

## Article

# Does Formal Contract Farming Improve the Technical Efficiency of Livestock Farmers? A Case Study of Fattening Pig Production in Hanoi, Vietnam

Le Thi Thu Huong <sup>1</sup>, Luu Van Duy <sup>2,\*</sup>, Bui Phung Khanh Hoa <sup>3</sup>, Bui Thi Nga <sup>4</sup> and Nguyen Van Phuong <sup>5</sup>

<sup>1</sup> Faculty of Accounting and Business Management, Vietnam National University of Agriculture, Hanoi 12406, Vietnam; [thuonglt.qtkd@gmail.com](mailto:thuonglt.qtkd@gmail.com) or [ltthuong@vnua.edu.vn](mailto:ltthuong@vnua.edu.vn)

<sup>2</sup> Faculty of Economics and Management, Vietnam National University of Agriculture, Hanoi 12406, Vietnam

<sup>3</sup> Hanoi Department of Agriculture and Environment, Hanoi 151100, Vietnam; [khanhhoa0710@gmail.com](mailto:khanhhoa0710@gmail.com)

<sup>4</sup> Faculty of Tourism and Foreign Languages, Vietnam National University of Agriculture, Hanoi 12406, Vietnam; [hieu0306@gmail.com](mailto:hieu0306@gmail.com)

<sup>5</sup> Department of Marketing, Institute of Business Administration, Vietnam National University, Hanoi 123080, Vietnam; [phuonglangvan@gmail.com](mailto:phuonglangvan@gmail.com)

\* Correspondence: [luuvanduy@vnua.edu.vn](mailto:luuvanduy@vnua.edu.vn) or [luuvanduy@gmail.com](mailto:luuvanduy@gmail.com); Tel.: +84-987-912-915

**Abstract:** Contract farming has become a sustainable strategy in agriculture around the world. Formal farming contract in pig production is one of the priorities of the Vietnamese Government for livestock development. Due to the differences in husbandry methods, a comparison of the technical efficiency between contract and noncontract pig farms has not been studied in Vietnam yet. This study attempts to do so and proposes implications for the sustainable development of pig production in Vietnam. In this study, we surveyed 201 pig farms (63 contract farms and 138 noncontract farms) in Hanoi, Vietnam, and applied data envelopment analysis (DEA) with a meta-frontier. Under group frontiers, the technical efficiency of the contract and noncontract farms are 96.11% and 88.64%, respectively. However, the meta-technology ratios of the two groups are 82.30% and 99.99%, respectively, which means that contract farms' technical efficiency is lower than noncontract farms. An interesting finding is that although the technical efficiency of contract farms is lower than noncontract farms, their annual pig income is significantly higher, making contract farming attractive to farmers. Results of Tobit regression models showed that land rent is one of the important factors that reduce the technical efficiency of both contract and noncontract farms. This result implies that the Vietnamese government should revise the land limit policy so that farms can own more land. Another finding is that the high feed price reduces the technical efficiency of noncontract farms. The policy implication from this finding is that the Vietnamese government should develop domestic raw material areas for feed production to lessen the dependence on imported raw materials from abroad, which contributes to reducing the feed prices in Vietnam.

**Keywords:** formal contract farming; data envelopment analysis; pig production; technical efficiency; livestock production



Academic Editor: Sebastiana Failla

Received: 24 February 2025

Revised: 26 March 2025

Accepted: 3 April 2025

Published: 15 April 2025

**Citation:** Huong, L.T.T.; Duy, L.V.; Hoa, B.P.K.; Nga, B.T.; Phuong, N.V. Does Formal Contract Farming Improve the Technical Efficiency of Livestock Farmers? A Case Study of Fattening Pig Production in Hanoi, Vietnam. *Sustainability* **2025**, *17*, 3557. <https://doi.org/10.3390/su17083557>

**Copyright:** © 2025 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

## 1. Introduction

According to the Food and Agriculture Organization [1], pork is the most widely eaten meat in the world (36%), followed by poultry (33%), beef (24%), and goats/sheep (5%). With a total production of 3.56 million tons, accounting for 3% of global pork production,

Vietnam ranks 6th in world pork production [2]. Pig production is the primary livestock sector in Vietnam, accounting for 62% of the total weight of animal meat [3]. Pig production is also a livelihood for rural households because it contributes 14% of total family income and 25% of total income from agriculture [4]. With the increase in population and the growing protein content in the Vietnamese people's diet, the demand for pork is increasing [1].

Small-scale livestock farmers with limited resources (e.g., land, capital, infrastructure, and technology) have been unable to meet the increasing demand for pork quantity and quality. Faced with the inherent challenges of small-scale livestock farming, the Vietnamese government has issued a series of policies to develop large-scale farms and strengthen the linkage between farms and commercial integrators [5]. One of the most popular forms of linkage is a farming contract, which mutually benefits farmers and integrators. By participating in the farming contracts, farmers receive the inputs (e.g., piglets, feed, and technical advice) without payment, and wage for pig raising from the integrators [6]. By joining the contract, integrators can control the quality of pigs produced by contract farms. Furthermore, integrators can avoid their responsibility to comply with environmental regulations by passing them to contract farmers [7,8].

Technical efficiency evaluates the ability to use resources efficiently [9]. In other words, it measures how much inputs could be saved with observed outputs or how much outputs increase with existing inputs. Improving technical efficiency is the basis for improving farmers' incomes and livelihoods.

Various studies have examined technical efficiency in pig production, identifying key factors such as technology adoption [10], education level, farming experience, and access to extension services [11]. Studies on the technical efficiency of noncontract pig farmers in Vietnam pointed out the influencing factors including the education level of household heads, access to credit, pig density, family income, herd size, and percentage of own-produced piglets and feeding modes [12], farming systems [13], live weight per fattening pig, breeding time, experience, family member joining in pig production, income from pig, and access to veterinary services [14,15]. Moreover, contract farming is often promoted to enhance smallholder productivity by improving access to inputs, credit, extension services, and markets. However, its impact on technical efficiency remains debated. While some studies highlight efficiency gains, others argue that contract rigidity and increased costs may limit these benefits. Research by Liang, Bi and Zhang [16] has shown that contract farming can significantly increase income and technical efficiency in the agricultural production of beef cattle farmers in China. Begum, Alam [17] argued that contract farming is positively and significantly related to the technical, allocative, and economic efficiency of poultry farms in Bangladesh.

Prior studies on technical efficiency in pig production in Vietnam only focused on finding ways to improve the technical efficiency of noncontract farmers but ignored farmers with formal farming contracts. These studies believe that noncontract farmers are more vulnerable than contract farmers because they do not receive any support from integrators. However, contract farming has become a leading trend in developing countries, including Vietnam. African swine fever (ASF) has had a devastating impact on Vietnam's pig industry since its emergence in February 2019, leading to the culling of six million pigs [18]. ASF has significantly changed Vietnam's pig industry, shifting towards reducing small-scale households and increasing higher levels of biosecurity and high-technology farms as formal contract farms of FDI integrators [18]. This shows that developing contract farming in livestock production is a sustainable strategy of the Vietnamese government. In the context of cooperation between farmers and integrators, improving technical efficiency offers win-win solutions for both integrators and farmers. By improving technical efficiency, the contract farmers would gain more benefits under the contract.

In measuring technical efficiency in pig farms, previous studies mainly used regular inputs such as feed, piglets, labor, depreciation of fixed assets, and other variable costs (e.g., veterinary medicine, vaccine, electricity, and other fees). However, fattening pig production in tropical countries consumes a large amount of water to cool and clean barns, which is then discharged into the environment, causing pollution [19,20]. Regarding water scarcity and severe environmental pollution, using water efficiently in livestock farming benefits farmers and communities. Therefore, this study attempts to add water to the normal input set to improve the models for measuring technical efficiency in pig farms.

Previous studies measure the technical efficiency of contract and noncontract livestock farms with a single production frontier, which makes the results biased due to the heterogeneity of livestock farms. In fact, due to different production characteristics, contract and noncontract livestock farms have their own production frontiers, so using the same production frontier would distort the technical efficiency. Scholars offer a solution to limit this bias by using the meta-frontier technique. This study uses the DEA model and the meta-frontier technique to measure and compare technical efficiency between contract and noncontract pig farms.

