 1 using the matched sample. Columns (3) of Table 3 show the effect of contract farming on pro-environmental behavior using the sample after PSM. The coefficient of contract farming (0.841) is positive and significant ($p < 0.01$), which is consistent with our baseline regression results. This suggests that contract farming still contributes significantly to farmers' pro-environmental behavior even after accounting for self-selection bias.

4.2.3 Heckman two-stage method

We constructed a Heckman two-stage model for robustness testing to address the endogeneity problem caused by sample selection bias. Specifically, the first stage uses whether farmers participate in contract farming and calculates the inverse Mills ratio (IMR) after subjecting the control variables to probit regression. The second stage takes the calculated IMR and substitutes it into the model as a new control variable for regression. As shown in Table 3, the inverse Mills is significantly and positively associated with pro-environmental behavior at the 5% level, and the coefficient of contract farming remains significantly positive at the 1% level after effectively controlling for the inverse Mills ratio, indicating that the estimation results are robust.

5 Additional findings

5.1 Mediation analysis

According to the previous analysis, participation in contract farming contributes significantly to farmers' pro-environmental behavior. However, the effect of contract farming on farmers' pro-environmental behavior requires further testing. As pointed out earlier, contract farming affects farmers' pro-environmental behaviors mainly through three mechanisms: one is to improve farmers' expected economic benefits through participation in contract farming, which affects farmers' pro-environmental behaviors; second is to improve farmers' production technology levels through participation in contract farming, which enhances their expected ecological benefits and affects farmers' pro-environmental behavior; and the third is to improve farmers' information acquisition through participation in contract farming, which enables them to fully understand pro-environmental production technology. Third, through participation in contract farming, the ability of farmers to obtain information improves, which makes them better able to recognize the role of pro-environmental technologies in increasing production and reducing costs, thus positively affecting the formation of farmers' pro-environmental behaviors. The specific testing process is presented in Table 4.

5.1.1 Mechanism test of the impact of expected economic benefits

Contract farming not only mitigates the impact of price fluctuations of beef cattle farmers but also provides convenient conditions for farmers to purchase production materials and production services. This is conducive to reducing the production and transaction costs of farmers, which in turn enhances the expected economic benefits of farmers and promotes the formation of pro-environmental behaviors of farmers in a sustainable manner. According to the regression results in column (2) of Table 4, expected economic benefits of farmers' participation in contract farming are significantly positive at the 1% level, indicating that participation in contract farming helps to increase the expected economic benefits of farmers. Column (3) indicates that the increase in expected economic benefits can significantly promote farmers' pro-environmental behavior, which suggests that expected economic benefits can act as an intermediate transmission mechanism for contract farming to influence farmers' pro-environmental behavior and hypothesis H2a is tested.

This finding suggests that farmers, as rational economic agents, first consider the expected economic benefits of pro-environmental behavior. The adoption of pro-environmental production technologies by farmers is influenced by a combination of factors, including ease of implementation and economic viability. The economic benefits that farmers perceive from adopting environmentally friendly production technologies have been shown to influence their decisions.

TABLE 3 Robustness test results.

Variables	pro-environmental behavior			
	Ologit	OLS	PSM	Heckman
	(1)	(2)	(3)	(4)
Contract farming	0.069***	0.821***	0.841***	0.791***
	(0.016)	(0.084)	(0.115)	(0.088)
Age	0.000	−0.001	−0.002	−0.003
	(0.000)	(0.004)	(0.005)	(0.004)
Gender	0.008	0.145	0.124	0.173
	(0.009)	(0.113)	(0.127)	(0.113)
Education	0.001	0.024	−0.023	0.032
	(0.003)	(0.040)	(0.049)	(0.041)
Health	0.006**	0.095**	0.099**	0.107**
	(0.003)	(0.040)	(0.045)	(0.042)
village cadre	0.012	0.130	0.139	0.061
	(0.008)	(0.117)	(0.133)	(0.120)
Breeding number	0.001	0.014	0.013	0.008
	(0.001)	(0.014)	(0.015)	(0.015)
Training time	0.002	0.029*	0.021	0.019
	(0.001)	(0.017)	(0.015)	(0.017)
Breeding years	0.000	0.002	−0.000	0.005
	(0.000)	(0.004)	(0.004)	(0.005)
Farm size	0.000*	0.000**	0.000**	0.000*
	(0.000)	(0.000)	(0.000)	(0.000)
Specific investments	0.015***	0.188***	0.220***	0.102
	(0.004)	(0.033)	(0.043)	(0.063)
Ease of selling beef cattle	0.001	−0.011	−0.095*	0.044
	(0.003)	(0.044)	(0.052)	(0.054)
IMR				0.332**
				(0.150)
Constant	—	1.046***	1.289***	1.431***
		(0.320)	(0.393)	(0.386)
N	560	560	425	560
Pseudo R^2	0.1500	0.329	0.273	0.332

