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Development of Livestock Farming System and Technical Efficiency: A Case Study on Pig Production in Vietnam

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Pork is the most consumed meat in the world and is dominantly produced in Asian countries. Numerous studies analyze pig production efficiency under alternative farm sizes which are classified by the number of pigs. While this classification does not reveal the development of farming systems, this study develops a new typology for pig farming systems: industrial farms (IFs) and traditional farms (TFs). This study describes the specific characteristics of these systems, analyzes their technical efficiency (TE), and investigates the TE's determinants. By surveying 246 pig farms in Vietnam, we found that housing systems, feeding modes, and contract farming are the key points to distinguish IFs from TFs. Results of data envelopment analysis show that TEs of IFs and TFs are 73.8% and 65.7%, respectively, meaning that their input costs of them could reduce by 26.2% and 34.3%, accordingly, without any decreases in the outputs. In addition, analysis of scale efficiency indicates that IFs operate nearer their optimal scales than TFs do. This finding suggests the potential for TFs to increase their TE by adjusting their production scale in the long run. For short–run solutions, using Tobit models, we analyze the TE's determinants under variable return to scale within each farming system. Various determinants were investigated, of which land rent and ratio of the manure treatment area to pigpen area substantially reduce TE of IFs, while farm–prepared feed significantly increases TE of TFs. These findings imply the need to research less–occupying manure treatment plants for IFs and lower feed prices for TFs through promoting domestic feed production and self–made feed that utilizes food waste and agricultural by–products.

Key words: data envelopment analysis, livestock farming system, pig production, technical efficiency

INTRODUCTION

A growing population combined with an improved standard of living has prompted people all over the world to consume more meat. Pork is the most consumed meat in the world, accounting for about 37% of all meat consumed in the world and is mostly produced in Asia (with 37.93% of the world's total pork), followed by America (37.92%) and Europe (23.16%)[2]. In Vietnam, the second largest pork producer in Asia, pork occupies a great proportion (71.5%) of the total meat consumption (GSO, 2017). Pig farming is considered the main source of income for rural households in Vietnam (Costales *et al.*, 2008; Huynh *et al.*, 2006; Nga *et al.*, 2014), accounting for 14% of total household income and 25% of income from agriculture (Van Hung *et al.*, 2015). With about 80% of Vietnamese pig farmers identified as poor or near–poor households, pig production is important for income generation and employment (Lapar, 2014).

Because Vietnamese consumers prefer to consume fresh pork, domestic production continues to be an important source of pork to meet demand (Lapar, 2014). However, Vietnam's pig production is unstable because of disease outbreaks, which substantially reduces the domestic supply. The period 2009–2010 was one of the most difficult periods for pig production due to widespread disease outbreaks (i.e., foot–and–mouth disease and porcine reproductive and respiratory syndrome) (Lapar, 2014). In February 2019, African swine fever was first detected in Vietnam and has now spread to all 63 provinces in the country. The disease led to the death and culling of approximately 5.9 million pigs or approximately 22% of the total swine population, pushing prices to record highs (USDA, 2019). In addition, costs of electricity, coal, feed, transportation, and interest rate increased by 16%, 43%, 13%, 20%, and 9%, respectively, which has also adversely affected the domestic supply (Lapar, 2014). Therefore, to stabilize the domestic pork market, pig farms in Vietnam need to find ways to improve their production efficiency.

To promote domestic livestock production, Decision 984/QD–BNN–CN approving the "Livestock sector restructuring scheme towards greater added value and sustainable development" was issued in May 2014., which included three main points for restructuring: (*i*) pig raising regions, (*ii*) pig breeding, and (*iii*) pig raising schemes (MARD, 2014). For the latter, the decision aimed to increase the number of pig heads produced by large–scale farms[3] from 30% in 2013 to 52% by 2020. With various supporting programs, the pig population increased by nearly 1.4 million heads in 2018 (GSO,

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[2] FAOSTAT. (2018). Livestock Primary. from FAO http://www.fao.org/faostat/en/#data/QL/visualize

[3] From 2011, a large–scale farm is a farm earning VND 1 billion of annual revenue, or equivalent to a pig herd of more than 200 sold in a year; otherwise, it is defined as a small–scale farm (Lapar, 2014).

2018). Following the trend of intensification in livestock production, large–scale farming increased rapidly from 12,642 farms in 2014 to 19,639 farms in 2018 (GSO, 2018). Moreover, for the last 10 years, the participation of foreign feed enterprises in Vietnamese pig production, through contract farming[4] to large–scale pig production, has expanded production and created mutual benefits, such as reducing market risks for producers and risks in quality management for firms (Ogishi *et al*., 2003; Saenger *et al*., 2013).

Improving technical efficiency (TE) is one of the main factors affecting the productivity and profitability of livestock production; therefore, numerous studies have assessed TE and its determinants in pig farms (Asmild & Hougaard, 2006; Delgado *et al*., 2008; Labajova *et al*., 2016; Lansink & Reinhard, 2004; Ly *et al*., 2016; Yang, 2009). TE is the economic approach that reflects the efficiency of resource utilization in production. TE denotes the ability of the farm to maximize output from current inputs (output–oriented) or minimize inputs used to yield observable outputs (input–oriented) (Farrell, 1957).

Among the aforementioned studies, Jabbar and Akter (2008) and Delgado *et al*. (2008) compared TEs among different farm scales (i.e., household and commercial pig farms, or different farm sizes) in Vietnam. Although the two studies provided insights into the TE of pig production, several research gaps were found. First, these studies did not indicate which farms are in constant, increasing, or decreasing returns to scale. Meanwhile, scale adjustment is considered to be an important solution to improve production efficiency in the long term (Gadanakis *et al*., 2015). Second, these studies assume that the stochastic frontier is the same for all pig growers. However, agricultural production technologies may be different across various farming systems (i.e., organic versus conventional plantations and livestock production) (Breustedt *et al*., 2011; Tu *et al*., 2019; Tzouvelekas *et al*., 2001). Additionally, Labajova *et al*. (2016) indicated that different technologies (i.e., different types of housing types, feeding modes, and cleaning activities) were the important farm–specific characteristics affecting the TE of Sweden's pig production. Hence, the alternative farming systems should belong to different production frontiers that are used to assess the relative TE of pig farms. In Vietnam, while livestock farms are officially categorized by the number of animals, the classification does not show differences between the farms in terms of development levels. Therefore, we categorize the farm as industrial farms (IFs) and conventional farms (CFs), which is important for the policies on livestock development to discriminate according to different production patterns. To provide detailed information on the TE of pig farms in Vietnam, we analyzed the TEs of IFs and CFs by constructing individual production frontiers for them.

