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Industrialized organizational models and the green transformation—evidence from pig farming in China

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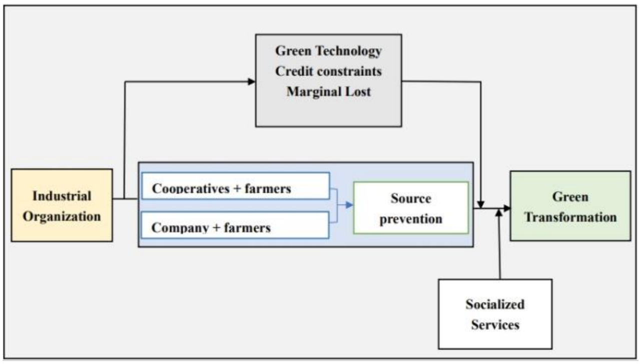
Graphical abstract



Abstract

Based on micro-panel data from Sichuan Province and Jiangsu Province collected in 2022 and 2023, multiple linear regression models are used to explore the impact of different industrial organization models on the green transformation of pig farming. The study found that the participation of pig farmers in pig industrialization organizations significantly promotes the green transformation, particularly in the input factors at the front and middle stages of pig farming, but has no significant impact on the final stage. The "company+farmer" model significantly promotes the green transformation of pig farming, but the promotion effect of the "cooperative+farmer" model is minimal. Further, industrialized organizations mainly promote green transformation by improving farmers' breeding technology, reducing financing constraints, and decreasing medical and epidemic prevention costs. In addition, livestock socialization services lessen the role of industrialized organizations in contributing to the green transformation. Finally, different types of industrialized organizations can significantly promote green transformation for farmers without implementing the planting and breeding cycle.

Keywords Industrialized organization; Pig farming; Green transformation; Cooperative

1. Introduction

Animal husbandry has led to severe agricultural non-point source pollution, which seriously impacts on ecological security and human health (Xu *et al.* 2022; Jiang *et al.* 2024). At present, the production of pig manure in China exceeds 600 million tons, accounting for about one-third of the total amount of livestock manure, and the comprehensive utilization rate is less than 50%. A large number of antibiotic-resistant genes are transmitted in the food chain through pig feces, and the source of bacterial transmission is difficult to determine (Hennessy and Wolf, 2018). The large-scale development of live pigs has also caused serious pollution of the surrounding air and groundwater, directly affecting human health (Bai *et al.* 2016; Jiang *et al.* 2023). To address the environmental pollution caused by pig farming, the State Council officially implemented the "Regulations on the Prevention and Control of Pollution from Livestock and Poultry Scale Breeding" in 2014. However, the pollution caused by pig farming in China is widespread and covert, resulting in high government supervision costs, and environmental pollution issues remain severe (Si *et al.* 2021; Li and Xiao, 2024; Li *et al.* 2024). Therefore, the green transformation of pig farming that is the strict enhancement of green and clean production of pig farming in the whole industrial chain, including source prevention, process control, and terminal governance is an inevitable trend for future development (Tan *et al.* 2022; Shao *et al.* 2023), and exploring the key mechanisms of the transformation of pig farming production methods is necessary.

Since the outbreak of African swine fever, influenced by the demand for disease prevention and risk sharing, pig farmers aim to reduce market risks and gain potential returns. Various industrial organization models of Chinese live pigs have accelerated their development pace, roughly forming two types: contract production models, represented by "companies+farmers" and "cooperatives+farmers" (Hu *et al.* 2022; Wilkinson *et al.* 2023). Taking the "company+farmer" model as an example, in 2021, a total of 96.6795 million live pigs were sold by 12 leading aquaculture enterprises in China, accounting for 14.43% in the country—an increase of 11.78% compared to 2.65% in 2014. In addition, the number of pig industry cooperatives reached 131000 in 2020—a year-over-year increase of 32.32%.

There is no consensus regarding research conclusions about the impact of industrialized organizations on the transformation of green production among farmers. Some scholars believe that industrialization is beneficial for green transformation. Industrialization organizations influence the green production behavior of pig farmers through the implementation of effective contractual arrangements, including providing high-quality piglets, green feed, veterinary medicine, and technical guidance (Zhu *et al.* 2020). Industrial organizations also strengthen the utilization of pig manure resources through effective supervision and incentive policies, ultimately affecting the efficiency of clean pig production (Saenger *et al.* 2013). Large and leading pig enterprises can provide sufficient financial support and technical training on pollution control, and their rich management experience can also help farmers effectively cope with the pollution problem of pig farming (Tan *et al.* 2022). In addition, effective contractual arrangements reduce the moral hazard and inefficiency of pig manure treatment caused by information asymmetry (Si *et al.* 2021). Others believe that the diseconomies of scale caused by farmers' participation in industrial organizations are not conducive to the transformation of green production. For example, the "company+farmer" model requires farmers to have large-scale pig farming operations to cooperate with the company, which results in the problem of insufficient quantities of land in pig farming to absorb fecal pollution, causing serious pollution of local soil and air (Thu *et al.* 2012; Kim *et al.* 2023). Overly intensive pig farming can also cause the spread of pig diseases and death (Fan *et al.* 2021), which are not favorable to the transformation of green production through process control.