To address the research gaps, this study measures and compares the technical efficiency of contract and noncontract pig farms with the first appearance of water in the input set. In addition, the study also analyzes the factors affecting the technical efficiency of each group of contract and noncontract farms, which provides solutions to improve the technical efficiency.

## 2. Contract Farming in Pig Production in Vietnam

Contract farming in livestock production began to develop in Vietnam in the 2000s when the Vietnamese government strongly supported it by issuing Decision 80/2002/TTg. The most prominent feature of this decision is the promotion of cooperation between four partners: the state, farmers, researchers, and enterprises [5]. There are two common types of farming contracts in pig production: formal and informal. A comparison of the types of formal, informal contract, and noncontract livestock farming is presented in Table 1.

**Table 1.** Comparison of formal and informal farming contracts.

Criteria	Farming Contract					Noncontract
	Formal			Informal		
	Type 1	Type 2 (for This Study)	Type 3	Type 1	Type 2	
Forms of contract	Written agreement	Written agreement	Written agreement	Unwritten agreement	Unwritten agreement	N/A
Actors	- Integrators; - Farmers.	- Integrators; - Farmers.	- Integrators; - Farmers.	- Cooperatives; - Farmers.	- Input suppliers; - Farmers.	- Farmers.
Operation	Integrators rent livestock facilities from farmers.	Integrators provide farmers feed, piglets, vaccines, and technical advice; collect slaughtered pigs; and pay the farmers wages for pig raising.	Integrators buy slaughtered pigs from farmers.	Cooperatives act as representatives for farmers to buy inputs and sell outputs.	Piglet sellers or feed distributors sell piglets or feed to farmers with credit.	Farmers buy inputs and sell outputs by themselves.
Housing	- The facility can confine at least 500 fattening pigs; pigpens with automatic cooling system certified by the integrators; far from the residential zone; qualified waste treatment plant; 3-phases electricity; hygiene water source.		N/A	Participating the cooperatives	N/A	N/A

Table 1. Cont.

Criteria	Farming Contract					Noncontract
	Formal			Informal		
	Type 1	Type 2 (for This Study)	Type 3	Type 1	Type 2	
Feeding mode	- Commercial feed; - Follow the Integrators' instructions.		- Commercial feed; - Follow the Integrators' instructions.	- Follow the technical advice from cooperatives.	- Follow the technical advice from feed distributors.	- Commercial and/or mixed with agricultural by-production.
Breeds	- Qualified piglets provided by integrators.		- Piglet sellers.	- Piglet sellers.	- Piglet sellers.	- Piglet sellers.
Disease management practices	- Fully vaccinated by the integrators; - Limited access to the farms.		- Vaccination depends on the financial capacity of the farms.	- Vaccination depends on the financial capacity of the farms.	- Vaccination depends on the financial capacity of the farms.	- Vaccination depends on the financial capacity of the farms.
Pig income	Integrators pay the farmers at the rate of 420,000 VND–540,000 VND/pig	Integrators pay the farmers at the rate of 3000 VND–4500 VND/1 kg weight gain.	Integrators pay the farmers 1000 VND–2000 VND/kg liveweight higher than the market price. Pig income depends on market.	Pig income depends on market.	Pig income depends on market.	Pig income depends on market.

Sources: Author's compilation based on secondary document review.

Formal contracts are written agreements between vertically integrated feed–breed–meat processing–export companies and large-scale farmers [21]. Formal contracts for pig production in Vietnam have been provided by CP-Vietnam since 2000 and by Indonesia's Jappa Comfeed since 2003. Formal contracts are usually provided to farrow to wean and grow to finish operations. Currently, there are three types of formal contracts between integrators and farmers: facility rental, hiring farmers for pig raising, and buying slaughtered pigs [22].

For the first type, integrators only rent facilities from farmers. The rent is calculated based on the capacity and quality of the facilities. The integrators pay contract farmers with a rental rate of 420,000 VND to 540,000 VND/pig. The facilities must meet the criteria for waste treatment, electricity, and water.

For the second type, the integrators provide contract farmers with piglets, feed, veterinary medicines, vaccines, and technical instructions for pig raising. The farmers use their own facilities and bear the expenses for labor, water, electricity, and other fees. Farmers are responsible for raising the pigs and following the integrator's instructions. Integrators would collect all pigs when they reach the slaughtered weight and pay farmers the wage rate of 3.8 to 4.5 thousand VND/kg of weight gain. In addition, farmers also receive bonuses if feed use efficiency is high and the pig death rate is low. The contract term is five years for the new and one year for the old facilities. The integrators only contract with the farms owning the facility confining at least 500 fattening pigs. The pigpen must be equipped with an automatic cooling system, three-phase electricity, and a hygienic water source. The farm must be located far from residential areas to reduce disease risks and environmental pollution. In this study, we focus on this type of formal farming contract since it is the most popular one in Vietnam [23].

For the third type, the integrators buy live slaughtered pigs from the farmers. They pay farmers a price of 100 to 2000 VND/kg higher than the market price at the time of purchase. The price depends on whether the pigs are GAP-certified or not. Farmers must buy all inputs (e.g., piglets, feed, and veterinary medicine) by themselves. According to Hoang Vu Quang [22], the average facility cost is about 1.968 million VND/pig for the first

two formal contract types and 1.800 million VND for the third one, while it is 1.1 million VND for informal and noncontract farms. The unqualified facility is the main difficulty of noncontract pig farms in participating in the farming contracts.

Informal contracts are unwritten agreements between farmers and cooperatives or input suppliers [5]. In the first type, farmers are members of cooperatives which may produce or purchase agricultural products. In this form, cooperatives sign contracts with integrators or suppliers for the supply of feed and stocks on behalf of their members. The members may sell their pigs to the cooperative or a slaughterhouse. Alternatively, cooperatives may sign the farming contracts with integrators while the members are the ones who carry out the contracts. In this way, farmers with limited resources can still participate indirectly in farming contracts. The cooperatives control the pig quality of its members by providing technical support services and ensuring the quality of feed and stocks. Members are assisted in selling slaughtered pigs at optimal transport costs and reasonable selling prices.

In the second type, farmers have linkages with input suppliers (e.g., feed distributors and piglet sellers). The feed distributors sell feed to farmers and earn additional profits through feed credit (farmers can buy feed without having to pay immediately but would have to pay a higher price for the buying on credit). The farmers enter this linkage for assured feed quality and managing cash flow with feed credit.

The study by Le [24] measured the production efficiency of pig farms among four groups: FDI integrators, cooperatives, domestic integrators, and households. The results showed that pig farms of FDI integrators operated most effectively because they had large capital, modern production technologies, qualified facilities, and steady sales. The efficiency of the farms participating in the cooperatives or contracting with the domestic integrators is lower than that of the FDI integrators. Pig households have the lowest efficiency due to the low quality of facilities and breeding stock, high feed costs, and unstable sales.