Standard errors are reported in parentheses. *, **, and *** represent statistical significance at the 10, 5, and 1% levels, respectively.

Consequently, the stability of contract farming ensures the predictability of economic benefits for farmers. Those farmers who anticipate profit are more likely to adopt pro-environmental production technologies.

5.1.2 Mechanism test of the impact of expected ecological benefits

Farmers participating in contract farming are more likely to have access to modeling and guidance on pro-environmental technologies. As an exogenous shock to farmers' technology demand, contract farming provides farmers with tailored green farming technology demands and enhances the sustainability of pro-environmental behavior. According to the regression results in column (5) of Table 4, contract farming has a significant positive effect on expected ecological benefits, implying that contract farming can provide farmers with targeted technical support, which helps to increase their expected ecological benefits. In column (6), the regression coefficients of both contract farming and expected ecological benefits variables passed the significance test, indicating a mediating effect of expected ecological benefits on the relationship between contract farming and farmers' pro-environmental behavior, thus verifying hypothesis H2b.

The findings of this study suggest that incentives from external factors, such as the market, government, and society, not only increase farmers' expected economic returns from pro-environmental production technologies, but also increase their awareness of ecological values. The driving incentives in contract farming, as well as the communication exchanges in social networks, have the potential to deliver more comprehensive information to farmers and address the information constraints of closed rural societies (Ton et al., 2018). A comprehensive understanding of pro-environmental production technologies and an elevated level of ecological awareness are advantageous for farmers. Furthermore, the adoption of pro-environmental behavior by farmers during the process of beef cattle breeding has been demonstrated to exert a favorable influence.

5.1.3 Mechanism of action test for information acquisition

Farmers participating in contract farming are more likely to have access to enhanced market intelligence, technical support, and production services. The application of contract farming can provide farmers with assistance in technology, information, product sales, and capital from the demand side to alleviate structural contradictions in the supply and marketing of beef cattle farmers. However, the stronger the information acquisition ability of farmers, the stronger their ability to identify and digest information, and the more they can absorb and apply information on the importance of pro-environmental behaviors from various information acquisition channels; thus, the more likely they are to adopt pro-environmental technologies of production and participate in agro-ecological environmental protection. According to the regression results in column (8) of Table 4, contract farming significantly and positively affects information acquisition. Farmers can take advantage of contractual enterprises to reduce information asymmetry, prompting them to acquire market information in a timely and effective manner, which helps increase the information acquisition ability of farmers. In column (9), the regression coefficients of both contract farming and information acquisition variables pass the significance test, indicating a mediating effect of information acquisition in the relationship between contract farming and farmers' pro-environmental behavior, and hypothesis H3 is verified. The contract firms have stronger financial and information advantages than farmers, and the intervention of contract farming changes farmers' information, technology, and resource endowment status, which in turn promotes the formation of pro-environmental behavior of farmers.

This finding suggests that facilitating access to information plays a crucial role in the impact of contract farming on farmers' pro-environmental behavior. Despite the modest overall level of information access among the sample farmers, discernible disparities emerge among the different groups. The correlation between the strength of information access and the capacity of farmers to recognize, process, and apply information is well-documented. Specifically, there is a direct relationship between improved information access and farmers' ability to absorb and apply green production technologies from diverse sources. This, in turn, leads to an increased likelihood of adopting pro-environmental production technologies, such as contract farming. This finding aligns, to a certain degree, with the perspective put forth by Ma and Zheng (2023). They contend that farmers with superior information acquisition capabilities are more likely to access a broader array of information

TABLE 4 Mechanism analysis of the impact of participation in contract farming on farmers' pro-environmental behavior.