The existing literature has focused on the relationship between contract agriculture and the green production behavior of farmers, but two aspects need further in-depth research. First, most studies only use a single indicator to measure the green transformation of pig farming, without comprehensively examining green production behavior from the perspective of the whole pig farming industry chain. Secondly, the current literature mainly focuses on the impact of joining industrial organizations on farmers' green production behavior. However, further research is needed on the differential effects and mechanisms of various industrial organization models on farmers' green production transformation. Thirdly, the reasons for the impacts of different types of pig industrialization organizational models on the green transformation have not been explored, and whether the government-promoted socialized services for livestock and poultry have a regulatory effect still needs further investigation.

Therefore, we use micro survey data from Sichuan and Jiangsu provinces collected in 2022 and 2023 to comprehensively evaluate the green transformation of pig farming using the entropy method. In view of the whole hog farming industry chain, we investigate the impact and mechanism of different industrial organization models on green transformation，especially in source prevention, process control and terminal governance. Furthermore, we explore the moderator effects of socialized services for livestock and poultry. The marginal contributions of this article are as follows: Firstly, in the realm of research, this paper deepens the exploration of the green transformation issues in the pig farming industry. By adopting an integrated industrial chain analytical framework and innovatively applying the entropy method, this paper quantifies the implementation level of green transformation at three critical stages: source prevention, process control, and terminal treatment. This provides a practical and feasible approach for effectively assessing environmental pollution issues caused by the pig farming industry. Secondly, in terms of research perspective, this paper focuses on the impact and underlying mechanisms of different types of industrial organization models on the green transformation of pig farming, particularly through heterogeneity analysis at various production stages, offering valuable reference for the future green development path of the pig farming industry. Lastly, we further investigate the moderating role of socialized services for livestock and poultry between industrial organizations and green transformation, shedding light on their crucial function in fostering synergistic growth. This insight serves as a source of inspiration for subsequent research endeavors.

2. Theoretical analysis and research hypothesis

The organizational model of the pig industry can be roughly divided into "cooperatives+farmers" and "companies+farmers" models. There are significant differences in the impact of different industrial organization models on the green transformation of pig farming. First, the industrial organization model helps to encourage farmers to adopt green technology. Companies have advantages in increasing productivity and tend to play a dominant role in organizational cooperation, while farmers are in a disadvantaged position. With the government's constraints on food safety through environmental regulations, profit-maximizing companies must put clear requirements on farmers' production processes and implement a monitoring mechanism, which contributes to farmers' adoption of green farming techniques (Ji *et al.* 2019; Hou *et al.* 2023). Second, the industrial organization model helps to ease the credit constraints of farmers. Credit constraints caused by farmers' lack of collateral, high information costs, and high agricultural business risks, having always been important issues that restrict agricultural development in China.

Fortunately, industrialized organizations are the main means of alleviating credit constraints on farmers (Hu *et al.* 2022). On the one hand, financial institutions can identify risks throughout the entire agricultural industry chain, which can reduce credit risks and improve the availability of credit for farmers. On the other hand, companies and farmers often engage in internal credit, including credit sales of feed and prepaid purchase payments, which to a certain extent alleviate the material constraints on farmers (Zhuo *et al.* 2020). Thirdly, industrialized organizations have effectively reduced the marginal cost of medical and epidemic prevention, which is conducive to promoting the green transformation of pig breeding. The “company+farmer” model has advantages in management and epidemic prevention measures, which not only supports the effective avoidance of production risks but also reduces the marginal cost of medical and epidemic prevention. Based on this, this paper proposes:

Hypothesis 1：Compared to independent pig farmers, “company+farmer” model significantly promotes the green transformation of pig farmers. However, the promotion effect of “cooperatives+farmers” is minimal.

In accordance with the incomplete contract theory, pig farmers who join different modes of industrial organization differ in the way of contract signing. Compared with the “cooperative + farmer” model, the “company + farmers” model has a stronger binding contract (Karantininis and Graversen, 2008; Hu *et al.* 2022). Owing to differences in contract binding forces among industrial organizations, their impact on the green production transformation of farmers at different stages differs significantly (Rich, 2008).

According to producer decision-making theory, pig farmers’ green production transformation decisions are the result of cost–benefit tradeoffs，and directly affect the degree of transformation in each green production stage (Si *et al.* 2021). The green transformation of pig farming involves three main production stages: source prevention, process control and terminal governance. Different types of industrialized organizational models have different institutional arrangements and constraints on green production behavior of farmers in the three stages of pig farming, resulting in significant differences in the cost and degree of green transformation in different production stages (Tan *et al.* 2022; Zhang and Zeng, 2022).

In the stage of source prevention, independent breeders are free to choose piglet suppliers or engage in self-breeding, and the adoption rate of improved breeds is relatively low. In contrast, under the “company+farmer” model operating mechanism, the company provides a unified and standardized feed supply for breeders with improved piglets; and the contract also explicitly prohibits farmers from using prohibited drugs, strictly implements an off-medication period, and strictly manages the input items. Additionally, the cost of antibiotics and medical epidemic prevention is borne by the company and guided by professional technical personnel. Therefore, joining industrialized organizations is beneficial for the green transformation in the source prevention stage (Fan *et al.* 2021).

In the process control stage, after joining the industrial organizations, the companies and the cooperatives provide green production support facilities and corresponding technology guidance for farmers. In addition, joining industrial organizations is convenient for professional aquaculture technology exchange and information sharing among farmers, reducing market transaction costs (Borda-Rodriguez *et al.* 2016), as well as for industrial organizations to supervise the harmless treatment of waste such as sick and dead pigs. In summary, industrial organizations are conducive to the promotion of the harmless treatment of waste and dead pigs by farmers.

