Comparative analysis of technical efficiency of piglet farming in three production center provinces in Indonesia

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ABSTRACT

Pork production occupies the third position in Indonesia, after chicken and beef. Even pigs occupy the top rank in contributing to Indonesia's live animal exports. The purpose of this study was to compare the level of technical efficiency of smallholder piglet production farming in three centers of pig production areas, namely North Sumatra, Bali, and East Nusa Tenggara (NTT). The research data was sourced from secondary data at the farm level, collected by the Central Statistics Agency of Indonesia, through the Livestock Business Household Survey. This research utilized the stochastic production frontier model to assess the production efficiency and the one-step maximum likelihood estimation (MLE) method to measure the level of technical efficiency and the significance of the factors. The results show that the average level of technical efficiency of piglet production farms in Indonesia is relatively low. Piglet production farms in Bali have the highest efficiency level and NTT is the lowest of the three provinces being compared. The number of pigs, feed expenditure, capital, and vaccinations are important factors in influencing production and the level of technical efficiency. Public policies that can increase farmers' access to production factors and better pig farm vaccine management become a necessity.

Keywords: Bali, Household survey, Stochastic production frontier, Vaccination

INTRODUCTION

The majority of Indonesia's population are adherents of Islam. For Muslims, pork and its various derivative products are forbidden for consumption. However, based on data from Livestock and Health Animal Statistics of Indonesia (LHASI) in 2020, it could be seen that pig farming is an important livestock business. Pork production occupies the third position after chicken and beef. The share of pork production was 5.2% of the total meat production in 2020 which is 4.6 million tons. Meanwhile, the share of chicken and beef at the same year were 79.3% and 11.0% respectively. National pork production is supported by the pig population which is
increasing every year with a national average growth in 2014 to 2020 of 2.58%. The growth of Indonesia's pig population is higher than other countries such as China 1.70%, Vietnam -0.89%, or the Philippines -0.17% (Nga et al., 2014). Pig farming is also the mainstay of Indonesia's livestock exports. Live animal exports were dominated by pigs, with a share of 99.1% of total live cattle exports in 2019. On the other hand, live animal imports were dominated by cattle, which amounted to 94.3% of total live animal imports.

Basically, the pig farming industry in Indonesia is centered in three regions, namely North Sumatra, Bali, and East Nusa Tenggara (NTT). Based on Livestock in Figures 2020 published by the Central Agency of Statistics of Indonesia (BPS), the three regions accounted for 66.2% of the total domestic pig production. The share of swine production in North Sumatra, Bali, and NTT were 16.7%, 30.0%, and 19.5%, respectively, of the total pig production in Indonesia, with the rest spread over 21 other regions (provinces).

Although pigs produce is the mainstay of livestock exports in Indonesia, the structure of pig agribusiness is still considered to be relatively unequal. The development of pig farming is not supported by developments in the downstream industry, especially livestock that specifically produces and provides piglets. Based on a household survey of livestock business in 2014 conducted by BPS, there are only 0.8% of pig farms that specialize in producing piglets. More than 52.8% of small-scale pig farmers use pig seeds that come from the piglets they raise, and not from purchases. In general, domestic pig farming businesses still have subsistence characteristics in the production factors they use (Keraru et al., 2021). In the future it is necessary to have better quality pig breeds so that pig agribusiness in Indonesia will be more competitive. Therefore, it is necessary to study the efficiency level of the piglet industry on a smallholder farm scale. If the efficiency level is still low, then the performance can be improved by increasing the efficiency to get closer to the frontier. On the other hand, if the piglet industry is already efficient, it is necessary to have a technological breakthrough to improve the performance of the piglet industry at small holder farm scale.

Various studies on pig farms generally discuss the characteristics and performance of grower-finisher pig farming (Dedecker et al., 2005; Galanopoulos et al., 2006; Aminu and Akhigbe-Ahonkhai, 2017). Likewise, research that utilizes the stochastic production frontier model in assessing the performance of piglet production farms, has not been widely carried out (Sharma et al., 1997; Lansink and Reinhard, 2004; Umeh et al., 2015; Zhou et al., 2015; Wang et al., 2021). The objective of this study is to analyze and compare the level of technical efficiency of piglet production farms in three production centers in Indonesia, namely North Sumatra, Bali and NTT. As far as the best authors knowledge, no one has specifically discussed the level of technical efficiency of piglet production farms, namely farms that only raises breeding pigs to produce piglets, at the household level. Moreover, there has never been a comparison of the technical efficiency of pig farming in Bali, NTT, and North Sumatra. One of the main obstacles to assessing the technical efficiency of piglet production farms is the difficulty of obtaining sufficient research samples, especially cross section data that is suitable for analysis using the regression method. Less than 1 percent of the total smallholder pig farms in Indonesia that produce piglet are entirely dedicated to selling to the market. In the field, the characteristics of farms that produce piglets for their own use in the process of fattening pigs. The Livestock Census, which is the source of the data for this research, is an invaluable source of information to obtain an adequate number of observations for farms with a relatively small population in Indonesia. This research is based on the idea that piglet breeding is an important factor that determines the development of a pig farming business in an area. Thus, the knowledge of the technical efficiency of piglet breeding business is needed to be able to formulate appropriate public policies.
MATERIALS AND METHODS