To address the research gaps, this study had three main objectives: (1) to describe the specific characteristics of IFs and CFs in Vietnam; (2) to assess the TEs of these systems and indicate the specific characteristics of the farms in constant, increasing, or decreasing returns to scale; and (3) to analyze the determinants of TE in each system. The findings of this study are of great value considering the increasing input costs and disease breakouts in Vietnam's pig production. Furthermore, this study contributes to the literature and practice by being the first to describe the core differences among farming systems and suggests the direction of scale adjustment for the systems. In developing countries, although there is an increase in the number of IFs, small–scale production is expected to be dominant in the long run. Therefore, finding solutions to improve the TEs of both systems is crucial for the development of pig production in these countries. As Vietnam and other peer countries in Asia share similar livestock production structures (Huynh *et al*., 2006), the results of the present study will provide these governments with important information and solutions for sustainable livestock production.

RESEARCH METHODS AND DATA COLLECTION

Data collection

Hanoi is one of the localities with the largest number of pig heads in the country (1,635,000 heads), accounting for 5.8% of the country's pig herd (GSO, 2017). Hanoi is representative of Vietnamese pig production because it includes both types of farms (CFs and IFs). According to statistics published by the Hanoi Veterinary Department, in May 2018, in 16 districts of Hanoi, there were 101,813 owners of pig breeding facilities. Before conducting the survey, we had in–depth interviews with staff from the Hanoi Department of Agriculture and Rural Development about the location and number of farming systems in this area. Based on this information, we identified six districts as the target of the survey: Ba Vi, Phuc Tho, Thach That, Dan Phuong, Chuong My, and Thanh Oai (see Figure 1).

The local veterinary groups provided us with a list of all pig farms in the selected districts. For each district, we randomly selected 45 farms, totaling 270 producers. Randomly selected farms were surveyed using questionnaires that consisted of open–ended, closed–ended, semi–open, and multiple–choice questions, with three main categories: farm demographics and characteristics, livestock inputs, and outputs. Pig–fattening[5] production is most popular for IFs, while both farrow–to–finish[6] and pig fattening is a major choice of CFs (Costales *et al*.,

[4] According to Costales *et al*. (2006a) and Ogishi *et al*. (2003), contract farming is a formal agreement in which agribusiness firms provide inputs, such as genetic material and feed, to growers and receive grown animals that are processed and sold to final buyers.

[5] The weaned piglet is fattened for slaughter (Costales *et al*., 2006b).

[6] Keeping of breeding sows and production of offspring, then fattened to maturity, with the final product being slaughter hogs (full cycle operation) (Costales *et al*., 2006b).

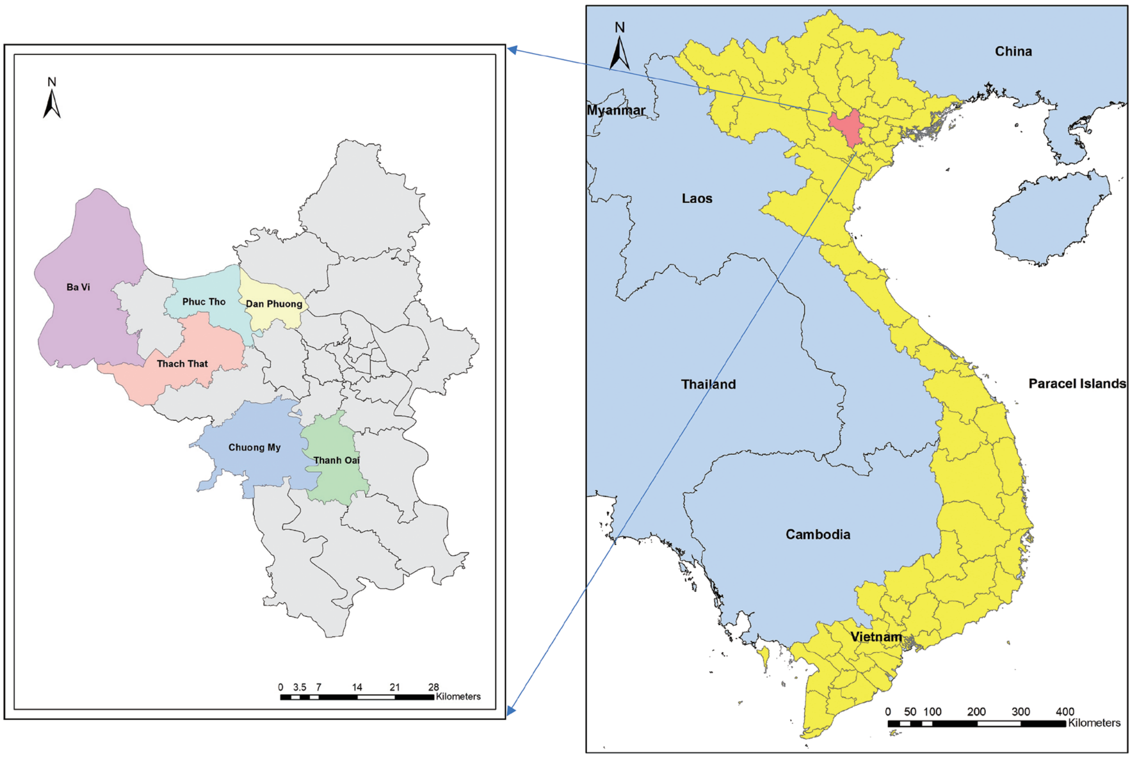

Fig. 1. Study site.

2006b). Therefore, we focused on the pig fattening activity on the farms and excluded farms that only produced piglets for sale. This reduced the valid samples for analysis to 246, comprising 46 IFs and 200 CFs.

Analysis method

Data envelopment analysis

There are two main approaches to measuring TE parametric techniques (e.g., stochastic frontier analysis [SFA]), and nonparametric techniques (e.g., data envelopment analysis [DEA]). Parametric techniques are used to define and estimate a parametric production function that represents the best available technology. The advantage of this technique is that it provides researchers with a robust framework for testing hypotheses and constructing confidence intervals (Reinhard *et al*., 2000). However, it requires assumptions of a form of the production frontier and the distribution of the technical inefficiency term (Reinhard *et al*., 2000). Studies that have applied an SFA to estimate the TE of pig farms in Vietnam are Delgado *et al*. (2008) and Jabbar & Akter (2008). The advantage of DEA is not requiring the assumption of a specific form or production frontier and distribution for inefficiency terms while indicating the constant return to scale, decreasing and increasing return to scale (Reinhard *et al*., 2000). Thus, we choose DEA for measuring the TE of the pig farms.