At the stage of terminal governance, the scale of independent farmers is relatively small, and the efficiency of combining planting and breeding is relatively high. The scale of “company+farmer” breeding is relatively large, and the efficiency of utilizing manure resources is also high. The binding force of the “cooperative+farmer” contract is relatively low, and the supervision of the utilization of manure resources is not strict. Based on this, this paper proposes:

Hypothesis 2: Compared to independent farmers, both the “company+farmer” and “cooperative+farmer” models can promote the green production transformation in two stages—source prevention and process control, whereas the “cooperative+farmer” model may not significantly promote the green transformation in terminal governance.

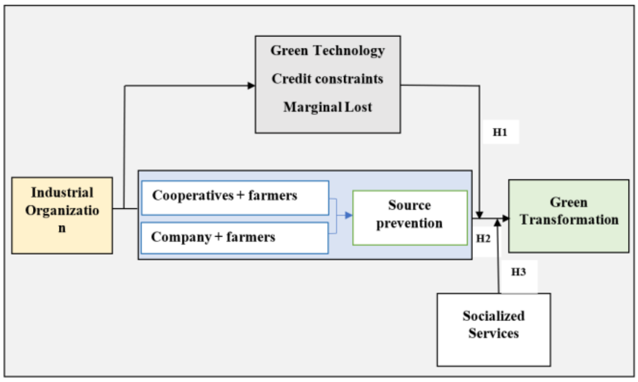


Figure 1. Theoretical analysis frame diagram

To promote the high-quality development of livestock and poultry farming, local governments vigorously develop socialized services in livestock and poultry farming, which helps livestock and poultry farmers to prevent market risks and reduce their production costs (Hennessy and Wolf, 2018). For independent farmers, such services effectively decrease the transaction costs of searching for green feed to a certain extent, promoting the green production transformation of source prevention and process control for pig farmers. For most independent farmers who implement the “planting and breeding cycle”, the socialized services for manure effectively help farmers return to their fields in a scientific manner. Considerably reducing the cost of manure treatment for terminal governance, and further promoting the green transformation.

However, for farmers who join industrial organizations, the situation is significantly different from that of independent farmers (Parcell and Langemeier, 1997; Ji *et al.* 2019). The feed and epidemic prevention drugs of the “company+farmers” model are uniformly provided by the company. Therefore, the socialization of livestock and poultry services is limited in purchasing feed, medical epidemic prevention products, and other products for farmers who join the company, making it difficult to effectively form a green transformation synergy effect in each stage of pig breeding. Therefore, the following hypothesis is proposed.

Hypothesis 3: Socialized services for livestock and poultry farming contribute to the green transformation of pig farming for independent farmers, but weaken the positive role of industrial organizations in the green transformation of pig farming.

Table 1 Measurement indicators for green transformation of pig farming

Green transformation of pig farming	Source prevention (reduction in factor investment)	Proportion of adoption of improved varieties	The proportion of adoption of improved varieties in pig farms to the total variety (%)
		Ecological feed proportion	The proportion of branded green feed to the total feed input (%)
		Degree of reduction in veterinary antibacterial drugs	Reduction in proportion of veterinary antibiotics compared to 2017 (%)
		Degree of antibiotic reduction	Reduction in the proportion of antibiotic use compared to 2017 (%)
		Medical epidemic prevention level	Proportion of medical and epidemic prevention expenses to total cost (%)
	Process control (waste treatment in aquaculture)	Status of harmless treatment of aquaculture waste	The proportion of harmless waste treatment to the total amount (%)
		Harmless treatment rate of sick and dead pigs	The proportion of harmless treatment of diseased and dead pigs to the total amount (%)
		Supporting rate of harmless treatment facilities	Supporting rate of harmless treatment facilities for pig farm waste (%)
		Efficiency of pig farm exhaust gas treatment	Proportion of investment cost for cleaning up waste gas emissions from aquaculture farms (%)
	Terminal treatment (utilization of fecal resources)	Utilization rate of dry manure (including biogas residue)	The proportion of dry manure resource utilization to the total amount of manure pollution (%)
		Utilization rate of sewage (including biogas slurry)	The proportion of sewage resource utilization to the total amount of fecal pollution (%)
		Proportion of fecal pollution discharge up to standard	The proportion of pig farm manure discharged to the standard in total manure (%)

Table 2 Descriptive statistics

Variables	**Variable Definition**	**Mean**	**Std. Dev**	**N**
Age	Actual age	52.377	12.859	713
Education	Years of education	9.849	3.086	713
Experience	Breeding period	15.389	8.709	713
Cadre	Village cadres=1, otherwise 0	0.098	0.302	713
Health	Health level	1.244	0.499	713
Intelligence	Intelligence level of pig farms	2.878	1.286	713
Risk	Risk appetite	3.433	1.145	713
Regulation	Number of environmental inspections	2.957	5.489	713
Support	Degree of technical support	3.905	1.035	713
Scale	Total area of pigsty	14.719	62.284	713
Income	Net income from pig farming	3.736	0.966	713
Insurance	Pig insurance price	70.589	866.654	713
Network	Neighborhood mutual assistance level	4.018	0.886	713
Social	Number of socialized services	4.457	4.448	713
rzy	Loan or not	0.442	0.497	713
ybz	Standardization level of pig farms	3.184	1.156	713
yzj	Resident technical personnel or not	0.216	0.412	713
ylf	Medical epidemic prevention fee	1.483	1.345	713
Green	Green transformation degree of live pigs	57.880	20.646	713
Source	Degree of source prevention	1.506	0.716	713
Mid-range	Degree of process control	50.116	19.849	713
End	Degree of terminal governance	0.422	0.081	713
Organization	Industrialization organization	0.2707	0.445	713
x1	Independent breeder	0.579	0.494	713
x2	“Cooperatives+farmers”	0.076	0.265	713