Source of Data

The data used in this study is part of the latest Livestock Farms Household Survey (ST2013-STU). This study covers pig farms throughout Indonesia using samples from 20 provinces. The number of samples in the Livestock Business Household Survey is 6,738 pig farms on a household scale, and from the total number of samples there are only 57 farms who are categorized as piglet production nursery. The sample used in this study was dominated by piglet production farming from North Sumatra 28.01%; East Nusa Tenggara 27.86%; and Bali 21.42%. These three provinces have contributed more than 77% of the total sample. The household of piglet production farming selected as a sample must use a cage, because it allows a more accurate calculation of the relationship between input and output of pig farming.

Empirical Model and Method of Estimation

Research on the technical efficiency of farming using the stochastic production frontier (SPF) model has been widely carried out in various countries. The SPF model used is based on the thoughts of (Aigner et al., 1977). The SPF estimation adopted is based on the ideas presented by (Jondrow et al., 1982), namely through the variance decomposition model. In this study, inefficiency effect was formulated using the model suggested by (Battese and Coelli, 1995).

There are two production function models that are commonly used in stochastic production frontier research, namely the Cobb-Douglas model and the Translog model. Based on the results of a survey of several major SPF studies using SPF, the Cobb-Douglas production function model is the most widely used (Meeusen and van Den Broeck, 1977; Ahmad and Bravo-Ureta, 1996; Coelli and Battese, 1996; Tabe-Ojong and Molua, 2017; Mwangi et al., 2020). In this study the Cobb-Douglas production function was deliberately chosen. There are two main reasons for using the Cobb-Douglas model in this study. First, the Cobb-Douglas production function requires a relatively small number of samples to obtain a degree of freedom equivalent to the Translog model. With the limited number of samples of piglet-producing farms obtained in the livestock national survey, which was only 57 samples, the Cobb-Douglas model became a more appropriate model. Second, the Translog model has a greater chance to violate the regression assumption, namely the existence of a high multicollinearity phenomenon among its independent variables, which is indicated by a high VIF value (Hair et al., 2010).

The specification of Cobb-Douglas stochastic production frontier function employed in this study are as follow:

\[
\ln Y_i = \ln \beta_0 + \beta_1 \ln X_{1i} + \beta_2 \ln X_{2i} + \beta_3 \ln X_{3i} + \beta_4 \ln X_{4i} + \beta_5 X_{5i} + v_i - u_i
\]

Description:

\(Y_i\) = the production value, namely the accumulation of livestock added value (IDR000)

\(X_{1i}\) = quantity of pig cultivated (head)

\(X_{2i}\) = quantity of labor (man days)

\(X_{3i}\) = quantity of feed (kg)

\(X_{4i}\) = capital, namely fuel, electricity, water; maintenance of livestock health; other expenses (IDR000)

\(X_{5i}\) = dummy pig origin (=1 if own production, =0 if otherwise)

\(\beta_0\) to \(\beta_5 > 0\) = coefficient of regression

\(v_i - u_i\) = error term

Where, \(v_i\) is a random component which is assumed to be independently identically distributed (iid). \(u_i\) is a random variable that represents the effect of technical inefficiency in production. \(i\) is \(i^{th}\) household of piglet production farm. The efficiency effect \((u_i)\) model used in this study employed the form function specification as suggested by Battese and Coelli (1995), which is...
empirically expressed in the following equation:

\[ \ln Y_i = \ln \beta_0 + \beta_1 \ln X_1_i + \beta_2 \ln X_2_i + \beta_3 \ln X_3_i + \beta_4 \ln X_4_i + \beta_5 X_5_i + v_i - u_i \]

from the production process in on-farm were determined not only in units of tails or kilograms but also by looking at non-measurable quality of the piglets they produce. Therefore, the production function model used in this study did not use tails or kilograms but uses a value-added measure. If the units used are physical (tails or kilograms), then the model cannot capture the dimensions of quality in the product, so the results of production function became biased.