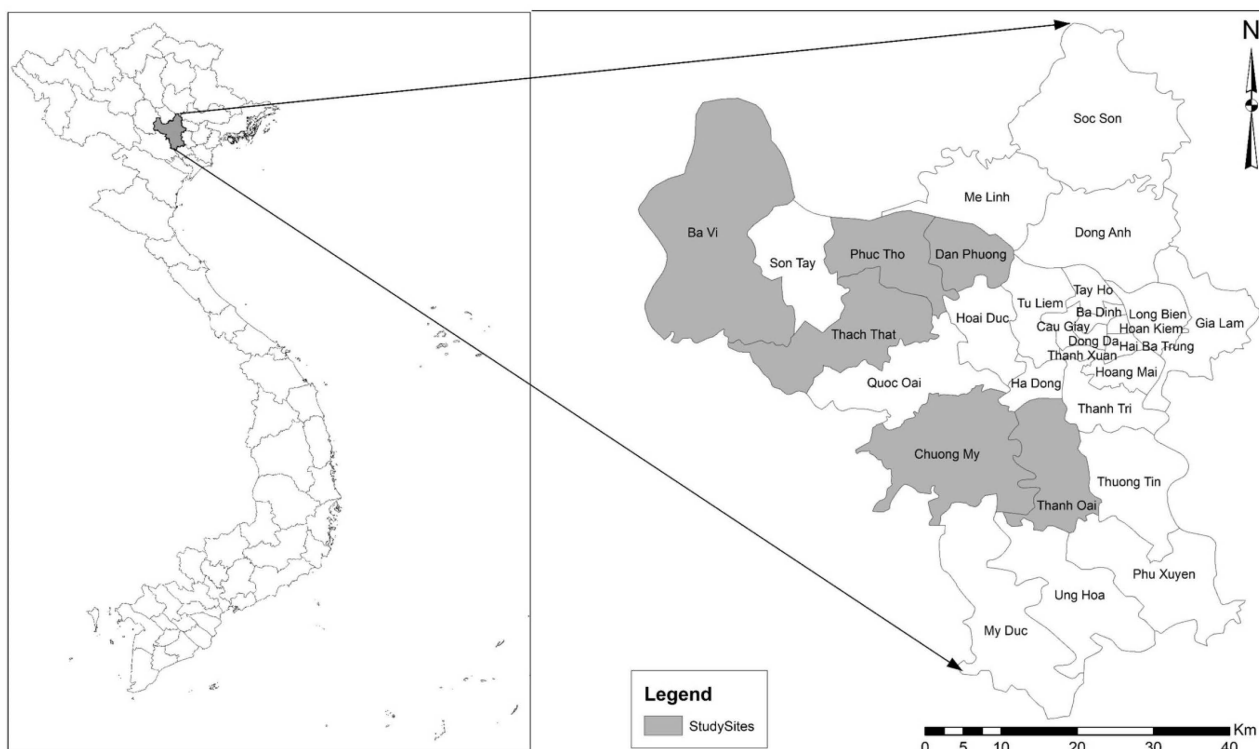
### 3. Research Methods

#### 3.1. Study Site

Hanoi was chosen as the research site because it is one of the three provinces with the most significant number of pigs in Vietnam, with about 1382,385 pigs, accounting for 5.11% of the country's total pig herd [3]. Moreover, pig production in Hanoi can represent different regions in Vietnam because it has different types of farming systems including industrial, semi-industrial, conventional systems, or different scales (e.g., large, medium, and small sizes), or/and alternative forms of linkage in production such as formal and informal contract farming or independent farming [20].

Hanoi is a province in the Red River Delta with a natural land area of 3345 km<sup>2</sup>, of which the agricultural land area is 1886 km<sup>2</sup>, accounting for 56.34% of the total natural land area. The Hanoi People's Committee has issued the Regulation on livestock density for sustainable livestock development. As of 2023, Hanoi's livestock density is 3.44 livestock units/ha which will reduce to 1.8 livestock units/ha by 2030 [25]. Hanoi includes 12 urban districts, 17 rural districts, and one town. Pig farms are in most rural districts of Hanoi. According to the statistics from the Department of Livestock and Veterinary Medicine of Hanoi, in 2023, there were 45,611 pig holders, including 43,256 pig households and 2355 pig farms. According to Decree 13/2020/ND-CP, the number of livestock units for pig households, small, medium, and large-scale farms is under 10, under 30, under 300, and 300 or more, respectively [26]. Among the 2355 farms, the number of formal contract farms is 273, accounting for 11.6% while the number of pigs produced by the contract farms is 410,512, accounting for 29.71% of the total pig population in Hanoi. Pig households produced 658,112 pigs (47.60%); the noncontract farms produced 313,761 pigs (22.69%).

The figures show that contract farms, although few, are large. Accounting for 56.12% of the pig population in Hanoi, six rural districts (Ba Vi, Phuc Tho, Thach That, Dan Phuong, Chuong My, and Thanh Oai) were selected to conduct the survey (see Figure 1).



**Figure 1.** Study site.

Since pig farms are growing while pig households are decreasing, our study focuses on pig farms. We only selected samples from the 2355 pig farms to reduce the heterogeneity in measuring technical efficiency. According to Yamane [27], when the population is known, the sample size is calculated as follows.

$$n = \frac{N}{(1 + N \times e^2)}$$

where  $n$  is the sample size;  $N$  is the population;  $e$  is the confidence level (e.g., 90%, 95%, or 99%).

The number of formal contract and noncontract pig farms in the study area were 273 and 2082, respectively. With the confidence level at 90%, the sample size for contract and noncontract farms should be at least 74 and 96, respectively.

The survey was conducted from April to July 2024. With the list of pig farms provided by the Department of Livestock and Veterinary Medicine of Hanoi, we planned to randomly select 74 contract farms in Chuong My, Thach That, and Phuc Tho districts, and 96 noncontract farms in Ba Vi, Dan Phuong, and Thanh Oai districts. However, due to the risk of disease, we failed to access some contract farms, the number of valid contract farms was 63. Access to noncontract farms appeared to be less difficult, so the number of samples collected was 138, which is larger than planned. We understood that the sample size of the two groups of pig farms was modest and could be biased, so we applied the bootstrap technique to the technical efficiency score to overcome the bias [28–30].

### 3.2. Data Envelopment Analysis

Technical efficiency measures the ability to save inputs with a given quantity of output (input-oriented) or the possibility of increasing outputs with a given quantity of inputs

(output-oriented) [9]. In this study, we prefer input-oriented rather than output-oriented methods because we expect to save inputs related to natural resources (water).

To measure technical efficiency in pig farms, scholars often use two methods: the parametric technique (stochastic frontier analysis—SFA) [7,31] and non-parameter techniques (data envelopment analysis—DEA) [15,32–35]. Although there is a difference in technical efficiency measurement, the production frontier constructed from these two techniques is the same, and the measuring results are consistent [36,37]. Each method has its own advantages and disadvantages. With SFA, its advantage is to provide solid information to test hypotheses and build confidence intervals [36]. However, it requires assumptions about the form of the production frontier and the distribution of efficiency scores [36]. The results may be biased if the wrong form of the production function is chosen. In addition, SFA does not allow for the reliability of inferences from small samples to be assessed. In other words, the maximum likelihood in SFA requires a larger sample size.

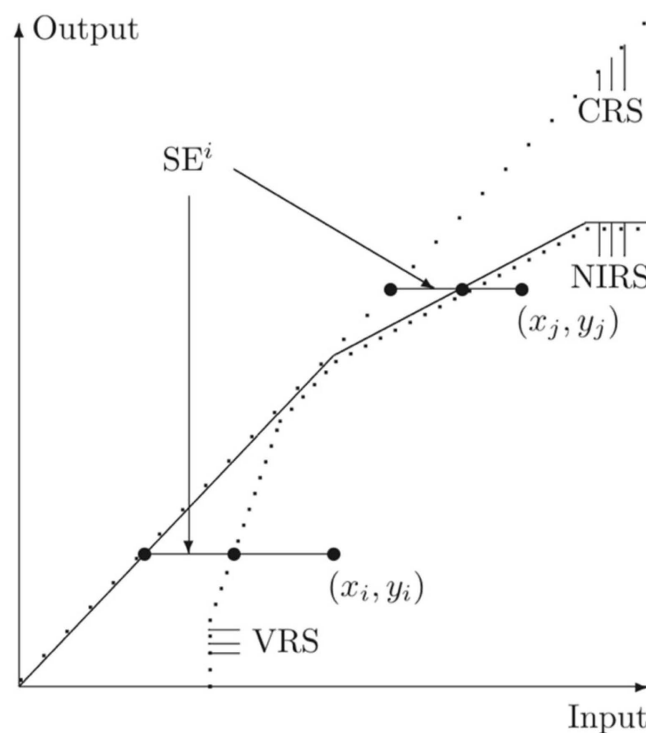
DEA's limitation compared to SFA is that it does not measure unobserved noises and has poorer capabilities in hypothesis testing and confidence interval building [36]. However, the strength of DEA is that the production frontier it generates is based on actual observations, so it does not require a specific production function form while allowing curvature conditions to be imposed [36]. Moreover, DEA does not require a large sample size like SFA. With a small sample size (204 farms), we choose DEA to analyze technical efficiency in this study.