The DEA provides an approach to measuring the difference in TE of farms with the best (on the production frontier). The farms on the production frontier are those that use the fewest inputs to produce current output (input–oriented models) or produce the most output with existing inputs (input–oriented models). We choose the input–oriented model to save resources rather than increase output. TE of farms is calculated based on a comparison with this production frontier. Many studies have measured TE at the pig farm level using the DEA model (Asmild & Hougaard, 2006; Labajova *et al*., 2016; Lansink & Reinhard, 2004; Ly *et al*., 2016; Yang, 2009).

The DEA model describes N farms, K inputs, and M outputs. For the i–th farm, the input and output data are represented by the column vectors x_i and y_i, respectively. The input matrix K–by–N (X) and the output matrix M–by–N (Y) represent data for all farms in the sample.

The DEA model to estimate the TE is given in Eq. (1):

$$Min_{\theta\lambda}\ \theta, \qquad \text{(Eq. 1)}$$

$$\text{Subject to } -y_i + Y\lambda \geq 0, \qquad (1)$$

$$\theta x_i - X\lambda \geq 0, \qquad (2)$$

$$N1'\,\lambda = 1, \qquad (3)$$

$$\lambda \geq 0, \qquad (4)$$

where θ, $N1$, and λ are scalar, vectors of ones and vectors of constants, respectively. Using the variables λ and θ, the TE of each farm is calculated based on the relative distance of each site of that farm to the production frontier. The value of θ, respectively, is TE for the ith farm, ranging from 0 to 1, where 1 indicates that the farm is borderline and efficient.

The first constraint ensures that the output produced by farm i is less than the output at the production frontier. The second constraint limits the input scaling when θ is minimized. The third constraint is a convex constraint that generates the variable return to scale (VRS) of the model. Without this constraint, equation (1) produces a constant return to scale (CRS). In agriculture, an increase in inputs does not necessarily lead to a proportional increase in output. Therefore, we believe that the VRS option is likely the best fit for our problem (Coelli *et al*., 2002; Haji, 2007; Rodriguez–Diaz *et al*., 2004).

In addition, we also find that economies of scale may not be present for the CFs considered in this study; so, both specifications are modeled. Also, comparing VRS and CRS scores is interesting, as it provides information on scale efficiency. Coelli *et al*. (2002) showed that SE = TE_{CRS}/TE_{VRS}, where SE is the scale efficiency, and TE_{CRS} and TE_{VRS} denote the TE under CRS and VRS, respectively. When SE = 1, a farm is operating at its optimal scale size; otherwise, SE < 1. The SE indicates the potential benefit of adjusting the size of a farm.

One shortcoming in measuring SE is that when SE < 1, it is difficult to indicate whether the farm is operating in the areas of increasing return to scale (IRS) or decreasing return to scale (DRS). The cases of CRS, IRS, or DRS depend on the relationship between the proportion of inputs used to produce output for a farm (Varian, 2014). For example, under the CRS, using twice as much of all inputs would produce twice the output, while it would produce more than twice the output under the IRS and less than twice the output under the DRS. This shortcoming can be solved if an additional DEA problem with non–scaling returns is posed. It can be achieved by substituting the $N1'\lambda = 1$ with $N1'\lambda \leq 1$ and then calculating the non–increasing technical efficiency (TE_{NIRS}). According to Fare *et al*. (1994), these three estimated frontiers under CRS, VRS, and NIRS can be used to identify the returns to scale characteristics of the technology at any given point. Specifically, (a) if $TE_{CRS} = TE_{NIRS} < TE_{VRS}$, the input–oriented projection of the VRS frontier is under IRS; (b) if $TE_{VRS} = TE_{NIRS} > TE_{CRS}$, it becomes DRS; and (c) CRS holds only if SE = 1 = $TE_{CRS} = TE_{NIRS} = TE_{VRS}$ (See Fig. 2).

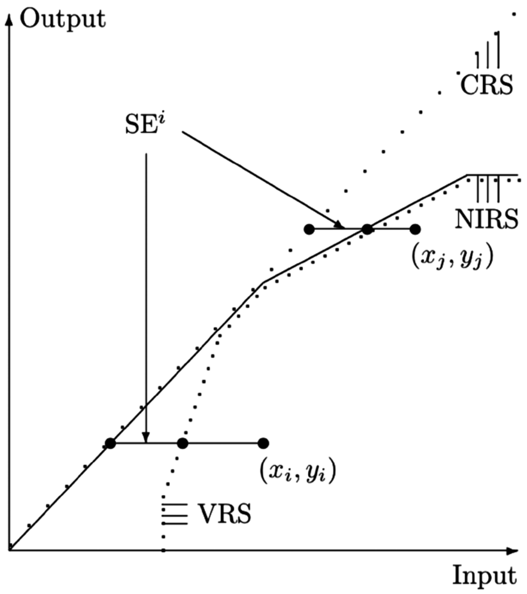

Fig. 2. Input–based technical and scale efficiency (Badunenko & Mozharovskyi, 2016).

Tobit model

After calculating the TE, the next step is to determine the TE determinants. Since TE is a continuous variable varying between about 0 and one (or between 0% and 100%), several regression models can be used, such as the ordinary least squares (OLS) or Tobit model (McDonald, 2009). However, the OLS model is not suitable for such analysis, because the predicted values of TE may be out of the range (Wooldridge, 2016), while the TE given by the DEA is in (0,1]. A two–limit Tobit model, known as a censored regression model, can overcome this problem because we can set the upper limit to 1 (or 100%) and the lower limit to 0, this makes sure that the predicted value of TE is within the time interval (Wooldridge, 2016). The Tobit model is expressed in Eq. (2) as follows (Wooldridge, 2016):

$$\theta^* = ZB + e$$

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

where:
Z: vector of independent variables,
θ: TE scores,
θ^*: latent variable,
B: estimated parameters,
e: error term.

RESULTS AND DISCUSSIONS

Specific characteristics of pig farming systems in Vietnam

General managerial practices

According to the policy of the Vietnamese government on promoting large–scale farming since 2014, IFs are at least 1 km away from residential areas, while CFs are not required to do so. As a result, the proportion of the surveyed farms located outside of residential areas is 100% and 19.5% for IFs and CFs, respectively. The location of a pig farm significantly affects production expansion, waste management, and pollution level (Huong *et al*., 2019; Thien Thu *et al*., 2012).