The value-added measure as a representation of output can capture the dimensions of quantity and quality of a product. Value added is also more suitable to represent output in farming where the harvest is not done at one time, such as harvesting corn or rice farming. Harvesting in piglets is not done at the same time but is harvested when the farmer needs cash or when it is deemed that the piglets are on time for sale. The stochastic production frontier function that did not use physical measurements for the relationship between output and input in pig farming had also been carried out by Etim et al. (2022) and Jabbar and Akter (2008). The stochastic frontier production function model does not have to be in the form of physical input-output relationship. It is possible that the input-output relationship represented by measurement of output and input in money value terms (Tenaye, 2020).

The estimation of the SPF model using the Cobb-Douglas production function above was carried out using the maximum likelihood estimation (MLE) approach without rejecting the assumption of heteroscedasticity, and the analysis was done with the help of the STATA 13 program (Wang and Schmidt, 2002; Belotti et al., 2013; Tian et al., 2015).

This study applied a single-stage MLE approach which it allows simultaneous estimation of the frontier production function and technical inefficiency model parameters and is free from high bias (Coelli et al., 2005). The SPF model has been widely used in research related to pig farming as in Adetunji and Adeyemo (2012); Tian et al.(2015); and Aminu and Akhigbe-Ahonkhai (2017).

The SPF model specification test is carried
out by testing two hypotheses using the likelihood ratio (LR) test, as follows:

$$LR = -2\left[\ln(L(H_0)) - \ln(L(H_1))\right]$$

The first hypothesis examines the existence of an inefficiency component of the total error term of the stochastic production function. In the first hypothesis test, $L(H_0)$ is the log likelihood value of the generalized linear model (GLM) and $L(H_1)$ is the log likelihood value of the Stochastic Frontier (SF). The second hypothesis tests that each explanatory variable in the inefficiency effect model has an influence on the level of inefficiency in the production process. In the second hypothesis test, $L(H_0)$ is the log likelihood value of the SF model without explanatory variables for the inefficiency effect model and $L(H_1)$ is the complete SF model with all explanatory variables for the inefficiency effect model. The calculated test statistic should be compared with the critical value of the mixed Chi-square distribution proposed by Kodde and Palm (1986). The null hypothesis is rejected if the LR test value is greater than the mixed Chi-square distribution at the 1% probability level.

RESULTS AND DISCUSSION

Performance of the Piglet Production Farming

Based on research samples, it can be said that piglet production is a small-scale farming business. The average number of pigs cultivated in one period is 15 pigs, consisting of 6 males and 9 females. Smallholder pig farming with the number of pigs below 50 heads is a business that is commonly found in many developing countries (Adetunji and Adeyemo, 2012; Thanapongtharm et al., 2016). The average feed consumption per head per period is 343 kg. The composition of feed comes from various sources, namely factory waste (39%), forage (17%), factory feed (14%), agricultural waste (12%), household waste (6%), and others (12%).

Based on the composition of the feed sources, the piglet production farm relies on various types of waste as its feed source, which is 57%. In contrast, the content of feed from feed mills is only 12%. This can be an indication that the nature of subsistence in piglet farming is still relatively high, especially from the aspect of providing production inputs. Research Phengsavanh et al. (2010) in Northern Lao, Mekuriar and Asmare (2014) in Northwestern Ethiopia, Ariana et al. (2014) in Indonesia, Nantima et al. (2015) along the Uganda-Kenya border, and Le-kule and Kyvsgaard (2003) in resource-poor tropical areas of Africa, also found important sources of pig food originating from the surrounding environment and from agricultural and industrial waste or by-products. The amount of feed per head per period in Indonesia is relatively less than pig farm in other country, which daily feed intake ranging from 1.8 kg – 2.5 kg (Pierozan et al., 2016). The optimum amount and

### Table 1. Cost Structure and Profitability in Piglet Production Farming of the Three Provinces in Indonesia per Pig Head Managed per Period

| Description          | North Sumatra | Bali      | NTT       |
|----------------------|---------------|-----------|-----------|
|                      | IDR | %    | IDR | %    | IDR | %    |
| A. Variable Cost     |     |      |     |      |     |      |
| Labor                | 1,426.74 | 38.55 | 1,057.79 | 21.95 | 1,598.16 | 33.81 |
| Feed                 | 796.49  | 47.68 | 760.44  | 66.58 | 732.73 | 43.84 |
| Capital              | 69.68   | 40.79 | 46.63   | 40.79 | 62.15  | 40.79 |
| B. Fixed Cost*       | 27.55   | 1.89  | 84.40   | 7.39  | 56.53  | 10.65 |
| C. Total Cost (A+B)  | 1,454.29 | 100   | 1,142.19 | 100   | 530.89 | 100   |
| D. Revenue (Value Added) | 2,717.39 | -     | 1,588.82 | -     | 1,510.00 | -     |
| E. Profit (D-C)      | 1,263.10 | 446.63 | 979.11  | 979.11 | 979.11  | 979.11 |