Variables	Expected economic benefits			Expected ecological benefits			Information acquisition		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	Y	M	Y	Y	M	Y	Y	M	Y
Contract farming	0.078***	0.109***	0.075***	0.078***	0.193***	0.073***	0.078***	0.112***	0.076***
	(0.017)	(0.035)	(0.016)	(0.017)	(0.036)	(0.016)	(0.017)	(0.034)	(0.016)
Expected economic benefits			0.012***						
			(0.004)						
Expected ecological benefits						0.012***			
						(0.004)			
Information acquisition									0.014*
									(0.008)
Control variables included	Yes			Yes			Yes		
N	560	560	560	560	560	560	560	560	560
Pseudo R^2	0.1423	0.0764	0.1481	0.1423	0.0790	0.1492	0.1423	0.0637	0.1440
Sobel test	$p = 0.000 < 0.05$, Mediating effect established			$p = 0.000 < 0.05$, Mediating effect established			$p = 0.000 < 0.05$, Mediating effect established		

Standard errors are reported in parentheses. *, **, and *** represent statistical significance at the 10, 5, and 1% levels, respectively.

channels and are more inclined to adopt green prevention and control technologies.

5.2 Heterogeneity analysis

The effect of contract farming on farmers' pro-environmental behaviors was examined using an ordered probit model. However, this estimate only reflects the marginal impact of farmers' participation in contract farming on the implementation of the five pro-environmental behaviors. For farmers with different endowments, differences in comparative advantage, subjective perceptions, and behavioral capabilities can lead to divergence in the adoption of pro-environmental production technologies. This study draws on the results of existing, we grouped farmers according to the pro-environmental technologies they specifically adopted to analyze the differences in the effects of contract farming on their pro-environmental behavior. Simultaneously, we also grouped farmers according to specific investments, farm size, training time, and environmental regulations to analyze the differences in the effects of farmers' participation in contract farming on their pro-environmental behaviors under different constraints. To ensure the effectiveness of the analysis, we first calculated the mean values of the variables for the different endowment groups of farmers. Then, we compared the "greater than mean" and "less than mean" groups of sample farmers.

5.2.1 Impact of contract farming on different pro-environmental behaviors of farmers

The specific measures that correspond to farmers' pro-environmental behaviors are related to five aspects: input reduction, harmless treatment of sick and dead animals, manure resource utilization, farm standardization, and sanitary and epidemiological measures. In this section, we focus on the differences in the effects of contract farming on farmers' adoption of five pro-environmental technologies. Participation in contract farming significantly reduces farmers' inputs. As contract firms have certain quality requirements for farmers' products and implement monitoring and penalty measures for farmers, farmers' actor inputs are bound by contract firms, which in turn leads to a reduction in farmers' use of crop inputs. Some contract firms have formulated rules and regulations to strictly prohibit the use of banned drugs and other provisions and do not purchase products that do not meet the standards, which, to some extent, restricts farmers' production behavior.

Participation in contract farming significantly improves the environmentally sound treatment of sick and dead animals. Farmers mainly implement resource treatment of ill and dead cattle through composting, fermentation, and chemical systems, which require wood chips, fermentation beds, and other resource treatment equipment. The purchase of inputs inevitably increases production and operating costs. However, when farmers participate in contract farming, they provide appropriate resource treatment equipment and reduce the cost pressure on them. At the same time, through ecological education and training, contract firms understand that improper or simple treatment of sick and dead cattle may damage the environmental safety of soil, water, and other ecological safety, but may also cause the spread of epidemics and endanger public health. Therefore, they take the initiative to improve the degree of resource treatment of sick and dead pigs.

Participation in contract farming significantly improves the manure resource utilization by farmers. Some of these contract firms standardize the feeding process of farmers, and farmers are required to dispose of livestock and poultry manure according to the technical specifications of the contract firms. Such organizational constraints help to form effective constraints and supervision of farmers' behavior, and reduce the arbitrary handling of manure by farmers. In addition, under the guidance of the resource utilization technology of contract firms, as well as the support of environmental protection pressure and agricultural subsidies, farmers have complete manure treatment equipment and a higher utilization rate of manure resources. At the same time, it can also correct the adverse selection and moral hazard of adopting pro-environmental behavior by farmers, and change the adoption of environmental protection investment and harmless waste treatment behavior by farmers.