Knowledge of pig farming that can improve the performance of pig farms comes from the farm heads' own experiences, relatives, multimedia, veterinary services, and training by a feed company or technical support from agribusiness firms. Almost all IFs are contract farming, where technical staff from agribusiness firms visit the farm every day for support. All the IFs we surveyed reported that they received technical advice from agribusiness firms, while 98.5% of the CFs applied their knowledge and experience to pig raising. Information from relatives, veterinary services, and multimedia obtained by surveyed farms were modest, with 3.7%, 0.8%, and 5.7%, respectively. To promote the products, feed companies provided several technical training seminars with the participation of CFs and IF being 22.5% and 13.0%, respectively.

Housing systems

The most important feature that distinguishes IF from other systems is the use of a closed pigpen, which costs more to construct than other types. According to our survey, IFs and CFs paid US $53.3 and US $37.4, respectively, per square meter, to construct their pigpens. To control the temperature, humidity, and airflow in the closed pigpens, ventilation fans, and cooling pads are equipped. When the temperature inside exceeds 30°C, the cooling pads are wetted. The fans make the water in the cooling pad evaporate, thereby reducing the temperature of the barn. These pigpens may have one or two puddles, 50 m long, 1.2 m wide, and 10–15 cm deep (Fig. 3). A standard closed pigpen has an area of 750 m^2 and can hold 500–600 fattening pigs.

Housing is a highly significant factor influencing the workload related to taking care of the animals. Regarding the aforementioned feeding mode, CFs take time to cook the pig feed, while IFs feed the pigs with instant feed. Regarding pigpen types, IFs can save working time for cleaning floors and cooling pigpens because of using puddles and cooling systems. Therefore, the labor costs of IFs are much lower than those of CFs (Table 1).

Feeding modes and contract farming

Feed costs account for the largest proportion of total costs and have significant impacts on pig health and body growth (Galanopoulos *et al.*, 2006). IF feeds pigs

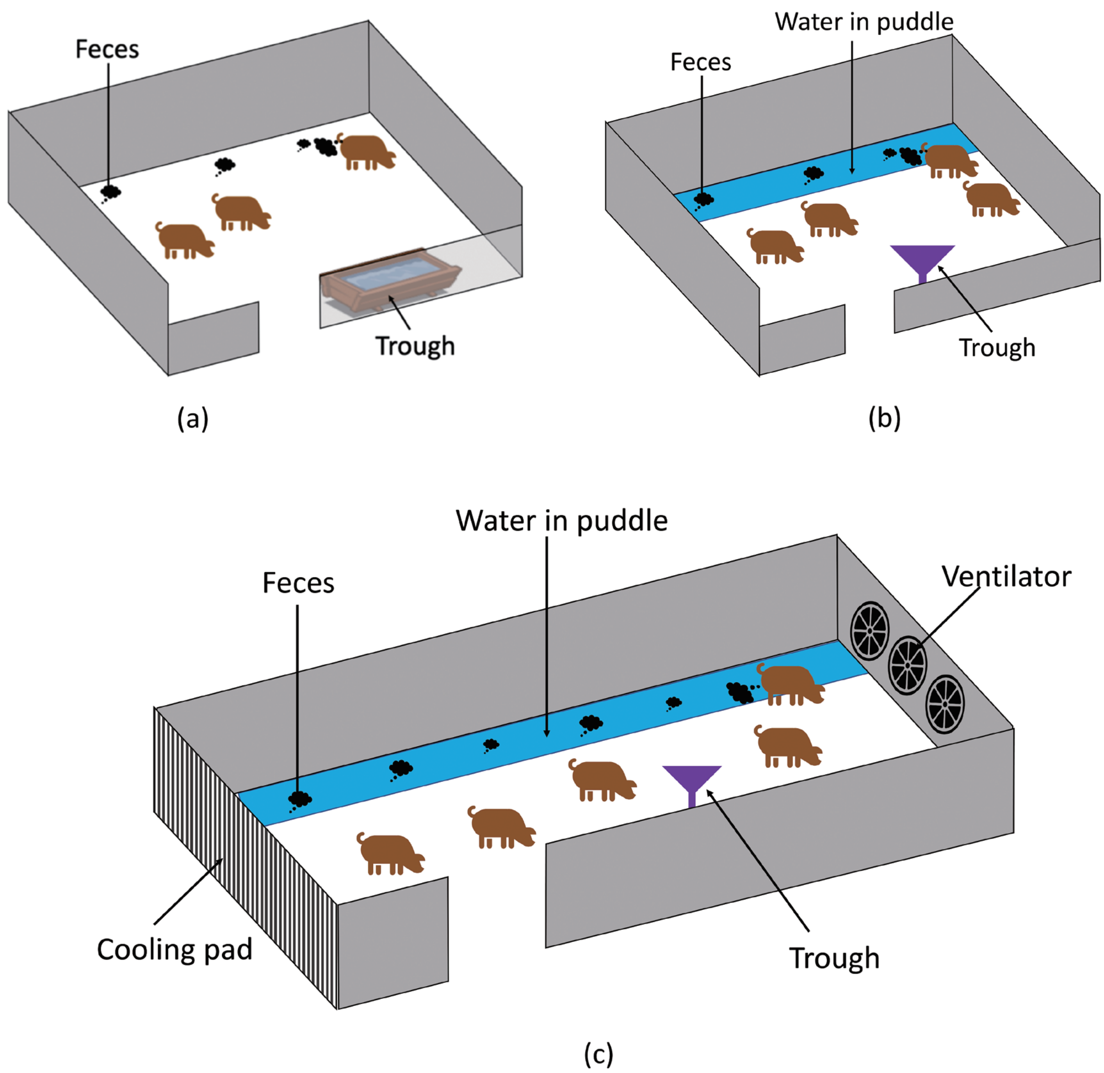

Fig. 3. Pigpen designs of conventional and industrial farms (Huong *et al.*, 2020).
(a) and (b) are conventional farms.
(c) is industrial farm.

with industrial feed while CF feeds pigs with instant feed or cook feed by mixing industrial feed with common ingredients such as rice bran, corn bran, rice wine distiller residue, leftovers, and vegetables. For the CFs using the mixed feed, the feed cost for a ton of slaughtered pigs is US $843.0, which is lower than that for those who feed pigs instant feed (US $1119.5). No data on the feed costs of IFs are available for collection because these farms are in contract farming, and they receive feed from agribusiness firms for free. Feeding style is uniformly regulated for all IFs by agribusiness firms; consequently, it is not necessary to use the feed costs to estimate the relative TE among IFs. In Vietnam, under contract farming, livestock farms use their land, barns, labor, electricity, and water to raise fattening pigs. They receive other inputs from the agribusiness companies such as piglets, feed, medicines, vaccines, and technical support. These enterprises collect slaughtered pigs for processing and pay farmers between US$0.11 and US$0.15 per kg of slaughtered pigs.