$N$ ,  $K$ , and  $M$  denote the number of farms, inputs, and outputs of the farms, respectively. The column vectors  $x_i$  and  $y_i$  present the input and output data for farm  $i$ -th, respectively. Data for all farms ( $N$ ) in the sample are displayed in the  $K$ -by- $N$  input matrix ( $X$ ) and  $M$ -by- $N$  output matrix ( $Y$ ).

TE is measured in the DEA by Equation (1) as follows:

$$\begin{aligned} & \text{Min}_{\theta\lambda} \theta, & (1) \\ & \text{Subject to } -y_i + Y\lambda \geq 0, \\ & \theta x_i - X\lambda \geq 0, \\ & N1'\lambda = 1, \\ & \lambda \geq 0, \end{aligned}$$

where  $N1$  and  $\lambda$  denote vectors of ones and constants, respectively.  $\theta$  denotes the technical efficiency of  $i$ -th farms, which presents the largest radial contraction of the input vector  $x_i$ .  $\theta$  ranges from 0 to 1, where 1 is the score of the efficient farms at the frontier. The first constraint ensures that the output of any  $i$ -th farm is lower than the outputs of the farms forming the production frontier. The second constraint limits the proportional reduction in the input to the best farming technique among the surveyed farms. The third constraint concerns the convexity of the production frontier. Without this constraint, DEA automatically generates the constant return to scale (CRS), which describes the proportional increase in output when the input is increased (Figure 2). However, an increase in inputs does not always lead to a proportional increase in outputs, especially in the agricultural sector, which creates the production frontier with a variable return to scale (VRS) [38]. The difference in scale explains the difference between CRS and VRS. Scale efficiency (SE) is measured by  $TE_{CRS}/TE_{VRS}$ , where  $TE_{CRS}$  and  $TE_{VRS}$  are the TE under CRS and VRS, respectively [38].  $SE = 1$  means that the farm is operating at the optimal scale, while  $SE < 1$  means that it can adjust its scale in the long run to increase its technical efficiency.



**Figure 2.** Input-based technical and scale efficiency. Note: SE: Scale efficiency; CRS: Constant return to scale, VRS: Variable return to scale. Source: [39].

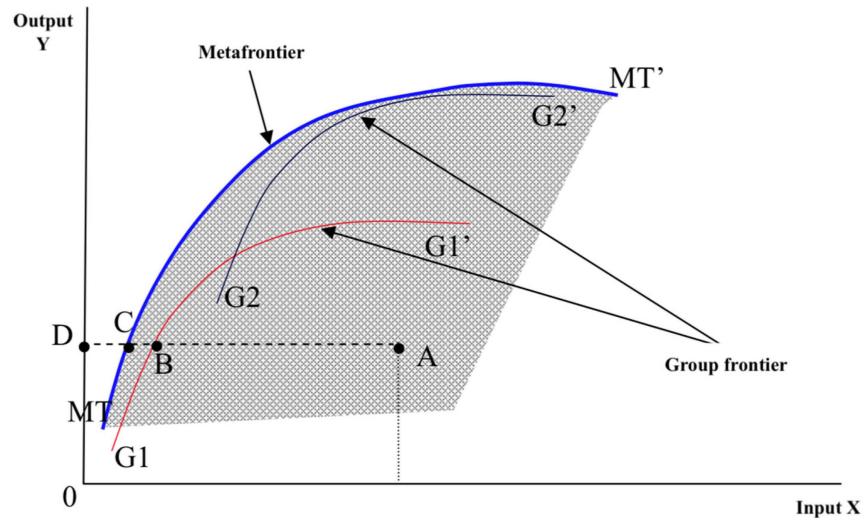
DEA ignores white noise because DEA's technical efficiency is estimated based on a finite number of surveyed farms. At the same time, that deviation from the production frontier is solely attributed to the inefficiency [40]. Bootstrapping can correct bias in technical efficiency scores caused by sampling variation [28,29].

### 3.3. Meta-Frontier

Contract and noncontract pig farming have different operating methods (e.g., housing system and feeding mode), so assuming that farms share a common production frontier is inappropriate. Scholars propose using meta frontiers to measure technical efficiency that considers differences between different farming operations [41,42].

Technical efficiency is calculated by comparing the performance of any farm with a production frontier constructed from the best-performing farms in one sample. Contract and noncontract farms differ in how they operate, forming two different production frontiers. However, because they use the same inputs and produce the same outputs, they share similar characteristics, forming a common production frontier encompassing all the individual production frontiers [42]. Figure 3 describes the meta frontier and group frontiers.  $G1G1'$ ,  $G2G2'$ , and  $MTMT'$  are the production frontiers of groups G1, G2, and the meta-frontier. DEA first measures the technical efficiency of farms in each group with respect to the production frontier of that group. Then, it measures the technical efficiency of all farms with respect to the common production frontier for both groups (meta frontier). The meta-technology ratio (MTR) of the two groups is used to compare the technical efficiency of these two groups. The group with a higher average value of MTR has higher technical efficiency. MTR is calculated as follows.

$$MTR_i = \frac{\theta_i^m}{\theta_i^g} \quad (2)$$



**Figure 3.** Meta-frontier to measure the technical efficiency of different groups.

$\theta_i^m$  and  $\theta_i^g$  are technical efficiencies with meta frontier and group frontiers, respectively. The technical efficiency of A under  $G1G1'$  is  $DB/DA$ . Its technical efficiency under meta-frontier is  $DC/DA$ . So, MTR is calculated as  $DC/DB$ .

### 3.4. Tobit Model

The technical efficiency scores resulting from DEA were bootstrapped 1000 times for smoothing the empirical distribution, which provides more consistent results in Tobit Regression [28–30]. Since technical efficiency is a continuous variable ranging from 0 to 1 (or 0% to 100%), some regression models such as ordinary least squares (OLS) or Tobit models can be used to analyze the factors affecting it [43]. The Tobit model is preferred in this study because it overcomes the drawback of the OLS model, which is that the predicted values of technical efficiency may be out of range from 0 to 1. A two-limited Tobit model ensures that the predicted technical efficiency values lay in the interval [44]. Equation (3) below expresses the Tobit model [44]:

$$\theta^* = ZB + e \quad (3)$$

$$\theta = \begin{cases} \theta^* & \text{if } 0 < \theta^* < 1 \\ 0 & \text{if } \theta^* < 0 \\ 1 & \text{if } \theta^* > 1 \end{cases},$$

where

Z: Independent variables including gender, experience in farming, education level, household size, land rent, access to credit, location, pig density, raising period, feed cost, death ratio, percentage of own-produced piglets, waste treatment area [12–15,20,45];

$\theta$ : TE scores;

$\theta^*$ : latent variable;

B: parameters to estimate;

e: error term.

## 4. Results and Discussion

### 4.1. Inputs and Outputs of Contract and Noncontract Pig Farms

A summary of inputs and outputs in pig production between contract and noncontract farms is presented in Table 2. Feed Conversion Rate (FCR), one of the indicators used to evaluate the efficiency of feed use is the amount (kg) of feed for 1 kg of weight gain.

The results show that the FCR of contract farms (2.4) is higher than that of noncontract farms (2.21), meaning that noncontract farms have higher feed use efficiency than contract farms. Studies on FCR in fattening pig production showed that the optimal selling weight of pigs is between 80 kg and 110 kg [46], which achieves the best FCR. Normally, contract farms reach the optimal FCR due to the high quality of housing systems, stocks, and raising techniques [20,45]. However, at the time of the survey, the average liveweight of slaughtered pigs of contract farms was 115.05 kg, while that of noncontract farms was 101.74 kg. Normally, integrators collect the slaughtered pigs from contract farms when they reach the optimal weight of about 110 kg. However, integrators delayed this due to unfavorable markets. Contract farms must continue to raise the slaughtered pigs until the integrators collect them. When pigs reach a weight of over 110 kg, they consume more feed but the growth of body weight decreases. Meanwhile, noncontract farms usually sell the slaughtered pigs at about 100 kg, so FCR is often at an optimal level. The FCR of the contract farms is similar to the FCR of small-scale contract farming of swine in Lampang, Thailand (2.42) [47].