x3	"Company+farmers"	0.187	0.389	713

3. Methodology, variables and data

3.1. Methodology

To verify the scientific and feasibility of the above research hypotheses, we constructed a benchmark model for Equation (1). This model includes green, which signifies the degree of green transformation in pig farming, and Organizition, which represents the organizational model of pig farming. We also considered a series of control variables designated as X:α signifies parameters that need to be estimated, while ε stands for the random error term, and *i* represents every breeder. In Equation (2), Social denotes livestock and poultry socialized services, while Organizition*Social means the interaction term between socialized services and industrial organization models to test the moderating effect, β signifies estimated parameters, and the meanings of the other variables are the same as those in Equation (1).

$$Green_i = \alpha_0 + \alpha_1 \text{Organizition}_i + \alpha_2 X_i + \varepsilon_i \quad (1)$$

$$\text{Green}_i = \beta_0 + \beta_1 \text{Organizition}_i * \text{Social}_i + \beta_2 \text{Organizition}_i + \beta_3 \text{Social}_i + \beta_4 X_i + \varepsilon_i \quad (2)$$

3.2. Variables

3.2.1. Dependent variable

Green transformation of pig farming. In this article, we draw on the research of Wu (2009) and Tan *et al.* (2022) to construct an evaluation index system for green production transformation of aquaculture households based on the principles of source prevention, process control, and end of treatment. The specific indicators are shown in **Table 1**. Considering the complexity and non-linear relationship between various indicators of green transformation evaluation, we use the entropy method to determine the weight of the indicators, and the weighted average is used to obtain the degree of green production transformation of farmers. The measurement formula is as follows.

First, obtain the positive consistency evaluation matrix (x_{ij}) for each indicator. The proportion of variables (k_{ij}) is expressed as:

$$k_{ij} = \frac{x_{ij}}{\sum_{i=1}^{n} x_{ij}} \quad (3)$$

Then, calculate the information entropy (m_{ij}) of each research variable in (k_{ij}):

$$m_j = -\frac{\sum_{i=1}^{n} k_{ij} \ln(k_{ij})}{\ln(n)} \quad (4)$$

The difference coefficient (p_j) of each indicator can be obtained from the value of information entropy:

$$p_j = 1 - m_j \quad (5)$$

Normalize for m_j to obtain the total weight of each research indicator as 1; then, obtain the weight of each research indicator n_j:

$$\eta_j = \frac{p_j}{\sum_{j=1}^{m} p_j} \quad (6)$$

3.2.2. Core independent variable

According to conceptual definition and theoretical analysis, the types of industrial organization models are "cooperatives+farmers" (x2) and "companies+farmers" (x3). Independent pig breeders (x1) as the control group. Taking "company+farmer" as an example, if the farmer cooperates with the company to raise pigs, the value is 1; otherwise, it is 0.

3.2.3. Control variables

Individual characteristics, family characteristics, and external environment as control variables, that have a significant impact on the participation of farmers in contracted agriculture and green production transformation (Tan *et al.* 2022; Fan *et al.* 2021; Ji *et al.* 2018). The age of the head of household, education level, whether they are village cadres, health level, and risk preference were selected to reflect individual characteristics; intelligence level, scale (mu), net income, and experience (years) in pig farming were selected to reflect the characteristics of household management; and government regulation, government technical support, social network, social services (times), and pig insurance price (CNY) were selected as village characteristic variables.

3.3. Data

The data used in this article come from three field investigations conducted by our research group in Sichuan and Jiangsu provinces in 2022 and 2023. When selecting the sample area, we mainly considered that Sichuan Province and Jiangsu Province are densely populated areas for pig farming in China, with significant differences in economic development levels and industrial organization models, which are representative. In this research, we adopt a combination of stratified sampling and random sampling. The specific sampling steps are: select 3 townships in the sample counties (districts) and 3 villages in each township and conduct random research on farmers in the villages. A total of 780 questionnaires were distributed during the survey, and 713 valid samples were obtained, with a questionnaire efficiency of 91.41%. **Table 2** presents descriptive statistics for each variable.

4. Empirical results analysis

4.1. Benchmark regression analysis

The regression results of industrialization organizations with respect to the green transformation of pig farming are shown in **Table 3**. Research has found that participating in industrial organizations has a significant positive impact on the degree of green transformation in pig farming. In particular, the "company+farmer" model has played a significant role in promoting the green transformation of pig farming. Independent farmers are not conducive to the green transformation of pig farming, and the "cooperative+farmer" model variable has not passed the significance test. This indicates that compared to other organizational models, farmers under the "company+farmer" model under contractual constraints are more likely to adopt green production technologies and implement environmental protection measures. Pig farmers can obtain more information and technical support on pig farming through cooperation with companies, thereby better meeting environmental constraints and market demands. The company can provide stricter environmental monitoring and training for pig farmers and assist and supervise them in implementing green production behavior to ensure a stable supply of pigs for the company. Industrial organizations can also provide credit support and technical exchange platforms for farmers, further alleviate financing constraints, and promote the green transformation of pig farming. In summary, the participation of pig farmers in industrial organizations, especially in leading pig enterprises, plays an important role in promoting the green production transformation of pig farmers.