The feed has a significant impact on pig health and body growth (Galanopoulos *et al*., 2006). Underfeeding instructions from agribusiness firms, IFs change the types of feed according to pigs' development phases. However, CFs adjust the ingredients of the feed based on their own experiences and trained knowledge from feed companies. Although the duration of fattening phases among farming systems is not significantly different (Table 4), the average live weight of slaughter pigs produced by IFs is 115.70 kg, which is higher than that of CFs (100.29 kg). Galanopoulos *et al*. (2006) found that farms producing their feed were correlated with lower efficiencies and that commercial feed may be better prepared and may also be linked to nutritionist services.

Health and cleaning practices

To cope with six common disease outbreaks in Vietnam (swine respiratory disease, salmonellosis, septicemic pasteurellosis, swine fever, porcine reproductive and respiratory syndrome, and foot–and–mouth disease), pig farms vaccinate their pigs. As estimated by our survey, the average vaccination cost for a fattening pig in CFs is US $4.7. According to the vaccination program supported by agribusiness firms, fattening pigs in IFs are vaccinated against all common diseases, and the costs are estimated at approximately US $9 per pig.

In addition, with higher quality pigpens, pigs on IFs are healthier than those on CFs. Using puddles inside the pigpens can keep pigs' bedding separate from manure, which improves pig health. Without spraying the pig body with water, but using artificial cooling systems, IFs can prevent their pigs from getting sick. As a result, the death ratio of pigs on IFs (5.7%) is lower than that on CFs (12.5%) (calculated from our data).

Technical efficiency (TE)

The outputs and inputs used in the DEA models are described in Table 1. While CFs purchase piglets or breed themselves, IFs are supplied by agribusiness companies. In the case of buying piglets, the purchase price increases with the average weight of piglets. Piglets with a larger average weight are healthy and grow quickly. Fixed costs in pig production include depreciation, annual land rent (if any), and interest rate. Variable costs include vaccines, medicines, electricity, and minor repair costs. IFs produced 222.5 tons of slaughtered pigs, which was significantly more than CFs (8.8 tons).

Because the two farming systems have different methods of producing their outputs, we built separate production frontiers for each system that would be used to calculate the TE. We estimated the TEs under CRS and VRS as shown in Table 2. On average, under CRS and VRS, IFs could reduce 26.24% and 22.14% of inputs without any decrease in output level, respectively, while CFs could do that by cutting down 34.27% and 21.57% of the inputs. The TEs of IFs under CRS and VRS are nearly the same, resulting in high SE. However, the CFs under CRS are much lower than VRS, causing low SE. The results of SE indicated that IFs operate more closely to their optimal scales than CFs.

Most pig farms are in the IRS area, however, the proportions of farms in the DRS area are significantly different between IFs and CFs (Table 3). To understand the

Table 2. Technical efficiencies (TEs) of pig farming systems

Returns to scale	IFs N = 46		CFs N = 200	
	Mean	SD	Mean	SD
CRS	73.76	11.43	65.73	16.57
VRS	77.86	13.15	78.43	14.77
SE	95.17	6.11	84.21	14.53

Table 1. Descriptive statistics of the inputs and outputs used in the DEA

	Variables	Unit	IF N = 46		CF N = 200	
			Mean	SD	Mean	SD
Input	Feed cost	US $/ton	N/A	N/A	909.4	277.5
	Piglet cost	US $/ton	N/A	N/A	302.3	93.9
	Labor cost	US $/ton	21.9	4.0	152.8	173.4
	Fixed costs	US $/ton	61.4	117.9	67.9	197.9
	Other costs	US $/ton	19.3	12.4	71.6	46.7
Output	Total live weight	ton	222.5	124.0	8.8	12.5

characteristics of the farms belonging to IRS or DRS areas, we compared the inputs and outputs between the areas (Table 3). The IFs in IRS areas have higher fixed costs than the others; consequently, an increase in production size could help them to minimize the costs by economies of scale. The IFs who are in the DRS area have the highest other costs, which are mainly composed of electricity costs. In Vietnam, because electricity prices increase for extra kWh consumed, the more electricity is used, the more the electricity cost per unit of product is. The average monthly electricity charges for IFs are US $654.75, which is much higher than those for CFs (US $26.96). Therefore, a decrease in production size would help the farms to save on electricity costs.

CFs in the DRS area had higher feed costs than the others. Decreasing the production scale would help to reduce the feed costs; with smaller herd sizes, they could prepare the sufficient mixed feed. CFs in the IRS area has the highest labor costs; consequently, an increase in farm scale induces machine use to substitute labor. CFs in IRS areas incur higher fixed costs and other costs than in the ones in other areas. The expansion of production size would help farms to reduce fixed costs resulting from economies of scale. Other costs are mainly related to electricity costs that are consumed in the washing and cooling of pigpens. Because the floor space per pig in CFs is high (3.23 m^2/pig) (Table 4), it takes more time to wash the pigpens, resulting in more electricity being consumed. Therefore, increasing the herd size and pig density would help to reduce electricity costs.