**Table 2.** Summary of inputs and output of pig production.

Variable	Noncontract Farms ( <i>n</i> = 138)	Contract Farms ( <i>n</i> = 63)	All Sample ( <i>n</i> = 201)	Different <sup>(a)</sup>
Feed per 1 ton weight gain (ton)	2.21	2.40	2.27	−0.19 ***
Piglet (Mil. VND/ton)	6.94	6.19	6.70	0.75 ***
Labor cost (man-day/ton)	10.50	3.22	8.22	7.28 ***
Depreciation of fixed assets (Mil. VND/ton)	1.15	1.36	1.21	−0.21
Other variable cost (Mil. VND/ton)	1.62	2.18	1.80	−0.56 ***
Water-use (m <sup>3</sup> /ton)	194.80	87.29	161.10	107.51 ***
Total liveweight (ton)	16.34	212.68	77.88	−196.33 ***
Annual pig income (Mil. VND)	162.21	329.25	214.57	−167.04 ***
Pig income per ton (Mil. VND)	9.39	1.49	6.91	7.89 ***

<sup>(a)</sup> *t*-test were used to compare the mean values between noncontract and contract farms. \*\*\* *p* < 0.01.

The cost of piglets on noncontract farms is higher than on contract farms. Noncontract farms must buy piglets at market prices or produce piglets from their sows, while the integrators supply contract farms with qualified piglets. To estimate the cost of piglets of contract farms, we used the market price of piglets at the time of the survey. Due to concerns about the health risks of piglets, noncontract farms often buy piglets of over 15 kg, while contract farms receive piglets of 5–7 kg from the integrators [45], which makes the cost of piglets of noncontract farms higher than that of contract farms.

Due to the closed and automated pigpen system, contract farms consume less labor than noncontract farms. In pig raising, farmers must clean the pigpens and feed the pigs. The open pigpen system of noncontract farms consumes much time for cleaning the pigpen [20] because the farmers must scratch the floor to clean the manure and spray water until the floor is clean [48]. Although the investment cost in the pigpens of the contract farms is higher than that of the noncontract farms, the depreciation of fixed assets per ton of slaughtered pigs of the two groups of farms is not statistically significantly different.

Other variable costs, such as electricity, veterinary medicines, and vaccines of contract farms are higher than those of noncontract farms. Due to the automated pigpen system, the electricity cost of contract farms is higher than that of the open pigpen of noncontract farms. Since the integrators provide veterinary medicines and vaccines for contract farms, we use the market price to calculate variable costs. Contract farms must comply with the

integrators' instructions in the vaccination, so the cost of vaccines is higher than that of noncontract farms.

Because the closed pigpen system uses a circulating water-cooling system [20], the water loss is for evaporation only. Whereas the noncontract farms use sprayers to cool pigs. Therefore, the water consumed by contract farms is less than that of noncontract farms. In addition, the water would be discharged as wastewater without being able to be recycled, causing environmental pollution.

With a closed pigpen system, the number of pigs on contract farms is significantly larger than that on noncontract farms. Contract farming has grown quite enormously in recent years in Southeast Asia. Unlike contract farming in the Philippines, where integrators sign farming contracts with farms of different sizes, integrators in Vietnam prefer to contract with large-scale farms [5]. The pig density of contract farms is higher than that of noncontract farms. Accordingly, the farm's floor area per pig is 1.31 m<sup>2</sup>/pig and 3.16 m<sup>2</sup>/pig, respectively [20].

Contract farms earn more in annual pig income than noncontract farms. This is consistent with the research by Liang, Bi and Zhang [16], which dictates that contract farming can significantly increase the income of beef cattle farmers in China. Simmons, Winters and Patrick [49] also argued that contract farming increased returns to capital for broiler contract farms in Indonesia.

However, the income per ton of liveweight pigs of noncontract farms is higher than that of contract farms. Research by Delgado, Narrod [7] also shows that contract farms aim toward lower unit profits but more significant total revenue and profits than noncontract farms. The pig income of contract farms in Vietnam is calculated by taking the wages paid by the integrators to the farmers minus the farm's expenses, including electricity, depreciation of fixed assets, and some other variable costs. The pig income of noncontract farms is calculated by deducting the costs of piglet, feed, veterinary medicine, vaccines, electricity, depreciation of fixed assets, and some other variable costs from the revenue. The income of contract farms is stable and predictable because the wage rate is written in the farming contract. In contrast, the income of noncontract farms is unstable and depends on market demand, selling price, prices of piglets, feed, veterinary medicine, vaccines, etc. According to Dzung, Dao [23], participating in contract farming is a way for pig farms in Vietnam to cope with disease and price risks, while research by Kitchaicharoen, Suebpongsang and Jittham [50] suggests that swine contract farms in Thailand coped with low-level price risks but the production and income risks can still be observed as compared to noncontract farms.

#### *4.2. Technical Efficiency*

The technical efficiency by group and meta frontiers of contract and noncontract farms are presented in Table 3. The group frontier only measures the technical efficiency among farms within the contract or noncontract farms. The technical efficiency under CRS, VRS, and SE of noncontract farms is 88.64%, 91.08%, and 97.37%, respectively, which is higher than the efficiencies in the study by Ly, Nanseki and Chomei [15] on technical efficiency of pig households in Vietnam at 80.04%, 85.94%, and 93.64%. The difference can be explained by the study of Ly, Nanseki and Chomei [15], which measured the technical efficiency of pig production at the household level while our study focused on farm size. The technical efficiency under CRS and VRS of contract farms is 96.11% and 96.58%, respectively, which is similar to the results of the research by Labajova, Hansson [33] on the technical efficiency of pig production in Sweden.

**Table 3.** Summary of technical efficiency by group and meta frontiers.

Technical Efficiency	Group Frontiers		Meta-Frontier			
	Noncontract Farms	Contract Farms	Noncontract Farms	Contract Farms	All Samples	Different <sup>(a)</sup>
CRS	88.64	96.11	88.62	79.11	85.64	9.51 ***
VRS	91.08	96.58	90.99	92.67	91.51	−1.68 *
SE	97.37	99.51	97.44	85.48	93.69	11.96 ***

<sup>(a)</sup> *t*-test were used to compare the mean values between noncontract and contract farms within the meta-frontier.  
\*  $p < 0.1$ ; \*\*\*  $p < 0.01$ .

The technical efficiency of the group frontier of contract farms is higher than that of noncontract farms. The reason is that contract farms practice the husbandry according to the integrators' technical instructions, which optimizes the production. Therefore, the difference between inefficient farms and the frontier is negligible. Meanwhile, noncontract farms have diversity in housing systems, husbandry techniques, and experience, which leads to large differences between efficient and inefficient farms. When considering the scale of the farms, the technical efficiency under VRS of contract and noncontract farms was 96.58% and 91.08%, respectively. The scale efficiency of both groups was 99.51% and 97.37%, respectively, showing that most farms are operating on optimal scale.

The meta frontier forms a single frontier for both contract and noncontract farms, from which inefficient farms would be compared. With the meta-frontier, noncontract farms' technical efficiency under CRS, VRS, and SE is higher than contract farms (Table 4). The meta-technology ratio (MTR) considers the technical efficiency of the group and meta-frontier levels simultaneously, the larger the MTR, the higher the technical efficiency. The result shows that the MTR under CRS and VRS of noncontract farms is higher than that of contract farms. This finding contrasts with the results of previous studies, which found that contract farming increases the technical efficiency of beef cattle farmers in China [16], broiler farmers in Nigeria [51], and poultry farmers in Bangladesh [17]. This contrast may be due to the different forms of farming contracts. In previous studies, integrators bought outputs from farmers while in Vietnamese pig production, integrators provide some essential inputs (feed, stock, and vaccines) for contract farmers and collect outputs from them.

**Table 4.** Comparison of TE using the meta-technology ratio (MTR).

	Noncontract Farms		Contract Farms		Different <sup>(a)</sup>
	Mean	SD	Mean	SD	
MTR under CRS	99.99	0.14	82.30	2.79	17.69 ***
MTR under VRS	99.90	0.55	95.98	4.65	3.92 ***

<sup>(a)</sup> *t*-test were used to compare the mean values between noncontract and contract farms. \*\*\*  $p < 0.01$ .