*With the following details: fuel, electricity, water; maintenance of livestock health; other expenses. **With the following details: capital goods improvements; land lease; rent on stables, buildings, machinery, and tools; tax and levies; interest on loans.
composition of feed depends on the age, body weight, and breed of the pig, and the management of the pig's feed (Njoku et al., 2013; Patience et al., 2015; Colpoys et al., 2016).

Based on research data, feed and labor were the dominant production factors in the cost structure of piglet farming (Table 1). Piglet farming in North Sumatra employed more feed and labor than farms in Bali and East Nusa Tenggara. The share of the use of inputs other than feed and labor, namely capital, was largest in piglet farming in East Nusa Tenggara. However, piglet farming in North Sumatra provided the highest added value and profit compared to piglet farming in the other two provinces.

Technical Efficiency of Pig Nursery-Farming

Based on the results of the likelihood ratio test on the SPF model used, it can be seen that there is an inefficiency effect in the model. This inefficiency effect is influenced by various factors, and this is also evident from the results of the likelihood ratio test obtained. Table 2 presents the results of the specification test on the Cobb-Douglas SPF model along with the factors that affect the inefficiency.

The estimation results of the SPF in Table 3 show that only labor inputs show no significant effect on production. By using primary data from a household-scale pig farming survey in East Ende – Ende Regency - NTT, the research of Sani et al. (2020) also found a positive effect of the number of pigs and feed on the level of production. However, the results of their research did not find a real effect of capital input on the level of production. On the other hand, this study found that capital has a significant positive effect on the level of piglet production farming.

In the SPF function to control the influence of seed sources, a dummy variable equal to 1 was included if the pigs that were cultivated come from own farming products and was equal to zero if others. The estimation results show that the origin of the pigs raised from the farm itself has a positive influence on the level of production. It seems that pigs that come from own live-

Table 2. Hypothesis Test for SPF Specification in Piglet Production Farming

| Description | Results |
|-------------|---------|
| No inefficiency effect; \( H_0: \gamma = 0 \) | LR Test 33.843 |
| Mixed Chi-square | 5.412 |
| Decision | Reject \( H_0 \) |
| Coefficient of inefficiency factors; \( H_0: \delta_0 = \delta_1 = \delta_2 = \cdots \delta_n = 0 \) | LR Test 29.266 |
| Mixed Chi-square | 28.485 |
| Decision | Reject \( H_0 \) |

Table 3. The Estimation Result of SPF in Piglet Production Farming

| Variable | Coefficient | Standar Error |
|----------|-------------|---------------|
| Constant | 6.269*** | 0.017 |
| Total pig | 0.360*** | 0.097 |
| Labor | 0.546ns | 0.353 |
| Feed | 0.198*** | 0.022 |
| Capital | 0.137*** | 0.020 |
| Pig’s origin | 0.797*** | 0.247 |
| Sigma_u sqr | 0.489*** | 0.098 |
| Sigma_v sqr | 0.000 | 0.000 |
| Log likelihood | -43.9379 | |
| Wald chi2(5) | 3.30E+09 | |
| Prob>chi2 | 0.0000 | |

*** p<0.01; ** p<0.05; * p<0.1; ns p>0.1
stock have better quality than pigs that come from other sources. Probably, breeders select the pigs it produces which were considered to have the best quality for the piglet production farm they are working on.

Based on the estimation results of the SPF model, the TE level of each observation can be measured. Of the 57 samples used in the SPF estimation, the average TE level of piglet production farms in Indonesia is 41.9% (Table 4), and can be categorized as a low level of TE, because it is below 70% (Coelli et al., 2005). The efficiency level of piglet production farms is relatively lower when compared to pig farming in other countries (Tian et al., 2015; Nguyen et al., 2016). The estimation results from this study indicate that there is still great potential to increase the productivity of piglet production farms in Indonesia. The currently available pig farming technology does not appear to be optimally applied by breeders. It is still possible to improve the allocation of resource use in order to obtain a higher level of piglet production farm productivity. Increasing production through a new technology is certainly more difficult to do, because many factors can hinder the decision to adopt technology by piglet farmers (Zanu et al., 2012).