Determinants of TE

Table 4 summarizes the variables used in the Tobit model. The higher live weight of slaughtered pigs of IFs compared to CFs is due to the IFs of industrial feed and the use of closed pigpens. The mean fattening time did not differ significantly between farm types but depended on piglet weight, feeding mode, and the market price of pork. For example, IFs typically raise piglets from around 5.5 kg, while CFs can purchase 15 kg piglets, which will help CFs shorten the fattening period. Nearly half of IFs rent land, while almost all CFs use their land for pig production. The floor space per pig of CFs is significantly higher than that of IFs because CFs do not have advanced cooling systems like IFs do. The total

Table 3. Characteristics of farms with CRS, IRS, and DRS

		IFs N = 46			CFs N = 200		
	Unit	CRS N = 2	IRS N = 36	DRS N = 8	CRS N = 17	IRS N = 172	DRS N = 11
Feed cost	USD/ton				681.4^{a}	924.5^{b}	1025.3^{c}
Piglet cost	USD/ton				286.1^{a}	304.7^{a}	289.0^{a}
Labor cost	USD/ton	15.3^{a}	21.8^{b}	24.2^{b}	123.4^{ab}	160.0^{a}	84.9^{b}
Fixed costs	USD/ton	19.1^{ac}	69.1^{b}	37.8^{c}	46.1^{ab}	71.6^{a}	43.8^{b}
Other costs	USD/ton	13.4^{a}	18.1^{a}	25.8^{b}	53.4^{ac}	75.1^{b}	44.0^{c}
Herd size	Head	2850.0^{a}	1671.9^{a}	2882.0^{b}	169.6^{a}	72.4^{b}	167.9^{ab}

t–tests were conducted to compare mean values of the costs among CRS, IRS, and DRS within each farming system.
^{a,b,c}: in each row, the numbers with different subscripts show statistically significant differences.

Table 4. Summary statistics for variables included in the Tobit regressions

Variables	Unit	IFs N = 46		CFs N = 200	
		Mean	SD	Mean	SD
Education	Year	9.52	3.69	7.82	3.06
Number of family labor	person	5.04	1.69	4.86	1.91
Liveweight of slaughtered pigs	kg/head	115.70	10.15	100.29	10.18
Duration of the fattening phase	Month	5.85	0.78	5.71	0.93
Land formation (0 = private, 1 = rent)	Dummy	0.43	0.50	0.04	0.20
Floor space per pig	m^2/pig	1.30	0.09	3.23	1.87
Total annual family income	100 USD	199.97	197.65	38.09	56.74
The ratio of the manure treatment area to the pigpen area		0.62	0.51	1.53	15.04
Number of fattening pigs	Head	1933.57	1080.67	85.92	120.73
The proportion of piglets bred on farms	%	0.00	0.00	78.96	34.66
Feed type (0 = commercial feed, 1 = mixture of traditional materials and commercial feed)	Dummy	0.00	0.00	0.55	0.50

annual income of farms includes income from crops, livestock, and off–farm jobs. There are significant differences in the ratio of manure treatment land area to pigpen area between IFs and CFs. The number of fattening pigs produced by IFs is significantly higher than that produced by CFs. Most piglets raised for fattening on CFs are produced on the farms, and the remaining are purchased.

Table 5 shows the results of the Tobit models, in which we analyzed the determinants of TE under VRS. Each additional schooling year of farm heads increases the TE of CFs by 0.6% but does not affect that of IFs. The positive impact of education level on the TE of CFs is consistent with the results of Tian *et al.* (2015) and Jabbar and Akter (2008). Without the technical support by the company as the counterpart IFs have, the educational attainment of farm heads in CFs is important to the application of advanced technology to pig production. Each additional family labor reduces the TE of CFs by 1.3% but does not influence the TE of IFs. This finding was mentioned in the study of Jabbar and Akter (2008). Although pig production is the main job of IFs, it is the supplemental work of CFs; thus, family labor in CFs pays less effort on pig raising, resulting in lessening the TE. Increasing the live weight of slaughtered pigs by 1 kg increases the TE of IFs by 0.7% but did not affect the TE of CFs. Because closed pigpens structures do not require a high workload for cleaning and washing floors, increasing pig weight does not increase labor costs in IFs but has a large effect on labor costs in CFs.

Average fattening time increased by 1 month reducing the TEs of IFs and CFs by 7.2% and 2.5%, respectively. Lengthening the phase causes extra costs incurred, while the speed of weight gained is slowed down. Renting land at IFs reduces TE by 6.6% as IFs often rent a substantial amount of land to build their pig housing system. Land rent does not affect the TE of the CFs as most of the CFs use their land for pig production. A larger floor area per pig reduces the TE of CFs but does not affect IFs. CFs require a larger floor space per pig than IFs, resulting in a larger pigpen area for cleaning, which in turn increases labor and electricity costs.

Table 5. Determinants of technical efficiency (TE) under VRS

Variables	IFs N = 46	CFs N = 200
Education	–0.2627	0.5991*
Number of family labor	–0.6872	–1.3381**
Liveweight of slaughtered pigs	0.6934***	–0.0374
Duration of the fattening phase	–7.2049***	–2.5174**
Land formation (1 = rent)	–6.6475*	–3.3798
Floor space per pig	–27.1593	–1.0415*
Total annual family income	0.0304***	0.0952***
The ratio of treatment area to pigpen area	–5.4816*	–0.0191
Number of fattening pigs	–0.0055***	0.0402***
The proportion of piglets bred in farms	–	–0.1454***
Feed type (1 = mixture)	–	12.1601***
Constant	92.5111***	101.5959***
LR chi2	36.02	75.99
Prob > chi2	0.0000	0.0000
Pseudo R^2	0.1037	0.0512
Log likelihood	–155.7177	–704.7057

*** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

Each additional US $100 in total annual income increases the TE of IFs and CFs by 0.03% and 0.1%, respectively. Farmers who earn a higher income might be better able to manage their use of inputs, resulting in a higher TE. An increase in the treatment area to pigpen area ratio reduces the TE of IFs by 5.5% but does not affect that of CFs. With a large quantity of fattening pigs, IFs need to have a substantial land area for waste treatment plants. According to Huong *et al.* (2019), extensive manure treatment plants in Vietnam, including biogas plants, stabilization ponds, or a combination of the two, are mainly based on biological processes and require more land area. Therefore, a large area of land is rented to build the treatment plants, which incurs a high fixed cost, resulting in a reduction in the TE of IFs.

Each additional fattening pig reduces the TE of IFs but increases that of CFs, which can be explained by the aforementioned results of the scale efficiency analysis. A percentage increase in piglets bred at farms reduces the TE of CFs. Traditionally, farrow–to–finish is the most cost–effective way to produce slaughtered pigs in CFs. However, when the market price of piglets decreases, buying the piglets would be more cost–effective than farrow–to–finish. At the time of the survey, pig production in Vietnam faced a serious oversupply situation, pushing the price of pigs to an extreme low. Therefore, raising bought–weaned piglets could lessen the piglet costs, and increase the TE of the CFs. Compared to industrial feed, mixed feed increases the TE of CFs by 12.1% because it incurs lower costs.