Participation in contract farming significantly improves the farm standardization of farmers' operations. Contract firms help farmers build standardized farms and equip facilities for manure collection, storage, treatment, and use. This organizational support helps farmers move away from unregulated waste disposal. Contract farming can reduce the disease and mortality rates among cattle farmers, transfer production and price risks from farmers to contractors, and help farmers withstand market risks. In addition, by providing credit services to farmers and improving their credit capacity, contract farmers can invest more capital in production, thus expanding the scale of production and improving the scale, facilities, standardization, and industrialization of farms.

Participation in contract farming does not significantly affect the farmers' sanitary and epidemiological practices. Contract farming affects farmers' pro-environmental behavior mainly by reducing feeding costs rather than by increasing environmental awareness. Raising awareness of the economic, social, and environmental benefits of pro-environmental behaviors is necessary to motivate farmers to adopt sanitary and epidemiological practices. The more farmers are aware of sanitary and epidemiological measures and the more optimistic they are about their development prospects, the more likely they are to adopt them. Nevertheless, research indicates that the study areas universally provide compulsory immunization services against prevalent animal diseases, including small ruminant diseases, foot-and-mouth disease, and brucellosis, in line with the National Animal Disease Prevention Subsidy Policy. This policy requires farmers to independently manage the cleaning and disinfection of barns and procure veterinary medications to prevent and treat common ailments. Consequently, the contribution of contract farming participation to enhancing farmers' sanitary and epidemiological practices remains insufficiently pronounced (Table 5).

5.2.2 Impact of contract farming on environmental behavior of farmers with different constraints

Indeed, there are differences in the participation of different types of farmers in contract farming on their pro-environmental behavior. While the preceding analysis assessed the impact of contract farming on farmers' pro-environmental behaviors, it did not take into account the variability of farmers with different characteristics or explore the cohort differences in the adoption of pro-environmental production

TABLE 5 Differences in the impact of contract farming on different pro-environmental behaviors of farmers.

Variables	Input reduction	Harmless treatment of sick and dead animals	Manure resource utilization	Farm standardization	Sanitary and epidemiological
	(1)	(2)	(3)	(4)	(5)
Contract farming	0.636***	1.859***	0.818***	0.602***	0.439
	(0.219)	(0.460)	(0.229)	(0.221)	(0.413)
Age	−0.031***	−0.050**	−0.036***	−0.038***	−0.035***
	(0.012)	(0.020)	(0.013)	(0.012)	(0.013)
Gender	−0.118	−0.441	−0.201	−0.382	−0.327
	(0.366)	(0.494)	(0.375)	(0.382)	(0.363)
Education	0.364	0.319	0.344*	0.289	0.305
	(0.231)	(0.209)	(0.205)	(0.198)	(0.208)
Health	0.513***	0.647***	0.555***	0.519***	0.547***
	(0.167)	(0.199)	(0.161)	(0.169)	(0.169)
Village cadre	−0.047	−0.209	0.115	−0.090	−0.083
	(0.547)	(0.643)	(0.705)	(0.582)	(0.555)
Breeding number	0.841***	0.939***	0.690**	0.806**	0.763**
	(0.319)	(0.347)	(0.317)	(0.323)	(0.323)
Training time	0.360**	0.549***	0.368**	0.266	0.337**
	(0.173)	(0.198)	(0.170)	(0.167)	(0.168)
Breeding years	0.013	0.023	0.009	0.011	0.013
	(0.020)	(0.022)	(0.018)	(0.019)	(0.018)
Farm size	0.005*	0.006	0.004*	0.004	0.003**
	(0.003)	(0.004)	(0.002)	(0.003)	(0.002)
Specific investments	0.447***	0.344**	0.421***	0.480***	0.491***
	(0.133)	(0.162)	(0.129)	(0.129)	(0.137)
Ease of selling beef cattle	−0.430*	−0.443	−0.434	−0.444*	−0.404
	(0.250)	(0.291)	(0.271)	(0.247)	(0.250)
Constant	−1.974	−2.463	−1.525	−0.760	−1.500
	(2.049)	(1.995)	(1.769)	(1.729)	(1.826)
N	560	560	560	560	560
Pseudo R^2	0.3851	0.4913	0.4010	0.3721	0.3905

Standard errors are reported in parentheses. *, **, and *** represent statistical significance at the 10, 5, and 1% levels, respectively.

technologies by different types of farmers. This study contributes to the existing body of knowledge on the differentiation of contract farming and farmers' pro-environmental behavior. According to the preceding theoretical analysis, clusters are to be divided according to four aspects: specific investments, farm size, training time, and environmental regulations. This division allows for the testing of the differential response of contract farming on farmers' pro-environmental behavior.