If piglet production farms were grouped based on the area where the farm is located, it can be seen that piglet production farms in Bali have the highest average TE value and NTT is the lowest. Based on the research results presented in Table 5, the average TE values of piglet production farms in Bali and NTT are 50.1% and 35.9%, respectively. Bali also has the lowest diversity of TE values compared to the other two regions, with a coefficient of variation of 45.7%.

The TE value of piglet production farms in Bali relatively higher to the other two provinces was supported by Budaarsa's (2014) explanation that pig breeders in Bali have widely applied artificial insemination (IB). The positive effect of insemination methods and breeding practices for increasing pig farming productivity was also found by Galanopoulos et al. (2006) research in Greece.

**Sources of Technical Inefficiency**

The average value of technical efficiency in the three provinces which was classified as low, with available technology, indicates that there is a great opportunity to increase the productivity of piglet production farms. Table 6 presents the

| Table 4. Distribution of TE Level in Piglet Production Farming |
|---------------------------------------------------------------|
| Technical Efficiency | Number of Observation | Percentage (%) |
|----------------------|-----------------------|----------------|
| <0.5                 | 37                    | 64.91          |
| 0.5-0.6              | 7                     | 12.28          |
| 0.6-0.7              | 4                     | 7.02           |
| 0.7-0.8              | 2                     | 3.51           |
| 0.8-0.9              | 2                     | 3.51           |
| 0.9-1                | 5                     | 8.77           |
| Total sample         | 57                    | 100            |
| Mean                 | 0.419                 |                |
| Std. Dev             | 0.266                 |                |
| Min                  | 0.052                 |                |
| Maks                 | 0.999                 |                |

| Table 5. The Comparison of the Mean and Coefficient Variation of TE of Piglet Production Farming in Three Provinces |
|----------------------------------------------------------------------------------------------------------------|
| Province           | Mean of TE | CV of TE |
|--------------------|------------|----------|
| North Sumatera     | 0.437      | 0.645    |
| Bali               | 0.501      | 0.457    |
| NTT                | 0.359      | 0.618    |

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results of the estimation of factors that affect production inefficiency in piglet production farms. Table 6 should be presented as an integral part of Table 3, because it is generated by estimation using a one-step procedure with the maximum likelihood method, as suggested by Coelli et al. (2005). However, for the purposes of a clearer explanation followed, the results of processing the models of factors that affect technical inefficiency are separated into Table 6. Piglet production farms located in North Sumatra, Bali, and NTT are more efficient than in other provinces. This is indicated by the significant negative effect of the variable dummy of province on technical inefficiency.

Based on the estimation results, the age of the breeder has a negative effect on increasing technical efficiency. The older age of the head of the household has a negative and significant effect on the efficiency level of the piglet production farm. It seems that the younger generation is less and less interested in running a small-scale pig farming business, and prefers to work in the non-agricultural sector or work in urban areas.

The experience of raising pigs is a factor that can significantly affect the efficiency of a piglet production farm. Small-scale pig farms tend to use technology that has been traditionally passed down from generation to generation, so experience is a determining factor for success (Zanu et al., 2012). This was reinforced by the estimation results which show the level of education and extension variables that do not have a significant effect. Likewise, the effect of the variable presence of feed land which significantly increases inefficiency can be an indication that piglet production farms that rely on feed sourced from nearby forages are lower in efficiency compared to farms that rely on feed from other feed sources.

The estimation results also show that vaccination, although with a low statistical significance level, does increase inefficiency. This is certainly contrary to expectations, where vaccination should be expected to improve the technical efficiency of piglet production farms. However, the estimation results that were contrary to this expectation could be an indication of the need to improve a more credible vaccination program in pig farms. Vaccinations that do not show the expected results may be caused by vaccination management or inadequate biosecurity practices at the internal pig farming level (Delsart et al., 2020; Mutua and Dione, 2021). With the complexity of the problems surrounding pig farming, especially with the increasing ASF pandemic in pig farms, the role of research institutions and universities is urgently needed (Gunnarsson et al., 2020) to improve the effectiveness of vaccination.