Discussion and policy implications

Discussion

With the changes in the structure of livestock sectors in Asian countries, pig farming systems are mainly classified by size or scale (i.e., small, medium, and large scale) (Huynh *et al.*, 2006). This classification is based on the number of animals raised on the farm and is dissimilar across countries. Small–scale farms are defined as farms that raise less than 25 adult pigs in Sri Lanka (Fernando, 2017), less than 500 pigs in Thailand (Kashyap, 2017), less than 21 heads of adult swine or 10 adults and 22 young in the Philippines (PSA, 2016), and less than 200 fattening pigs sold per year in Vietnam (Lapar, 2014). The other farms are defined as commercial/large–scale farms in the Philippines and Vietnam (Lapar, 2014; PSA, 2016). Medium–scale farms in Thailand and Sri Lanka are defined as those raising less than 5000 pigs and 50 pigs, respectively, while farms rearing more than that are classified as large–scale farms (Fernando, 2017; Kashyap, 2017). The classification by the number of pigs does not fully reflect the intensification trend because the pig production revolution corresponds to the introduction of modern technologies and farm management (Thanapongtharm *et al.*, 2016), including the use of evaporated cooling systems in closed pigpens, which provides ideal temperatures inside pigpens that prevent pigs from being susceptible to heat stress, and optimized feed ingredients and additives. These innovations have allowed farms to raise more pigs per square meter with faster production cycles, through high investment in infrastructure, technology, health care, and feeds that contribute to increased productivity (Thanapongtharm *et al.*, 2016). Although large–scale farms mainly apply these innovations in Asian countries, they can be obtained by small–scale farming. Hence, classification by development level (i.e., IFs and CFs) can better reveal the differences between pig farming systems.

Along with innovations in the engineering aspects, the appearance of IFs in Vietnam has created new relationships between agribusiness firms and producers under contract farming. Unlike pig production in the Philippines, where contract farming is conducted in different–sized farms (Delgado *et al.*, 2008), in Vietnam, contract farming works with only large–scale IFs raising at least 500 fattening pigs (Huong *et al.*, 2019). Delgado *et al.* (2008) concluded that in the Philippines and India, smallholders have a higher absolute value of profit efficiency than large–scale producers; and smallholder contract farmers also have a higher value than large–scale contract farms regarding swine in Thailand. However, large–scale farms and contract farms aim toward smaller unit profits but larger volumes of sales (Delgado *et al.*, 2008), with lower market risks (Ogishi *et al.*, 2003) and better preparation for disease outbreaks (USDA, 2019).

The differences in the aims of IFs and CFs induce alternative resource uses, resulting in individual production frontiers for each farming system that are used to estimate the relative production efficiencies among pig farms. TEs under the CRS of IFs, CFs, and pooled samples in this study were 73.7%, 65.7%, and 67.2%, respectively. The aggregate TE is lower than that in the study of Jabbar and Akter (2008) in Vietnam (73.0%) and Tian *et al.* (2015) in China (59.1%) (output–oriented TE). The TE of CFs is lower than that of farrow–to–finish pig households in the study of Ly *et al.* (2016) (80.4%) and is consistent with the output–oriented TE of the farrow–to–finish pig farms in Taiwan (66.6%) (Yang, 2009). The TE of IFs is much lower than those of growing–to–finish pig farms in developed countries in Europe, such as Sweden (94.0%) (Labajova *et al.*, 2016) and Belgium (94.3%) (Van Meensel *et al.*, 2010). The differences in TE among studies result from econometric approaches (DEA vs. SFA) (Van Meensel *et al.*, 2010), assumptions of production frontiers (input vs. output–oriented), types of pig raised (farrow–to–finish vs. fattening pig), and development levels (developing vs. developed countries).

The SEs of IFs and CFs surveyed in this study were 95.2% and 84.2%, respectively, indicating that IFs are operating nearer to the optimal scale than CFs are. The SE of CFs in this study was lower than that in the study of Ly *et al.* (2016) (93.64%). These authors focus on only CFs that raise less than 100 fattening pigs, while this study additionally surveyed the farms owning more than 100 fattening pigs. Therefore, the heterogeneity in the sample resulted in a low SE.

Previous studies estimated the SE from the calculation of TE under CRS and VRS (Ly *et al.*, 2016; Van Meensel *et al.*, 2010), but did not indicate the direction of scale adjustment. This study showed that 78.2% and 17.4% of IFs belong to the areas of IRS and DRS, respectively, while 86.0% and 5.5% of CFs fall into these areas. The proportions of farms that do not need to adjust the production size (CRS) were only 4.3% and 8.5% for IFs and CFs, respectively. The magnitude of adjustment on the farm scale of IFs was lower than that of CFs.

Overall, 79.3% of pig farms in the study site operate in the area of IRS, indicating that there is a potential to increase production efficiency and hence profitability in the long term (Gadanakis *et al.*, 2015) by expanding the production scale. The relationship between farm size and productivity in Asian developing countries might be in the same direction or inverted. Otsuka *et al.* (2016) indicated that when the wage rate is low, which induces a labor–intensive production method, small–scale farms dependent on family labor are more efficient than large farms as they avoid the costs of monitoring hired laborers. When the wage rate increases and labor–saving mechanical production methods become efficient, large–scale mechanized farms are more efficient.

While analysis of RTS offers long–term solutions for scale adjustment, investigation of the determinants of TE under VRS proposes immediate suggestions to improve the TE of pig farms. The negative (increase in the duration of the fattening phase) and positive (increase in the live weight of slaughtered pigs) impacts on TE confirmed the findings of Ly *et al.* (2016). Hence, to shorten the phase and increase the live weight, pig farms should feed their pigs optimized feed ingredients and additives according to the growing phases. Galanopoulos *et al.* (2006) indicated that purchased feeds may be better formulated or accompanied by the services of a nutritionist who can help formulate feeds that better meet the nutritional needs of the animal and increase the TE of pig farms in Greece. Contrarily, our results showed that using mixed feed prepared at the farms helps CFs in Vietnam increase the TE because the feeding mode incurs less cost than feed that is bought ready–made. Feed costs account for 65%–75% of the variable costs of pig production (Lapar, 2014), so the prices of feed ingredients have a great impact on TE. The feed costs in Asian countries increased from US $25 in 2006 to US $44 per pound of pig live weight in 2010 (Lapar, 2014). Meanwhile, the pork prices in the U.S. and EU were relatively steady because of lower feed costs and higher productivity.