#### 4.3. Determinants of the Technical Efficiency

The variables used in the Tobit models are presented in Table 5. To analyze the factors affecting the technical efficiency of each group considering the scale, we use the technical efficiency under VRS with group frontiers. To limit the bias due to sampling, we bootstrap 1000 times the efficiency scores.

**Table 5.** Summary of variables used in Tobit models.

Variables	Noncontract Farms	Contract Farms	Difference <sup>(b)</sup> ( <i>t</i> -Test/ <i>chi</i> <sup>2</sup> )
Dependent variable			
Bootstrapped DEA efficiency score <sup>(a)</sup>	85.73	94.37	−8.64
Explanatory variables			
Gender (1 = male, 0 = female)	0.80	0.86	0.54 NS
Experience in farming (year)	17.82	7.90	9.92 ***
Education level (schooling year)	8.10	9.64	−1.56 **
Household size (person)	4.85	5.17	−0.32 NS
Land rent (dummy)	0.10	0.50	26.84 ***
Access to credit (dummy)	0.36	0.55	4.23 **
Location (1 = outside of residential zones, 0 = others)	0.33	1.00	52.67 ***
Pig density (pig/m <sup>2</sup> )	0.30	0.65	−0.35 ***
Raising period (month)	5.43	5.86	−0.32 ***
Feed cost (Thousand VND/kg liveweight)	24.33	-	-
Death ratio	11.14	5.76	5.83 ***
Percentage of own-produced piglets (%)	78.25	-	-
Waste treatment area (m <sup>2</sup> /pig)	4.43	0.98	3.45 NS

<sup>(a)</sup> 1000 times of bootstrapping DEA under VRS by group frontiers; <sup>(b)</sup> The *chi*<sup>2</sup> test is performed with nominal or dummy variables, and the *t*-test is performed with the remaining variables. \*\* *p* < 0.05; \*\*\* *p* < 0.01, NS: non-significant.

Noncontract farmers were older but had fewer years of education than contract farmers. Contract farms had better access to credit, rented more land, and were located far from residential areas. Contract farms had higher pig densities and longer fattening times but lower pig death rates than noncontract farms.

The results of the Tobit models are presented in Table 6. The multicollinearity test results in Appendix A show no signs of multicollinearity. Land rent reduces the technical efficiency of both contract and noncontract farms. This finding contrasts with a study by Huy and Nguyen [52], which argued the positive impact of land rent on technical efficiency in cultivation in Vietnam. However, in the livestock sector, farms must comply with environmental regulations, so renting land is not only for building pigpens but also for installing waste treatment facilities. Labajova, Hansson [33] also note that manure treatment reduces the technical efficiency of grow-to-finish pig farms in Sweden. In Vietnam, the policy on land quota (each individual/household is not allowed to own more than 3 ha of agricultural land) and land fragmentation hinders the expansion of agricultural production [53].

High pig density increases the technical efficiency of noncontract farms but does not affect the technical efficiency of contract farms. Research by Lee, Choi [54] showed that the survival rate of fattening pigs increased when floor space ranged from 1.10 to 1.27 m<sup>2</sup>/head, and increasing the space from 1.27 to 1.47 m<sup>2</sup>/head increased the productivity of the pigs. The average pig density of noncontract farms is 0.3 pig/m<sup>2</sup> (equivalent to 3.3 m<sup>2</sup>/head). With such a low pig density, the cost of pigpen depreciation, electricity, and water consumption for cooling and cleaning the pigpens increase, reducing technical efficiency. With contract farms, pig density is fixed by the integrators' regulations, so there is no significant difference among the farms.

**Table 6.** Determinants of technical efficiency under VRS.

Variables	Noncontract Farms	Contract Farms
Gender	−0.1768	−1.3273
Experience in farming	0.0021	−0.0129
Education level	0.1227	0.0719
Household size	−0.2726	−0.2193
Land rent	−5.8729 ***	−2.4023 ***
Access to credit	−1.7986	0.4039
Location	−0.4260	−
Pig density	8.6206 ***	2.6393
Raising period	0.0294	−1.9834 ***
Feed cost	−1.3805 ***	−
Death ratio	−0.0959 **	0.0027
Percentage of own-produced piglets	0.0351 *	−
Waste treatment area	0.0155	−0.9224 *
Constant	122.1414 ***	107.8262 ***
Number of observations	138	63
LR chi2	74.12	25.82
Prob > chi2	0.000	0.004
Log likelihood	−282.5931	−95.2944
Pseudo R2	0.1159	0.1193

\*  $p < 0.1$ ; \*\*  $p < 0.05$ ; \*\*\*  $p < 0.01$ .

The long fattening period reduces the technical efficiency of contract farms but does not affect noncontract farms. Research by Wittayakun, Chainetr [47] argues that the average fattening time of small-scale contract farming in Thailand is 158 days/cycle (5.3 months/cycle), which is shorter than that of contract farms in Vietnam (5.86 months/cycle). After this period, the pig's weight gain rate decreases while the feed consumed increases. The farms must continue to pay the depreciation costs of the barn, electricity, and water until the integrators collect the slaughtered pigs. For some reason, the integrators can delay collecting the slaughtered pigs, causing a long fattening period.

High feed costs reduce the technical efficiency of noncontract farms. Feed costs account for the largest proportion of total production costs (70%) and significantly influence pig health [55]. The feed price in Vietnam is relatively high because feed enterprises must import raw input materials from abroad [13]. Noncontract farms often buy feed on credit, resulting in a higher feed price than a lumpsum payment. This result implied that the Government should develop raw material areas to promote domestic feed production, which contributes to reducing the feed price in Vietnam.

A high pig death rate reduces the technical efficiency of noncontract farms since it increases input costs for piglets, feed, veterinary drugs, and other variable costs. The pig death rate of noncontract farms is about two times higher than contract farms. The reason is that piglets of noncontract farms are bought from unreliable hatcheries, while contract farms are supplied with qualified piglets from integrators' hatcheries. In addition, the quality of the pigpens of noncontract farms (conventional type) is lower than that of contract farms (industrial type). Moreover, pig disease prevention in noncontract farms is worse than in noncontract farms.

A high percentage of own-produced piglets increases the technical efficiency of the farms. Piglets of noncontract farms come from two sources: own production and buying from hatcheries. Own production is considered the traditional way to ensure the quality of piglets and save costs [13].

Large waste treatment area per pig reduces the technical efficiency of contract farms. To participate in farming contracts, farms must have appropriate waste treatment plants [45]. These plants may include biogas digesters and biological ponds, occupying a large amount of land because the decomposition of the plants depends on the biological process [56]. Farms must rent land to build piggens and waste treatment plants, so the larger the waste treatment area, the higher the rental cost, which reduces technical efficiency. The findings implied that the Vietnamese government should revise the land ownership policies that allow farmers to own land on a larger scale, which reduces land use costs.

In addition, waste treatment is mandatory for all livestock farms, so applying advanced waste treatment technology to reduce the occupied land area is necessary. Some technologies, such as the slatted floor, manure separation, and biological bedding, have been used to help utilize pig manure to produce organic fertilizer, reducing the load on waste treatment facilities [56].

## 5. Conclusions

Contract farming is being supported by governments in developing countries with the expectation of improving production efficiency, reducing market risks, and increasing farmers' income. As one of the six largest pig producers in the world, the Vietnamese government is also promoting the development of formal farming contracts in pig production. However, due to the specificity of formal farming contracts in the livestock sector in Vietnam, where contract farmers are provided with most of the essential inputs by the integrators, there has been no previous study in Vietnam comparing technical efficiency between contract and noncontract pig farms. This study applies a meta-frontier to compare the technical efficiency of the two groups.

The study results show that the technical efficiency of contract farms is lower than that of noncontract farms. Despite that, the annual pig income of contract farms is significantly higher than that of noncontract farms, which makes formal farming contracts attractive to farmers.

This study also analyzes the factors affecting technical efficiency in each group. The results show that land rental reduces the technical efficiency of both groups. For noncontract farms, higher pig density and a larger percentage of own-produced piglets increase technical efficiency, while feed cost and death ratio reduce technical efficiency. For contract farms, the longer fattening period and larger waste treatment area reduce the technical efficiency.