Table 3 Regression results of the impact of industrialized organizations on the green transformation

VARIABLES	Green	Green	Green	Green
Organization	11.631***			
	(1.724)			
x1		-11.804***		
		(1.721)		
x2			-2.435	
			(2.793)	
x3				15.679***
				(1.880)
Constant	53.403***	65.562***	53.736***	53.694***
	(7.928)	(8.015)	(8.735)	(7.670)
Control variables	Yes	Yes	Yes	Yes
Observations	713	713	713	713
R-squared	0.115	0.116	0.059	0.137

*Note: *, **, and *** indicate significance at the 10, 5 and 1% levels, respectively. The figures in parentheses indicate the standard errors.*

Source: Author's own conception, using STATA software.

(The following table is the same)

Table 4 Regression results of instrumental variable estimation

VARIABLES	(1) First-stage Organization	(2) Second-stage Green
Knowledge	0.041***	
Organization		0.214***
Control variables	Yes	Yes
Observations	713	713
F-test	18.660***	5.630***

4.2. Endogeneity testing

To solve the endogenous problems caused by possibly missing variables and data errors in the process of model construction, we use the instrumental variable estimation method and select the degree of pig farmers' understanding of pig leading enterprises or cooperatives as the instrumental variable estimation of industrial organizations. Because pig farmers' understanding of enterprises or cooperatives directly affects their participation in industrial organizations, but the understanding is not related to their green production behavior, meeting the selection requirements of instrumental variable estimation. The regression results of 2SLS are shown in **Table 4**. The first-stage regression results show that instrumental variable estimation is highly correlated with the independent variable and significant at the 1% level. The F statistical value is greater than 10, so there is no weak instrumental variable estimation problem.

The second-stage regression results indicate that the joining of industrial organizations by pig farmers can significantly promote the green transformation of pig farming. This result is consistent with the benchmark regression results, indicating that the more familiar pig farmers are with companies or cooperatives. The more suitably they can choose industrial organizations the more effectively they can obtain the green production technology and service "dividends" brought about by industrial organizations, which can promote the green transformation of pig farming. The regression results show that the instrumental variable estimation method selected in this paper has a positive effect on solving endogenous problems.

4.3. Robustness testing

To test the scientific and rigor of the empirical conclusions of this study, a robustness test was conducted. First, the proportion of harmless waste treatment to the total amount is used to replace the original explanatory variable. The empirical test results are shown in **Table 5**. The plus–minus sign and significance of each correlation coefficient are consistent with the benchmark regression. Therefore, this empirical result is still stable.

Table 5 Replacing explanatory variables

VARIABLES	Td	Td	Td	Td
Organization	1.647***			
	(0.393)			
x1		-1.674***		
		(0.394)		
x2			-1.047*	
			(0.538)	
x3				2.760***
				(0.453)
Control variable	Yes	Yes	Yes	Yes
Observations	713	713	713	713
R-squared	0.086	0.087	0.066	0.113

Table 6 Heterogeneity of planting and breeding cycle

	Breeding cycle				No breeding cycle			
VARIABLES	Green	Green	Green	Green	Green	Green	Green	Green
Organization	-0.780				17.079***			
	(2.988)				(2.296)			
x1		0.780				−17.495***		
		(2.988)				(2.290)		
x2			-0.397				-8.087**	
			(3.647)				(4.027)	
x3				-1.555				19.389***
				(4.863)				(2.093)
Control	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	415	415	415	415	298	298	298	298
R-squared	0.037	0.037	0.036	0.037	0.293	0.299	0.163	0.331

4.4. Heterogeneity analysis

In recent years, the central government has continuously encouraged the development of a moderate-scale of pig planting and breeding cycle to promote the transformation of green production. Therefore, heterogeneity analysises are conducted on whether pig farmers adopt the “breeding cycle” behavior and the empirical results are shown in **Table 6**. Research has found that industrialized organizations have a significant positive impact on the green transformation of pig farming only in the absence of a planting and breeding cycle. The “cooperative+farmer” model is significantly detrimental to the green transformation of pig farming in the absence of the planting and breeding cycle.

We further examined the differences between restricted and suitable areas based on regional resource endowments and environmental regulations. The regression test results are shown in **Table 7**. The industrialization organization of suitable breeding areas has a significant positive impact on the green transformation of pig farming, whereas restricted breeding areas are not significant. The use of the “company+farmer” model in suitable breeding areas can significantly promote the green transformation of pig farming, possibly because under contractual constraints, improved breeds, veterinary drugs, and feed are all provided uniformly by the company, which can improve the green transformation in the source prevention stage. Under reputation mechanisms and government regulations, the supervisory role of the harmless treatment of diseased and dead pigs and terminal manure treatment is stronger than that of independent breeders. However, the intensity of environmental regulations in restricted breeding areas is already high, and the number of industrial organizations is relatively small. Moreover, the contractual constraints related to green production behavior in pig farming are not significant compared to those of independent farmers.