The model proposed in this study is able to capture the influence of institutions, namely co-

| Variabel                      | Koefisien | Standar Error |
|-------------------------------|-----------|---------------|
| Constant                      | -0.241    | 0.755         |
| Head of household age         | 0.038***  | 0.012         |
| Number of household members   | -0.032    | 0.079         |
| Education of household head   | 0.010     | 0.023         |
| Gender of household head      | 0.255     | 0.332         |
| Farming experience            | -0.936**  | 0.370         |
| Feed area                     | 0.816**   | 0.340         |
| Vaccination                   | 0.594*    | 0.338         |
| Feed combination              | -0.767    | 0.619         |
| Access to financing           | 0.553     | 0.478         |
| Access to extension           | 0.398     | 0.392         |
| Member of cooperative         | -0.662*   | 0.399         |
| Market orientation            | -0.323    | 0.333         |
| Province                      | -0.754**  | 0.368         |

*** p<0.01; ** p<0.05; * p<0.1; ns p>0.1
operatives, in increasing the technical efficiency of piglet production farms. Farmer households who join cooperatives have a greater opportunity to gain access to the required input market and the output market for the piglets they produce. Members of agricultural cooperatives generally also have a higher level of technical efficiency when joining a cooperative (Ma et al., 2018; Qu et al., 2020; Olagunju et al., 2021).

CONCLUSION

The results show that the efficiency level of piglet production farms in Indonesia is relatively low. The production factors of the number of livestock, feed expenditure, and capital has a positive and significant influence on the level of production. Bali has the highest level of technical efficiency and also the lowest level of variation in technical efficiency. The experience of raising pigs and the implementation of vaccination have contributed to the reduction of technical inefficiency in this farm. Public policy that can increase farmers' access to sows, feed and capital is expected to increase piglet production.

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REFERENCES

Adetunji, M. O. and K. E. Adeyemo. 2012. Economic efficiency of pig production in Oyo State, Nigeria: A Stochastic Production Frontier approach. Am. J. Exp. Agric. 2:382–394.

Ahmad, M. and B. E. Bravo-Ureta. 1996. Technical efficiency measures for dairy farms using panel data: A comparison of alternative model specifications. J. Product. Anal. 7:399–415.

Aigner, D., C. A. K. Lovell, and P. Schmidt. 1977. Formulation and estimation of stochastic frontier production function models. J. Econom. 6:21–37. doi:10.1016/0304-4076(77)90052-5. Available from: https://linkinghub.elsevier.com/retrieve/pii/0304407677900525

Aminu, F. O. and C. E. Akhigbe-Ahonkhai. 2017. Profitability and technical efficiency of pig production in Nigeria: The case of Ekiti State. Agric. Trop. Subtrop. 50:27–35. doi:10.1515/ats-2017-0004.

Ariana, I. N. T., A. W. Puger, A. A. Oka, and N. L. P. Sriyani. 2014. Analisis ekonomi usaha ternak babi dengan pemberian sekam padi dalam ransum yang mengandung limbah hotel. Maj. Ilm. Peternak. 17:71–74.

Battese, G. E. and T. J. Coelli. 1995. A model for technical inefficiency effects in a Stochastic Frontier Production function for panel data. Empir. Econ. 20:325–332.

Belotti, F., S. Daidone, G. Ilardi, and V. Atella. 2013. Stochastic frontier analysis using Stata. Stata J. 13:719–758. doi:10.1177/1536867x1301300404.

BPS (Statistics Indonesia). 2020. Statistik Produksi Daging Babi Menurut Provinsi. BPS-Statistics Indonesia, Jakarta.

Budaarsa, K. 2014. Potensi ternak babi dalam menyumbangkan daging di Bali. Proceedings. Seminar Nasional Ternak Babi Seminar Nasional Ternak Babi, Fakultas Peternakan, Universitas Udayana, Jimbaran, Bali, Indonesia, Agustus 5, 2014. P. 1–18.

Coelli, T. and G. Battese. 1996. Identification of factors which influence the technical inefficiency of Indian farmers. Aust. J. Agric. Resour. Econ. 40:103–128.

Coelli, T. J., D. S. P. Rao, C. J. O’Donnel, and G. E. Batesse. 2005. An introduction to efficiency and productivity analysis. 2nd ed. Springer Science + Business Media, New York.

Colpoys, J. D., A. K. Johnson, and N. K. Gabler. 2016. Daily feeding regimen impacts pig growth and behavior. Physiol. Behav. doi:10.1016/j.physbeh.2016.03.003. Availa-
Dedecker, J. M., M. Ellis, B. F. Wolter, B. P. Corrigan, S. E. Curtis, and G. R. Hollis. 2005. Effect of stocking rate on pig performance in a wean-to-finish production system. Can. J. Anim. Sci. 85:1–6.

Delsart, M., F. Pol, B. Dufour, N. Rose, and C. Fablet. 2020. Pig farming in alternative systems: Strengths and challenges in terms of animal welfare, biosecurity, animal health and pork safety. Agric. 10:1–34. doi:10.3390/agriculture10070261.