**Author Contributions:** L.T.T.H.: conceptualization, methodology, data curation, writing—original draft. L.V.D.: conceptualization, investigation, data curation, writing—original draft. B.P.K.H.: writing—reviewing and editing. B.T.N.: writing—reviewing and editing. N.V.P.: writing—reviewing and editing. All authors have read and agreed to the published version of the manuscript.

**Funding:** This research was funded by the Vietnam National Foundation for Science and Technology Development (NAFOSTED), grant number 502.01-2021.47.

**Institutional Review Board Statement:** The study was conducted according to the guidelines of the Declaration of Helsinki and approved by the Ethics Committee of Vietnam National University of Agriculture (protocol code #352 on 20 March 2024).

**Informed Consent Statement:** Informed consent was obtained from all subjects involved in the study.

**Data Availability Statement:** Data are contained within the article.

**Conflicts of Interest:** The authors declare no conflicts of interest.

## Abbreviations

The following abbreviations are used in this manuscript:

CRS	Constant return to scale
DEA	Data envelopment analysis
FCR	Feed conversion rate
MDPI	Multidisciplinary Digital Publishing Institute
MTR	Meta-technology ratio
SE	Scale efficiency
SFA	Stochastic frontier analysis
TE	Technical efficiency
VRS	Variable return to scale
NIRS	Non-increasing return to scale

## Appendix A

**Table A1.** Variance inflation factor.

Variables	Tobit Model of Noncontract Farms	Tobit Model of Contract Farms
Gender	1.12	1.16
Experience in farming	1.10	1.52
Education level	1.12	1.45
Household size	1.05	1.43
Land rent	1.34	1.44
Access to credit	1.08	1.16
Location	1.32	-
Pig density	1.15	1.12
Raising period	1.16	1.23
Feed cost	1.17	-
Death ratio	1.07	1.41
Percentage of own-produced piglets	1.37	-
Waste treatment area	1.10	1.17
Mean	1.16	1.31

## References

1. Food and Agriculture Organization. *OECD-FAO Agricultural Outlook 2021–2030*; FAO: Rome, Italy, 2021.
2. USDA. *Production-Pork*; USDA, Ed.; USDA: Washington, DC, USA, 2024.
3. General Statistic Office. *Statistical Yearbook of Vietnam 2023*; General Statistic Office, Ed.; General Statistic Office: Hanoi, Vietnam, 2023.
4. Van Hung, P.; Nga, N.T.D.; Lapar, M. *Improving the Livelihood of Small Farmers in the Pig Value Chain: Experiences in the North of Vietnam*; Vietnam National University of Agriculture: Hanoi, Vietnam, 2015.
5. ILRI. *Contract Farming for Equitable Market-Oriented Swine Production in Northern Vietnam*; ILRI: Nairobi, Kenya, 2007.
6. Tiongco, M.; Catelo, M.A.; Lapar, M.L. *Contract Farming of Swine in Southeast Asia as a Response to Changing Market Demand for Quality and Safety in Pork*; International Food Policy Research Institute: Washington, DC, USA, 2008.
7. Delgado, C.L.; Narrod, C.A.; Tiongco, M.M.; de Camargo Barros, G.S.A. *Determinants and Implications of the Growing Scale of Livestock Farms in Four Fast-Growing Developing Countries*; International Food Policy Research Institute: Washington, DC, USA, 2008; Volume 157.
8. Huong, L.T.T.; Takahashi, Y.; Yabe, M. Manure management and pollution levels between contract and non-contract livestock farming in Vietnam. In *Integrated Land & Water Management and Climate Change in Vietnam and Japan*; Vietnam National University of Agriculture, Kyushu University: Hanoi, Vietnam, 2019.
9. Farrell, M.J. The Measurement of Productive Efficiency. *J. R. Stat. Soc. Ser. A (Gen.)* **1957**, *120*, 253–290. [[CrossRef](#)]
10. Cabas Monje, J.; Guesmi, B.; Ait Sidhoum, A.; Gil, J.M. Measuring technical efficiency of Spanish pig farming: Quantile stochastic frontier approach. *Aust. J. Agric. Resour. Econ.* **2023**, *67*, 688–703. [[CrossRef](#)]

11. Adewale, C.I.; Munezero, E.; Ndyomugenyi, E.K.; Mugonola, B. Determinants of technical efficiency of pig production systems in northern Uganda: A Stochastic Frontier approach. *SN Bus. Econ.* **2024**, *4*, 83. [[CrossRef](#)]
12. Huong, L.T.T.; Takahashi, Y.; Van Duy, L.; Duong, P.B.; Chung, D.K.; Son, C.T.; Nui, N.H.; Yabe, M. Feeding modes and technical efficiency of small pig holders in Vietnam: A case study in Hanoi. *Environ. Dev. Sustain.* **2024**. [[CrossRef](#)]
13. Huong, L.T.T.; Takahashi, Y.; Duy, L.V.; Chung, D.K.; Yabe, M. Development of Livestock Farming System and Technical Efficiency: A Case Study on Pig Production in Vietnam. *J. Fac. Agr. Kyushu Univ.* **2023**, *68*, 79–90. [[CrossRef](#)]
14. Ly, N.T.; Nanseki, T.; Chomei, Y. Are There Differences in Technical, Allocative, and Cost Efficiencies Among Production Scales? The Case of Vietnamese Household Pig Production. *J. Fac. Agr. Kyushu Univ.* **2020**, *65*, 379–388. [[CrossRef](#)]
15. Ly, N.T.; Nanseki, T.; Chomei, Y. Technical Efficiency and Its Determinants in Household Pig Production in Vietnam: A DEA Approach. *Jpn. J. Rural Econ.* **2016**, *18*, 56–61.
16. Liang, Y.; Bi, W.; Zhang, Y. Can contract farming improve farmers' technical efficiency and income? Evidence from beef cattle farmers in China. *Front. Sustain. Food Syst.* **2023**, *7*, 1179423. [[CrossRef](#)]
17. Begum, I.A.; Alam, M.J.; Buysse, J.; Frija, A.; Van Huylenbroeck, G. Contract farmer and poultry farm efficiency in Bangladesh: A data envelopment analysis. *Appl. Econ.* **2012**, *44*, 3737–3747. [[CrossRef](#)]
18. Nguyen-Thi, T.; Pham-Thi-Ngoc, L.; Nguyen-Ngoc, Q.; Dang-Xuan, S.; Lee, H.S.; Nguyen-Viet, H.; Padungtod, P.; Nguyen-Thu, T.; Nguyen-Thi, T.; Tran-Cong, T.; et al. An Assessment of the Economic Impacts of the 2019 African Swine Fever Outbreaks in Vietnam. *Front. Vet. Sci.* **2021**, *8*, 686038. [[CrossRef](#)]
19. Liang, J.B.; Kayawake, E.; Sekine, T.; Suzuki, S.; Lim, K.K. Developing zero-discharge pig-farming system: A feasibility study in Malaysia. *Anim. Prod. Sci.* **2017**, *57*, 1598–1602. [[CrossRef](#)]
20. Huong, L.T.T.; Takahashi, Y.; Nomura, H.; Van Duy, L.; Son, C.T.; Yabe, M. Water-use efficiency of alternative pig farming systems in Vietnam. *Resour. Conserv. Recycl.* **2020**, *161*, 104926. [[CrossRef](#)]
21. Costales, A.; Son, N.; Lapar, M.L.; Tiongco, M. *Smallholder Contract Farming of Swine in Northern Viet Nam: Inception Workshop; Pro-Poor Livestock Policy Initiative Research Report*; FAO: Rome, Italy, 2006.
22. Quang, H.V. Linkage between Enterprises and Producers in Hog Production—Consumption in Some Provinces in Vietnam. *Vietnam J. Agric. Sci.* **2018**, *16*, 282–289.
23. Dzung, D.; Dao, Moritaka; Liu; Fukuda, S. A Study on Risk-Sharing Scheme of Formal Contract Agreements in Swine Industry in Vietnam. *J. Fac. Agric. Kyushu Univ.* **2019**, *64*, 395–405.
24. Le, H.T.M. Economic efficiency of pig farms in Dong Nai. *Dev. Integr.* **2015**, *25*, 99–104.
25. Hanoi People's Committee. *Decision on Promulgating Regulations on Livestock Density in Hanoi Until 2030*; 18/2023/QĐ-UBND; Hanoi People's Committee, Ed.; Hanoi People's Committee: Hanoi, Vietnam, 2020.
26. Vietnamese Government. *Decree Detailing the Law on Animal Husbandry*; 13/2020/NĐ-CP; Vietnamese Government, Ed.; Vietnamese Government: Hanoi, Vietnam, 2020.
27. Yamane, T. *Statistics: An Introductory Analysis*, 2nd ed.; Harper and Row: New York, NY, USA, 1967.
28. Simar, L.; Wilson, P.W. Sensitivity Analysis of Efficiency Scores: How to Bootstrap in Nonparametric Frontier Models. *Manag. Sci.* **1998**, *44*, 49–61. [[CrossRef](#)]
29. Simar, L.; Wilson, P.W. A general methodology for bootstrapping in non-parametric frontier models. *J. Appl. Stat.* **2000**, *27*, 779–802. [[CrossRef](#)]
30. Simar, L.; Wilson, P.W. Estimation and inference in two-stage, semi-parametric models of production processes. *J. Econom.* **2007**, *136*, 31–64. [[CrossRef](#)]
31. Jabbar, M.A.; Akter, S. Market and other factors affecting farm specific production efficiency in pig production in Vietnam. *J. Int. Food Agribus. Mark.* **2008**, *20*, 29–53. [[CrossRef](#)]
32. Yang, C.-C. Productive efficiency, environmental efficiency and their determinants in farrow-to-finish pig farming in Taiwan. *Livest. Sci.* **2009**, *126*, 195–205. [[CrossRef](#)]
33. Labajova, K.; Hansson, H.; Asmild, M.; Göransson, L.; Lagerkvist, C.-J.; Neil, M. Multidirectional analysis of technical efficiency for pig production systems: The case of Sweden. *Livest. Sci.* **2016**, *187*, 168–180. [[CrossRef](#)]
34. Lansink, A.O.; Reinhard, S. Investigating technical efficiency and potential technological change in Dutch pig farming. *Agric. Syst.* **2004**, *79*, 353–367. [[CrossRef](#)]
35. Asmild, M.; Hougaard, J.L. Economic versus environmental improvement potentials of Danish pig farms. *Agric. Econ.* **2006**, *35*, 171–181. [[CrossRef](#)]
36. Reinhard, S.; Knox Lovell, C.A.; Thijssen, G.J. Environmental efficiency with multiple environmentally detrimental variables; estimated with SFA and DEA. *Eur. J. Oper. Res.* **2000**, *121*, 287–303. [[CrossRef](#)]
37. Van Meensel, J.; Lauwers, L.; Van Huylenbroeck, G.; Van Passel, S. Comparing frontier methods for economic–environmental trade-off analysis. *Eur. J. Oper. Res.* **2010**, *207*, 1027–1040. [[CrossRef](#)]
38. Coelli, T.; Rahman, S.; Thirtle, C. Technical, allocative, cost and scale efficiencies in Bangladesh rice cultivation: A non-parametric approach. *J. Agric. Econ.* **2002**, *53*, 607–626. [[CrossRef](#)]