4.5. Mechanism verification

To further explore the impact mechanism of industrial organizations on the green transformation of pig farming, we conducted mechanism tests considering paths:

financing constraints, standardization degree of pig farms, pig farming technology, and medical epidemic prevention. The relevant mechanism test results are shown in **Tables 8** and 9. According to the test results presented in **Table 8**, participating in industrial organizations significantly promotes the financial accessibility, standardization construction level, breeding technology, and medical epidemic prevention level of farmers. Especially under the organizational model of “company+farmer”, farmers joining the company can not only alleviate their financing constraints but also improve their breeding technology and medical epidemic prevention level. However, in terms of standardized construction level, the promotion effect of the company on farmers is relatively weak. This result has important implications for our understanding and promotion of the development of agricultural industrialization. Participating in industrial organizations can provide better financial support for farmers and help them alleviate financing constraints and, thus, better develop and implement green production technologies.

Table 7 Regional heterogeneity

	Restricted breeding area				Adaptive zone			
VARIABLES	**Green**	**Green**	**Green**	**Green**	**Green**	**Green**	**Green**	**Green**
Organization	2.642				12.509***			
	(7.845)				(1.896)			
x1		−2.642				−12.720***		
		(7.845)				(1.890)		
x2			-11.262				-0.614	
			(21.828)				(3.302)	
x3				4.879				15.747***
				(7.982)				(2.124)
Observations	32	32	32	32	618	618	618	618
R-squared	0.613	0.613	0.616	0.616	0.119	0.121	0.056	0.131

Table 8. Mechanism tests I

VARIABLES	**Financing constraints**		**Standardization construction**		**Breeding technology**		**Medical epidemic prevention**	
Organization	0.465***		0.165*		0.702***		-0.310***	
	(0.037)		(0.098)		(0.034)		(0.104)	
x3		0.506***		0.145		0.906***		-0.236**
		(0.037)		(0.111)		(0.019)		(0.113)
Control	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	713	713	713	713	713	713	713	713
R-squared	0.212	0.198	0.101	0.099	0.629	0.773	0.040	0.035

In addition, as a part of the industrialization organization, the company can provide professional technical support and medical epidemic prevention guidance to farmers, improving their breeding technology level and animal health management level.

However, in terms of standardized construction level, the promotion effect of the company on farmers is limited, possibly because in terms of standardization construction, pig farmers need more autonomy and initiation, and excessive intervention by the company may limit their innovation and implementation capabilities.

According to the test results presented in **Table 9**, financing constraints, breeding technology, and medical epidemic, prevention level are key mechanisms related to the impact of industrial organizations on the green production transformation of farmers. These mechanisms have a significant impact on the green production behavior of farmers. However, the mechanistic role of industrial organizations in improving standardization and further promoting green production transformation is not obvious. Financing constraints are important factors that constrain pig farmers from implementing green production. Participating in industrial organizations can help alleviate financing constraints and improve the financing capabilities of farmers, thereby promoting the green transformation of pig farming. Moreover, improvements in breeding technology and medical epidemic prevention levels are key elements for pig farmers to implement green production. Industrialization organizations provide technical support and guidance to help pig farmers improve their breeding technology and animal health management levels, thereby promoting the green transformation of pig farming.

5. Differentiation analysis of the different industrial organization models

5.1. The impact of different industrial organization models on different stages

The previous section confirmed that the joining of industrial organizations by pig farmers can effectively improve the green transformation of pig farming. Further analysis of the impact of joining different types of industrial organizations on the green transformation of pig farming at different stages can clarify the specific direction of optimization of the pig industry chain. The regression results of the impact of different types of industrialized organizational models on the green transformation of pig farming at different stages are shown in **Tables 10,11 and 12**. Joining industrialized organizations by pig farmers can significantly enhance the degree of green transformation in the source prevention and process control stages of pig farming, but it is significantly detrimental to the green transformation of terminal management. The reason for this is that farmers joining industrial organizations can obtain feed, veterinary drugs, etc., provided by the organizations, directly promoting the prevention of green transformation at the source of pig breeding. In addition, industrial organizations regularly supervise the green production behavior of pig farmers and organize the unified, harmless treatment of sick and dead pigs, further improving the green transformation of the process control stage.

Table 9 Mechanism tests II

VARIABLES	The degree of green transformation in pig farming							
Financing constraints	3.496**	2.821*						
	(1.669)	(1.677)						
Standardization construction			0.853	0.878				
			(0.699)	(0.684)				
Breeding technology					14.933***	11.713***		
					(3.079)	(3.375)		
Medical epidemic prevention							1.346**	1.259**
							(0.529)	(0.515)
Organization	10.007***		11.491***		1.142		12.049***	
	(1.848)		(1.726)		(2.818)		(1.707)	
x3		14.251***		15.552***		5.068		15.977***
		(2.048)		(1.879)		(3.561)		(1.820)
Control	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	713	713	713	713	713	713	713	713
R-squared	0.120	0.141	0.117	0.139	0.148	0.150	0.040	0.144

Table 10 The Impact of different industrialization organization models on the prevention stage

VARIABLES	Source	Source	Source	Source
Organization	0.229***			
	(0.048)			
X1		-0.230***		
		(0.049)		
X2			-0.188**	
			(0.091)	
X3		14.209***		0.412***
		(1.799)		(0.042)
Control	Yes	Yes	Yes	Yes
Observations	713	713	713	713
R-squared	0.084	0.084	0.070	0.111