Etim, N.-A. A., E. S. Ebukiba, E. J. Udoh, and E. U. Essang. 2022. Technical efficiency in swine production under different waste management techniques. World J. Soc. Sci. 9:38–49. doi:10.5430/wjss.v9n1p38.

Galanopoulos, K., S. Aggelopoulos, I. Kamenidou, and K. Mattas. 2006. Assessing the effects of managerial and production practices on the efficiency of commercial pig farming. Agric. Syst. 88:125–141. doi:10.1016/j.agsy.2005.03.002.

Gunnarsson, S., K. A. Segerkvist, T. Wallgren, H. Hansson, and U. Sonesson. 2020. A systematic mapping of research on sustainability dimensions at farm-level in pig production. Sus. 12:1–15.

Hair, J. F., W. C. Black, B. J. Babin, and R. E. Anderson. 2010. Multivariate Data Analysis. Vectors. 816. doi:10.21059/buletinpeternak.v45i4.6876.

Kementrian Pertanian Direktorat Jenderal Peternakan dan Kesehatan Hewan. 2020. Livestock and Animal Health Statistics 2020. Kementrian Pertanian, Jakarta.

Keraru, E. N., H. Harianto, and Y. Yusalina. 2021. Profitability of the three types of smallholder pig farming in Indonesia: An adaptation of enterprise budgeting method. Bull. Anim. Sci. 45:262–269. doi:10.21059/buletinpeternak.v45i4.68763.

Kodde, D. A. and F. C. Palm. 1986. Wald Criteria for Jointly Testing Equality and Inequality Restrictions. Econometrica. 54:1243. doi:10.2307/1912331.

Lansink, A. O. and S. Reinhard. 2004. Investigating technical efficiency and potential technological change in Dutch pig farming. Agric. Syst. 79:353–367. doi:10.1016/S0308-521X(03)00091-X.

Lekule, F. P. and N. C. Kyvsgaard. 2003. Improving pig husbandry in tropical resource-poor communities and its potential to reduce risk of porcine cysticercosis. Acta Trop. 87:111–117. doi:10.1016/S0001-706X(03)00026-3.

Ma, W., A. Renwick, P. Yuan, and N. Ratna. 2018. Agricultural cooperative membership and technical efficiency of apple farmers in China: An analysis accounting for selectivity bias. Food Policy. 81:122–132. doi:10.1016/j.foodpol.2018.10.009.

Meeussen, W. and J. van Den Broeck. 1977. Efficiency estimation from Cobb-Douglas production functions with composed error. Int. Econ. Rev. (Philadelphia). 18:435–444. doi:10.2307/2525757.

Mekuriaw, Y. and B. Asmare. 2014. Assessment of pig production and constraints in Mecha District, Amhara Region, Northwestern Ethiopia. Adv. Agric. 2014:1–5. doi:10.1155/2014/329254.

Mutua, F. and M. Dione. 2021. The context of application of biosecurity for control of African Swine Fever in smallholder pig systems: Current gaps and recommendations. Front. Vet. Sci. 8:1–11. doi:10.3389/fvets.2021.689811.

Mwangi, T. M., S. N. Ndirangu, and H. N. Isab...
oke. 2020. Technical efficiency in tomato production among smallholder farmers in Kirinyaga County, Kenya. African J. Agric. Res. 16:667–677. doi:10.5897/ajar2020.14727.

Nantima, N., M. Ocaido, J. Davies, M. Dione, E. Okoth, A. Mugisha, and R. Bishop. 2015. Characterization of smallholder pig production systems in four districts along the Uganda-Kenya border. Livest. Res. Rural Dev. 27.

Nga, N. T. D., H. N. Ninh, P. Van Hung, and M. L. Lapar. 2014. Smallholder pig value chain development in Vietnam: Situation analysis and trends. Nairobi, Kenya. Available from: https://egspace.cgiar.org/bitstream/handle/10568/53935/pr_situation_analysis_vietnam_web.pdf?sequence=7&isAllowed=y

Nguyen, T.-L., T. Nanseki, and Y. Chomei. 2016. Technical Efficiency and Its Determinants in Household Pig Production in Vietnam: A DEA Approach. Japanese J. Rural Econ. 18:56–61. doi:10.18480/jjre.18.56.

Njoku, C. P., A. B. J. Aina, O. M. Sogunle, O. A. Adeyemi, and O. O. Oduguwa. 2013. Evaluation of feed quantity offered, feeding frequency and duration of feeding on the performance of growing pigs. Thai J. Agric. Sci. 46:181–190.