As illustrated in Table 6, the results of the study demonstrate the heterogeneity of the effect of contract farming on farmers' pro-environmental behavior. The results of the heterogeneity analysis demonstrate that there is a significant difference in the effect of contract farming on farmers' pro-environmental behavior. This finding is similar to that of Bist et al. (2024), Xie and Huang (2021), and Gholamrezai et al. (2021). Farmers with more specific investments were more inclined to develop pro-environmental behaviors after participating in contract farming. Among them, farmers involved in production management and resource provision contracts contributed significantly to the formation of pro-environmental behaviors. This is because when farmers are willing to make higher specific investments, the likelihood that their inputs will be secured and locked in is greater. Contract firms provide farmers with services such as credit for inputs, market information acquisition, and production technology advice, which reduces their production constraints and transaction costs and motivates them to actively adopt pro-environmental technologies. The participation of larger farmers in contract farming has a greater impact on promoting pro-environmental behavior.

Meanwhile, farmers who participated in fewer agricultural trainings had a greater promotion of pro-environmental behavior by participating in contract farming. This suggests that it is more

TABLE 6 Differences in the impact of contract farming on pro-environmental behavior of farmers with different constraints.

Variables	Classification standards	Contract farming	Marketing contract	Production-management contract	Resource-providing contract
Specific investments	Larger than average	0.284***	0.093	0.041*	0.043***
		(0.082)	(0.072)	(0.022)	(0.015)
	Less than average	0.047***	−0.005	0.036***	0.030
		(0.015)	(0.007)	(0.010)	(0.024)
Farm size	Larger than average	0.173***	0.048*	0.002*	0.028
		(0.052)	(0.027)	(0.001)	(0.034)
	Less than average	0.060***	0.013	0.019	0.039***
		(0.016)	(0.008)	(0.026)	(0.013)
Training time	Larger than average	0.073***	0.019	0.033***	0.002
		(0.020)	(0.014)	(0.013)	(0.012)
	Less than average	0.087***	0.010	0.050***	0.058***
		(0.027)	(0.009)	(0.012)	(0.017)
Environmental regulations	Larger than average	0.118***	0.037**	0.036**	0.060***
		(0.029)	(0.018)	(0.016)	(0.013)
	Less than average	0.050***	0.002	0.033***	0.026*
		(0.018)	(0.006)	(0.010)	(0.016)

Standard errors are reported in parentheses. *, **, and *** represent statistical significance at the 10, 5, and 1% levels, respectively.

important for contractors to pay attention to the type, content, and quality of agricultural training they provide to their farmers and that high-quality training for beef farmers can effectively promote their pro-environmental behavior. In addition, we found a positive and significant effect of stronger environmental regulations on farmers' participation in contract farming in enhancing their pro-environmental behavior. A possible explanation is that when sound regulations are in place, the cost of haphazardly disposing farm waste increases, coupled with the fact that contract firms also provide farmers with the service of recycling farm waste, which promotes the implementation of pro-environmental behaviors by farmers.

6 Conclusion

Contract farming is becoming increasingly crucial in enhancing farm performance, improving household welfare, and boosting rural development. This study contributes to the literature by examining whether farmers' participation in contract farming can increase the adoption of pro-environmental behaviors using data collected from beef cattle farmers in China. We discussed the mediating roles of expected economic and environmental benefits and information acquisition in contract farming on farmers' pro-environmental behavior. Furthermore, we explored the differences in the effects of contract farming on the pro-environmental behaviors of farmers and the impact of farmers' participation in contract farming on their pro-environmental behaviors under various constraints.