From the perspective of different organizational models, independent pig farmers are significantly detrimental to the green transformation of source prevention and process control, but they are conducive to the resource utilization of end-stage feces. Owing to the lack of professional and authoritative institutions to provide green feed and qualified veterinary drugs for independent breeders, it is difficult to ensure the prevention of pig breeding at the source, in addition to a lack of a supervision mechanism for green production behavior of industrial organizations, which leads to obstacles in the transformation of process control green production. The “cooperative+farmer” model has a significant negative impact on the green transformation of pig breeding in the stage of source prevention and terminal treatment. The significant difference between farmers who join a cooperative and independent farmer is that the organization of the cooperative bears some of the risks of fecal pollution. Based on moral risk, farmers have a weak awareness of green production. The “company+farmer” model has significantly promoted green transformation in the stage of source prevention and process control, and the formal cooperative breeding agreement signed between the company and farmers has played a key role.

5.2. The moderator effect of socialized services for livestock and poultry

Further study the moderator effect of socialized services for livestock and poultry farming on the impact of industrial organizations on the green transformation of pig farming. The empirical results are shown in **Table 13**. The socialized services of livestock and poultry have weakened the positive impact of industrial organizations on the green transformation of pig farming, possibly because the current partially free opportunities for socialized services in livestock and poultry farming have led to more pig farmers enjoying this service, which, in turn, has led to “rent-seeking” phenomena in some institutions, resulting in lax environmental supervision and falsification of environmental data.

From the perspective of different industrial organization models, socialized services for livestock and poultry have a significant positive regulatory effect on the impact of independent pig farmers on green production transformation. Whereas for the "companies+farmers" model, the negative regulatory effect is significant, and the moderator effect on "cooperatives+farmers" is very small because socialized services for livestock and poultry can provide medical treatment, epidemic prevention, sales, and convenient treatment of pig manure for independent farmers; save pig breeding costs and transaction costs. And increase the enthusiasm of pig farmers to adopt green production behavior.

Table 11 The Impact of different industrialization organization models on the regulation stage

VARIABLES	Mid-range	Mid-range	Mid-range	Mid-range
Organization	10.498***			
	(1.664)			
X1		-10.651***		
		(1.662)		
X2			-2.378	
			(2.810)	
X3				14.209***
				(1.799)
Control	Yes	Yes	Yes	Yes
Observations	713	713	713	713
R-squared	0.100	0.101	0.050	0.120

Table 12 The impact of different industrial organization models on terminal treatment

VARIABLES	End	End	End	End
Organization	-0.015**			
	(0.007)			
X1		0.014*		
		(0.007)		
X2			-0.021*	
			(0.012)	
X3				-0.009
				(0.009)
Control	Yes	Yes	Yes	Yes
Observations	713	713	713	713
R-squared	0.053	0.053	0.052	0.049

From the perspective of the impact of socialized services in livestock and poultry farming on the green transformation of pig farming at different stages, socialized services in livestock and poultry farming mainly weaken the degree of green transformation in the two stages of source prevention and process control for pig farmers who join industrial organizations. The weakening effect on terminal governance is not significant. The empirical results are shown in **Tables 14,15and16**.

From the perspective of different industrial organization models, for independent breeders, socialized services for livestock and poultry have a significant positive moderator effect on the source prevention and green transformation of pig farming in the process control stage. Because independent breeders need to independently purchase pig farming equipment, feed, and veterinary drugs and pay for waste treatment and fecal resource utilization fees. Therefore, socialized services for livestock and poultry directly help independent breeders solve problems and reduce production and transaction costs, thereby encouraging independent breeders to enhance their awareness of green pig production behavior. Under the "cooperatives+farmers" models, the regulatory effect of socialized services for livestock and poultry in the stages of source prevention, process control, and terminal governance is not significant. Under the "companies+farmers" model, socialized services for livestock and poultry have a significant negative moderator effect on the green transformation in the source prevention and process control stages but have little moderator effect on the green transformation in the end-treatment stage.

6. Conclusion and discussions

In this article, we investigated the green transformation of pig farming and explored the impact mechanism and heterogeneity of different types of industrial organizations on green transformation. The research results indicate that the joining of industrialized organizations by farmers can significantly promote the green transformation of pig farming, especially at the stages of source prevention and process control, but is not conducive to promoting the transformation of terminal governance. Differences can also be observed in the impact of different organizational models on green transformation. Specifically, the "company+farmers" model can promote green transformation, whereas independent farming is not conducive to green transformation, and the promotion effect of farmers joining cooperatives is not significant. From an overall perspective, farmers joining industrial organizations is beneficial for promoting the green transformation of pig farming, which is consistent with existing research conclusions (Saenger *et al.* 2013; Ji *et al.*2018; Zhu *et al.* 2020; Tan *et al.* 2022). However, we innovatively considered the differences in the stages of green transformation and the models of industrial organizations, rather than treating these two variables homogeneously, responding to some studies that suggest the negative impacts of joining industrial organizations (Thu *et al.* 2012; Kim *et al.* 2023). Further investigation reveals that industrialized organizations mainly promote farmers' green production transformation by improving their breeding technology, reducing their financing constraints, and reducing medical and epidemic prevention costs.