39. Badunenko, O.; Mozharovskyi, P. Nonparametric frontier analysis using Stata. *Stata J.* **2016**, *16*, 550–589. [[CrossRef](#)]
40. Brümmer, B. Estimating confidence intervals for technical efficiency: The case of private farms in Slovenia. *Eur. Rev. Agric. Econ.* **2001**, *28*, 285–306. [[CrossRef](#)]
41. Breustedt, G.; Tiedemann, T.; Latacz-Lohmann, U. What is my optimal technology? A metafrontier approach using Data Envelopment Analysis for the choice between conventional and organic farming. In Proceedings of the International Association of Agricultural Economists Conference, Beijing, China, 16–22 August 2009.
42. O'Donnell, C.J.; Rao, D.S.P.; Battese, G.E. Metafrontier frameworks for the study of firm-level efficiencies and technology ratios. *Empir. Econ.* **2008**, *34*, 231–255. [[CrossRef](#)]
43. McDonald, J. Using least squares and tobit in second stage DEA efficiency analyses. *Eur. J. Oper. Res.* **2009**, *197*, 792–798. [[CrossRef](#)]
44. Wooldridge, J.M. *Introductory Econometrics: A Modern Approach*; Nelson Education: Toronto, ON, Canada, 2016.
45. Huong, L.T.T.; Takahashi, Y.; Nomura, H.; Son, C.T.; Kusudo, T.; Yabe, M. Manure management and pollution levels of contract and non-contract livestock farming in Vietnam. *Sci. Total Environ.* **2020**, *710*, 136200. [[CrossRef](#)] [[PubMed](#)]
46. Zhou, H.; Cheng, H.; Wang, Y.; Duan, D.; Han, J.; Zhou, S.; Xin, W.; Li, X. Development of a Feed Conversion Ratio Prediction Model for Yorkshire Boars Using Cumulative Feed Intake. *Animals* **2025**, *15*, 507. [[CrossRef](#)] [[PubMed](#)]
47. Wittayakun, S.; Chainetr, W.; Kongngoen, N.; Innaree, W.; Tancharoenrat, P.; Marjuki, I. Case study: Productive performance and prediction of operating income of small-scale contract farming of swine in Lampang, Thailand. *J. Agric. Sci. Technol. A* **2019**, *9*, 177–181. [[CrossRef](#)]
48. Thien Thu, C.T.; Cuong, P.H.; Hang, L.T.; Chao, N.V.; Anh, L.X.; Trach, N.X.; Sommer, S.G. Manure management practices on biogas and non-biogas pig farms in developing countries—Using livestock farms in Vietnam as an example. *J. Clean. Prod.* **2012**, *27*, 64–71. [[CrossRef](#)]
49. Simmons, P.; Winters, P.; Patrick, I. An analysis of contract farming in East Java, Bali, and Lombok, Indonesia. *Agric. Econ.* **2005**, *33*, 513–525. [[CrossRef](#)]
50. Kitchaicharoen, J.; Suebpongsang, P.; Jittham, V. Risks, Returns and Adaptation of Farmers in Contract Swine Production in Northern Thailand. In Proceedings of the International Conference on the 3rd Thailand-Taiwan Bilateral Conference and the 2nd UNTA meeting on Science Technology and Innovation for Sustainable Tropical Agriculture and Food, Bangkok, Thailand, 26–27 June 2014.
51. Adebisi, L.; Adebisi, O.; Owolabi, M.; Henshaw, E.; Asiyanbi, O. Economic analysis of contract farming and technical efficiency of broiler farmers. *Cercet. Agron. Moldova* **2021**, *53*, 426–433. [[CrossRef](#)]
52. Huy, H.T.; Nguyen, T.T. Cropland rental market and farm technical efficiency in rural Vietnam. *Land Use Policy* **2019**, *81*, 408–423. [[CrossRef](#)]
53. Tu, V.H.; Kopp, S.W.; Trang, N.T.; Hong, N.B.; Yabe, M. Land accumulation: An option for improving technical and environmental efficiencies of rice production in the Vietnamese Mekong Delta. *Land Use Policy* **2021**, *108*, 105678. [[CrossRef](#)]
54. Lee, J.H.; Choi, H.L.; Heo, Y.J.; Chung, Y.P. Effect of Floor Space Allowance on Pig Productivity across Stages of Growth: A Field-scale Analysis. *Asian-Australas. J. Anim. Sci.* **2016**, *29*, 739–746. [[CrossRef](#)]
55. Galanopoulos, K.; Aggelopoulos, S.; Kamenidou, I.; Mattas, K. Assessing the effects of managerial and production practices on the efficiency of commercial pig farming. *Agric. Syst.* **2006**, *88*, 125–141. [[CrossRef](#)]
56. Huong, L.T.T.; Takahashi, Y.; Duy, L.V.; Son, C.T.; Chung, D.K.; Yabe, M. Wastewater Treatment Efficiency of Small and Large-Scale Pig Farms in Vietnam. *J. Fac. Agr. Kyushu Univ.* **2021**, *66*, 291–297.

**Disclaimer/Publisher's Note:** The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of MDPI and/or the editor(s). MDPI and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.