This study indicates that contract farming is important for promoting pro-environmental behavior among farmers. Specifically, the extent to which farmers' participation in contract farming increases the probability of adopting pro-environmental behavior is 7.8%, with the involvement of resource-providing contracts increasing to a greater extent. This suggests that contract characteristics are important when formulating contract farming policies and estimating the impact of pro-environmental behavior. Mediation analysis revealed that farmers' participation in contract farming significantly promoted their adoption of pro-environmental behaviors by increasing expected economic and environmental benefits and improving information acquisition. Further analysis showed that farmers' participation in contract farming not only facilitated a significant reduction in input use but also promoted the adoption of three pro-environmental technologies, namely harmless treatment of sick and dead animals, manure resource utilization, and farm standardization; however, there was no significant effect on the adoption of sanitary and epidemiological measures. Moreover, there were cohort differences in the impact of participation in contract farming on farmers' pro-environmental behaviors, as evidenced by more specific investments, larger farm sizes, less farm training, and stronger environmental regulations, which improved farmers' adoption of pro-environmental behaviors.

The findings of this study have crucial policy implications for promoting the adoption of pro-environmental behaviors in China and other countries that promote environmentally friendly agricultural practices. In contrast to prior research, our study focuses on the impact of diverse contract types in contract farming on farmers' pro-environmental behaviors, thereby addressing the existing literature's limitations which predominantly centers on the influence of contract farming on farmers' pro-environmental behaviors (Mao et al., 2022). Furthermore, these findings have scientific significance for understanding the implementation logic of farmers' pro-environmental technology choices in beef cattle farming and their connotations, as well as for facilitating the formulation of pro-environmental behavior policies and the promotion and implementation of pro-environmental production technologies. The positive correlation between farmers' participation in contract farming and their adoption of pro-environmental behaviors suggests that the government should encourage smallholder farmers to join the "firm+farmer" type of contract farming and help them benefit from collective action. Once again, it has been demonstrated that enhancing the degree of farmers' organization can promote the adoption of pro-environmental behaviors by farmers and effectively enhance the level of livestock and poultry manure resource utilization (Cheng et al., 2023). The establishment of a close and stable benefit linkage mechanism between enterprises and beef cattle farmers should be strengthened to jointly promote the development of scale and specialization in the beef cattle industry.

Our survey revealed that Chinese beef farmers' adoption rates of pro-environmental behaviors remain low. In rural China, governmental agricultural extension agencies and cooperative entities to establish a system that advocates for environmentally sustainable practices. This involves amplifying awareness campaigns and augmenting the anticipated advantages for farmers who engage in such behaviors, leveraging their authoritative and professional roles in the dissemination of information (Ma and Zheng, 2023). Improve the information capacity of farmers and use information technology to promote the adoption of pro-environmental behaviors. With the swift proliferation of information and communication technology in China, providing farmers with abundant information resources. This transformation was facilitated by the integration of cell phones, computers, and other contemporary information devices into agricultural practices. The Internet has been instrumental in disseminating a diverse array of environmental policy and technology information to farmers, thereby enhancing their awareness of environmental protection and promoting the adoption of pro-environmental behaviors (Liao and Chen, 2017; Yin et al., 2024a, 2024b). According to different constraints, enterprises should formulate a type of contract with farmers in a targeted manner, gradually improve the benefit-sharing mechanism between enterprises and farmers and reduce the pressure on farmers' production cost inputs. At the same time, it is also necessary to help them master environmentally friendly technologies and production methods, enhance farmers' environmental protection awareness and ability, and promote win-win cooperation and benefit-sharing among various business units.

While our research advances the literature, it is not without limitations that provide opportunities for future research. First, we examined the relationship between farmers' participation in contract farming and pro-environmental behavior. We encourage further research on more specific mechanisms of the effects of contract farming on farmers' pro-environmental behavior and analysis of the moderating effects of other factors on contract farming and farmers' pro-environmental behavior. Second, due to data limitations, only cross-sectional data did not consider the bias caused by time dynamics in this paper. Therefore, future research can utilize panel data to conduct long-term studies and use more instrumental variables to determine the causal relationship between those variables. Finally, future research may extend the results from our studies to other regions of China or other countries to explore new pro-environmental behaviors and campaigns through different digital and offline channels and use other indicators.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Author contributions

YL: Conceptualization, Methodology, Supervision, Writing – original draft, Writing – review & editing. PZ: Methodology, Project administration, Validation, Writing – review & editing. WB: Formal analysis, Project administration, Writing – original draft, Methodology. QQ: Methodology, Validation, Writing – original draft. FX: Project administration, Software, Validation, Writing – original draft, Writing – review & editing.

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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.

Generative AI statement

The authors declare that no Gen AI was used in the creation of this manuscript.

Publisher's note

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