Table 13 The moderator effect of socialized services for livestock and poultry

VARIABLES	Green	Green	Green	Green
Social	0.371*	-0.715**	0.028	0.210
	(0.199)	(0.304)	(0.184)	(0.209)
Organization	16.772***			
	(2.222)			
Organization*Social	-1.076***			
	(0.365)			
x1		-17.100***		
		(2.208)		
Social*x1		1.098***		
		(0.360)		
x2			-3.691	
			(3.811)	
Social*x2			0.222	
			(0.549)	
x3				19.431***
				(2.566)
Social*x3				-0.830*
				(0.440)
Control	Yes	Yes	Yes	Yes
Observations	713	713	713	713
R-squared	0.127	0.129	0.059	0.143

Table 14 The moderator effect of socialized services—source prevention

VARIABLES	Source	Source	Source	Source
Social	0.022***	-0.001	0.017***	0.018***
	(0.007)	(0.007)	(0.005)	(0.006)
Organization	0.330***			
	(0.073)			
Organization* Social	-0.021**			
	(0.009)			
x1		-0.341***		
		(0.074)		
Social*x1		0.023**		
		(0.010)		
x2			-0.088	
			(0.159)	
Social*x2			-0.018	
			(0.018)	
x3				0.479***
				(0.060)
Social*x3				-0.015**
				(0.007)
Control	Yes	Yes	Yes	Yes
Observations	713	713	713	713
R-squared	0.088	0.089	0.071	0.113

Moreover, socialized services for livestock and poultry farming cannot effectively promote the strengthening of green production transformation in industrial organizations but are more beneficial for independent farmers. Specifically, socialized services for livestock and poultry farming mainly weaken the degree of green transformation in the two stages of source prevention and process control for pig farmers who join the industrial organizations, and the weakening effect on terminal governance is not significant. These research conclusions are similar to existing studies (Hu *et al.* 2022; Huan *et al.* 2022), but differs in that we found that socialized services can weaken the positive role of industrialized models.

Table 15 The moderator effect of socialized services—process control

VARIABLES	Mid-range	Mid-range	Mid-range	Mid-range
Social	0.238	-0.732**	-0.075	0.094
	(0.195)	(0.297)	(0.178)	(0.204)
Organization	15.129***			
	(2.152)			
Organization* Social	-0.970***			
	(0.357)			
x1		-15.358***		
		(2.144)		
Social*x1		0.975***		
		(0.353)		
x2			-3.839	
			(3.952)	
Social*x2			0.258	
			(0.570)	
x3				17.604***
				(2.439)
Social*x3				-0.751*
				(0.422)
Control	Yes	Yes	Yes	Yes
Observations	713	713	713	713
R-squared	0.111	0.112	0.051	0.125

Table 16 The moderator effect of socialized services—terminal treatment

VARIABLES	End	End	End	End
Social	-0.001*	-0.002**	-0.002**	-0.002***
	(0.001)	(0.001)	(0.001)	(0.001)
Organization	-0.011			
	(0.010)			
Organization* Social	-0.001			
	(0.001)			
x1		0.009		
		(0.010)		
Social*x1		0.001		
		(0.002)		
x2			-0.009	
			(0.018)	
Social*x2			-0.002	
			(0.003)	
x3				-0.015
				(0.012)
Social*x3				0.001
				(0.002)
Control	Yes	Yes	Yes	Yes
Observations	713	713	713	713
R-squared	0.054	0.054	0.053	0.050

From the perspective of the planting and breeding cycle, the joining of industrial organizations by farmers who have not implemented the planting and breeding cycle can significantly promote the transformation of green production, with the “company+farmer” model being particularly evident, whereas the impact of farmers who have implemented the planting and breeding cycle is minimal. From the perspective of regional heterogeneity, the integration of farmers in suitable breeding areas into industrial organizations can significantly promote the transformation of green production, with the "company+farmers" model being particularly significant, whereas the impact of restricted breeding areas is minimal.

Based on the above research conclusions, the following insights and policy recommendations are obtained. First, it will establish a sound organizational system for the pig breeding industry and optimize the organizational structure of pig industrialization. The government should improve the reward and punishment system for industrial organizations and establish a reasonable reward system based on the level of regional economic development and the endowment of pig breeding resources. Second, the government should promote the "planting and breeding cycle" according to local conditions. The pig breeding scale should be determined based on "land" and "breeding", and planting crops should be selected in combination with soil characteristics to improve the comprehensive economic, social, and ecological benefits of pig breeding. Third, the quality of socialized services for livestock and poultry farming should be improved. In addition, we also recommend that cooperation between pig breeding intermediary organizations, village governments, and pig breeding enterprises be promoted to leverage their advantages and synergies in their respective fields.

Although this paper has preliminarily clarified the impact of different industrialized organizational models on the green full-cycle production of breeding entities, there are still several shortcomings. Firstly, the research samples were collected from Jiangsu Province and Sichuan Province, China, and thus the conclusions may not necessarily be applicable to other regions. Secondly, the research primarily focuses on the pig farming industry in China, which does not fully encompass the entire livestock farming sector (Gan and Hu, 2016), leaving room for further exploration in future studies. Thirdly, when measuring green production, it would be more comprehensive to incorporate research from the materials field and adopt new methods for measurement (Kurian and Liyanapathirana, 2019; Loganathan *et al.* 2022; Mohanraj and Vidhya, 2023; Padmapoorani *et al.* 2023; Gopalakrishnan *et al.* 2024).

Ethics Approval and Consent to Participate

Not applicable.

Consent for publication

Not applicable.

Data availability

Data can be requested from the corresponding author.

Competing interests

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