Olagunju, K. O., A. I. Ogumiyi, Z. Oyetunde-U斯man, A. O. Omotayo, and B. A. Awotide. 2021. Does agricultural cooperative membership impact technical efficiency of maize production in Nigeria: An analysis correcting for biases from observed and unobserved attributes. PLoS One. 16:16–18. doi:10.1371/journal.pone.0245426.

Patience, J. F., M. C. Rossoni-Serāo, and N. A. Gutiérrez. 2015. A review of feed efficiency in swine: Biology and application. J. Anim. Sci. Biotechnol. 6:1–9. doi:10.1186/s40104-015-0031-2.

Phengsavanh, P., B. Ogle, W. Stür, B. E. Frankow-Lindberg, and J. E. Lindberg. 2010. Feeding and performance of pigs in smallholder production systems in Northern Lao PDR. Trop. Anim. Health Prod. 42:1627–1633. doi:10.1007/s11250-010-9612-4.

Pierozan, C. R., P. S. Agostini, J. Gasá, A. K. Novais, C. P. Dias, R. S. K. Santos, M. Pereira Jr, J. G. Nagi, J. B. Alves, and C. A. Silva. 2016. Factors affecting the daily feed intake and feed conversion ratio of pigs in growfinsishing units: The case of a company. Porc. Heal. Manag. 2:1–8. doi:10.1186/s40813-016-0023-4.

Qu, R., Y. Wu, J. Chen, G. D. Jones, W. Li, S. Jin, Q. Chang, Y. Cao, G. Yang, Z. Li, and L. J. Frewer. 2020. Effects of agricultural cooperative society on farmers’ technical efficiency: Evidence from stochastic frontier analysis. Sustain. 12:1–13. doi:10.3390/su12198194.

Sani, A. S., J. G. Sogen, and S. M. Makandolu. 2020. Efisiensi Penggunaan Faktor Produksi pada Usaha Ternak Babi Skala Rumah Tangga di Kecamatan Ende Timur Kabupaten Ende. J. Nukl. Peternak. 7:41–50.

Sharma, K. R., P. Leung, and H. M. Zaleski. 1997. Productive efficiency of the swine industry in Hawaii: Stochastic Frontier vs. Data Envelopment Analysis. J. Prod. Anal. 8:447–459.

Tabe-Ojong, M. P. J. and E. L. Molua. 2017. Technical Efficiency of Smallholder Tomato Production in Semi-Urban Farms in Cameroon: A Stochastic Frontier Production Approach. J. Manag. Sustain. 7:27. doi:10.5539/jms.v7n4p27. Available from: http://www.ccsenet.org/journal/index.php/jms/article/view/71395

Tenaye, A. 2020. Technical efficiency of smallholder agriculture in developing countries: The case of Ethiopia. Economies. 8. doi:10.3390/ECONOMIES8020034.

Thanapongtharm, W., C. Linard, P. Chinson, S. Kasemsuwan, M. Visser, A. E. Gaughan, M. Epprech, T. P. Robinson, and M. Gilbert. 2016. Spatial analysis and characteristics of pig farming in Thailand. BMC Vet. Res. 12:1–15. doi:10.1186/s12917-
Tian, X., F. Sun, and Y. Zhou. 2015. Technical efficiency and its determinants in China’s hog production. J. Integr. Agric. 14:1057–1068. doi:10.1016/S2095-3119(14)60989-8.

Umeh, J. C., C. Ogbanje, and M. A. Adejo. 2015. Technical efficiency analysis of pig production: A sustainable animal protein augmentation for Nigerians. J. Adv. Agric. Technol. 2:19–24. doi:10.12720/joaat.2.1.19-24.

Wang, G., C. Zhao, Y. Shen, and N. Yin. 2021. Estimation of cost efficiency of fattening pigs, sows, and piglets using SFA approach analysis: Evidence from China. C. A. Zúñiga-González, editor. PLoS One. 16:e0261240. doi:10.1371/journal.pone.0261240.

Wang, H. J. and P. Schmidt. 2002. One-step and two-step estimation of the effects of exogenous variables on technical efficiency levels. J. Product. Anal. 18:129–144. doi:10.1023/A:1016565719882.

Zanu, H. K., A. Antwiwaa, and C. T. Agyemang. 2012. Factors influencing technology adoption among pig farmers in Ashanti region of Ghana. J. Agric. Technol. 8:81–92.

Zhou, Y., X.-H. Zhang, X. Tian, X. H. Geng, P. Zhang, and B. J. Yan. 2015. Technical and environmental efficiency of hog production in China - A stochastic frontier production function analysis. J. Integr. Agric. 14:1069–1080. doi:10.1016/S2095-3119(14)60990-4.