Increased floor space per pig reduces the TE of CFs, which is consistent with the results of Jabbar and Akter (2008). However, the lack of space prevented the fattening pigs from getting bigger. Lee *et al*. (2016) argued that the survival rate of fattening pigs tends to increase when their floor space is between 1.10 and 1.27 m^2/head. Increasing the space from 1.27 to 1.47 m^2/head increases the productivity of the pigs. On average, the floor space per pig in CFs (3.25 m^2/head) is considerably higher than that in IFs. Therefore, these farm types could potentially decrease the floor space allowance per pig to improve the TE.

This study shows that land rent reduces the TE of IFs, in contrast to the study of Huy and Nguyen (2019), who argued that cultivation farmers who rent more cropland are more efficient. This opposition derives from the differences in land use between livestock production and crops. In the livestock sector, the more animals are raised, the more land is required to treat the animal waste. To meet the environmental regulations, IFs must pay more for renting land, which reduces their TE. On the other hand, in the crop sector, Huy and Nguyen (2019) explain the positive impacts of land rent on TE by economies of scale. Our finding is once again supported by the negative effect of the treatment area–to–pigpen area ratio on the TE of the IFs. Huong *et al*. (2019) indicated that the pig manure on IFs in Vietnam is often treated in liquid form and requires a large amount of land for manure treatment plants. In addition, Labajova *et al*. (2016) confirmed that treating liquid manure decreased the TE of grow–to–finish farms in Sweden.

Our results reveal that increased herd size decreases the TE of IFs but increases that of CFs. The latter is consistent with the result of Jabbar and Akter (2008), who argued that the most efficient farms have more pigs than the least efficient farms, and Yang (2009) and Galanopoulos *et al*. (2006), who indicated that the farms with more sows are more efficient. Therefore, expanding the production size is more helpful to CFs than to IFs.

Our results show that an increase in the proportion of piglets bred in farms lessens the TE of CFs. Farrow–to–finish pig farms keep breeding sows to produce offspring, then fatten them to maturity, with the final product being slaughtered hogs (full–cycle operation; (Costales *et al*., 2006b)). At the same time, some farms perform partial cycles with just a fattening phase, using piglets that are bought weaned. Farrow–to–finish is the conventional way to produce fattening pigs and is the most cost–effective. Because this phase requires more techniques and facilities than the fattening phase, raising farrow–to–finish pigs might have lower TE than raising finishing pigs, which is following the study of Labajova *et al*. (2016). However, the costs of pig finishing are significantly affected by the market price of the piglet; its increase or decrease can change the TE. Our finding implies that the chosen method of producing slaughtered pigs (full vs. partial cycle) can affect the TE of pig farms.

Policy implications

The findings of this study offer some important policy implications to improve the production efficiency of fattening pig production in Vietnam for IFs and CFs individually.

Regarding IFs, land for waste treatment accounts for a large proportion of the total livestock land, lowering the TE. The conventional handling of animal manure in Vietnam occupies a large land area and wastes a substantial amount of organic fertilizer due to treating the manure in the form of a slurry (Huong *et al*., 2019; Thien Thu *et al*., 2012). In–house manure separation is considered a solution to overcome the limitations of conventional treatment methods (Burton, 2007; Gebrezgabher *et al*., 2015) but has not become widespread in Vietnam because of its high investment costs, regardless of its future benefits (Huong *et al*., 2019). The findings of the present study also highlight the importance of researching and developing advanced manure treatment technologies that occupy less land and incur lower investment costs. In addition, for sustainable pig production, the Vietnamese government should combine livestock areas with cultivation areas to utilize animal manure for plantation and reduce land use for manure treatment.

Regarding CFs, the study results indicate that feeding pigs commercial feed reduces the TE because of the high price of the feed. Corn and soybean are the major ingredients for feed production and are highly dependent on the supply of the leading producer (the U.S.). In 2018, it was estimated that 70% of the total raw materials for animal feed in Vietnam were imported (GSO, 2018). In addition, the Vietnamese feed market share is largely dominated by large multinational corporations (Lapar, 2014) that determine the market feed price. Therefore, the price of animal feed can decrease—and the TE of CFs be improved—only when domestic feed enterprises are promoted to produce animal feed with less dependence on importing raw materials. To achieve this, the government should promulgate policies to support domestic feed enterprises to create their raw material zones to produce feed for the regions themselves, make use of locally available materials, and reduce transportation costs.

CONCLUSIONS

The structure of the livestock sector in Asian developing countries has changed with the emergence of large–scale farming. Numerous studies analyze the production efficiency of livestock farms according to the farm size (i.e., small, medium, and large), which is often defined by the number of animals. Because this classification does not reveal the development of farming systems, we here introduce a new typology, namely industrial farms (IFs) and conventional farms (CFs). This study contributes to the literature and practice by differentiating IFs from CFs in Vietnam by describing their key characteristics, analyzing their technical efficiencies (TEs), and investigating the determinants of TE within each system.

Our results show that from an engineering aspect, pig housing systems and feeding modes are the main differences between these farming systems, while in terms of economics, contract farming distinguishes IFs from CFs. These dissimilarities indicate that these farming systems do not belong to the same production frontiers; therefore, we used separate production frontiers to estimate the relative rates of these systems with the data envelopment analysis (DEA) approach. The results indicated that the input costs of IFs and CFs could be reduced by 26.2% and 34.3%, respectively, without any decreases in the outputs. Analysis of the SE showed that in the long term, CFs have more potential to improve their TE by adjusting their production scale than IFs. The results of RTS analysis suggested that in the long term, to be more efficient, 78% of IFs and 86% of CFs should expand their production size, with the potential of diminishing the average unit fixed costs.

Using Tobit models, the determinants of TE under VRS were analyzed to propose short–term solutions for each farming system. For CFs, using farm–made feed from food waste and agricultural byproducts significantly improved the TE. For IFs, some important determinants first found out by this study are the land rent and ratio of the waste treatment area to the pigpen area reducing the TE. These findings suggest the importance of researching and developing livestock waste treatment plants that occupy less land. In addition, they open a new research direction on land use efficiency, considering environmental factors in the context of the intensification trend in livestock production.

AUTHOR CONTRIBUTIONS

Le Thi Thu Huong formed the research idea, designed the questionnaire for the survey, collected, analyzed the data, and drafted the manuscript. Yoshifumi Takahashi supervised the research and made critical revisions to the manuscript. Luu Van Duy collected the secondary and primary data and edited the manuscript. Do Kim Chung edited the manuscript. Mitsuyasu Yabe suggested the research idea, supervised the research, commented on the manuscript, and provided funds for this work. All authors read and approved the final manuscript.

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