**An Alternative Approach to Estimate the Economic Loss of Porcine Epidemic Diarrhea (PED) via Data Envelopment Analysis: The Case in Taiwan**

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## Abstract

This study focuses on investigating how the PED (Porcine Epidemic Diarrhea) virus influenced the production efficiency of swine industry in Taiwan. A total 96 valid sample data were collected during March of 2014. The Data Envelopment Analysis (DEA) was adopted to evaluate production efficiency before, and after, the PED events. Results show that the PED events in Taiwan had weakened overall technical efficiency (TE) about 8.6%. Large scale farms, older farms, and Central area appeared to be the most heavily impacted. Meanwhile, the reproductive rate of Taiwanese hog farms was found to exhibit a polarization in that some farms were producing at a high efficiency, while others were not. Lastly, the percentage change in production efficiency in the DEA estimation are very close to the percentage changes in inventory on farms reported by government. This may imply that the DEA can be further discussed regarding the capability of estimation.



***Keywords*:** Porcine Epidemic Diarrhea (PED), Technical Efficiency, Data Envelopment Analysis (DEA)


## Introduction

The hog industry plays an important role at Taiwan's agriculture sector. The systematic survey and statistical data of total hogs produced could be traced back to the late 19$^{th}$ century during the Japanese colonial period, and the historical statistics shows that there were about 433,000 hogs produced in 1898. From the Japanese colonial period to the Republic of China governed period, the hog industry in Taiwan was primarily devoted to breeding new species, adjusting to modern management methods, improving feed formulas and developing vaccines. The total number of hogs produced was over 2 million head in 1952, and over 3 million head in 1966. After the 1960's, Taiwan started to export frozen hogs to Japan and the United States, and Taiwanese hog production achieved a historical peak of 10 million head (Tseng and Chu, 2013). After late 1980's, the market structure was changing in the hog industry. The large commercial hog operations benefitted from economies of scale, which lead to a decrease in the number of hog operations from 72,393 in 1986 to 26,153 in 1995. In this decade, the number of hog producers decreased by 64% and the average number of hogs produced per farm increased from 97 head to 402 head. This suggests that economies of scale in the hog industry gradually eliminated small, inefficient operations (Lin, 2011).

Although the number of total hog inventory reached a peak in 1996, the hog industry in Taiwan was struck by hog foot-and-mouth disease (FMD) in 1997. As of result of FMD, the Taiwanese hog industry lost its export markets. Additionally, the environmental issues associated with hog production and the establishment of water resource conservation laws also diminished the hog industry in Taiwan. The total number of hog farms fell to 13,753 in 2001 and total hog inventory was reduced to 7.16 million head. At the same time, the average number of hogs produced per farm increased to 521 head. It shows that economies of scale play a very important role in the hog industry (Lin, 2011). In 2002, Taiwan joined the World Trade Organization (WTO) and started to open their doors to hog imports. In addition, the prices of agricultural commodities and raw materials kept going up, which further increased the costs of hog production. As a result, the total number of hog farms and total number of hogs produced decreased to 7,973 and 5.51 million head respectively in 2015. At the same time, the average number of hogs produced per farm increased to 705 head (Council of Agricultural Executive Yuan, 2015).

Hsu and Huang (1995) show that 58% of hogs were marketed through farms associations or cooperatives through the auction markets; 38% of hogs were directly marketed to the meat markets or slaughter plants; 2% of hogs were marketed through contracts from frozen processing companies; only 0.4% of hogs were slaughtered and sold by hog farmers. Because of the impact of FMD, the hog price was at the lowest point ($36NT/kg) in 1997 over the last 20 years. Since 1997, the hog price has trended upward. The average price was about ($45NT/kg) during the time period 1998-2002, increased to $50NT/kg during 2008-2010, and went up to $70NT/kg in 2014 and 2015. Auction prices even broke their historical highs, reaching over $80NT/kg for over 14 consecutive months. The main reason for the historically high hog prices in Taiwan may well be the outbreak of Porcine Epidemic Diarrhea (PED) in late 2013.

PED is a highly epidemic disease impacting hogs. In the 1970's, PED broke out in Europe, was first found in the US in 2013, and struck Asian countries such as China, Japan, Korea and Taiwan in more recent years (Snelson, 2014). PED infected hogs typically show symptoms of diarrhea, vomiting and poor appetite. Motility could be as high as 40% and tends to have a greater impact on baby pigs. PED is a production disease, and there is no exception in Taiwan. Data provided by Council of Agricultural Executive Yuan suggest that PED led to a decrease of about 5% (300,000 heads) in total hog numbers and 6.8% (600 hog farms) in total hog inventory. Since January 2014, hog prices have been hovering around

$70NT/kg. The existence of PED around the world in recent years could be related to the structural change of the hog industry in Taiwan.

The spread of PED in Taiwan started in October 2013. At that time, there were no vaccines to prevent or cure the disease. The high motility, especially in baby pigs, represented a major shock to hog production, and led to extremely high hog prices in auction markets. The impact was felt across all scales of hog farms in Taiwan. Most people, including hog producers and the government, underestimated the impact that PED would have on the production efficiency of the hog industry. As a result, the objective of this study will focus on the effects of PED resulting from production efficiency declines in the Taiwan hog industry to examine how the hog farms, government and academia dealt with the problems differently.

In this study, data envelopment analysis (DEA) method is used to estimate the impact of DEA on the production efficiency in the hog industry. DEA is a non-linear programming model originated by Charnes, Cooper and Rhodes (1978) and is also called the CCR model, which is a multi-input and multi-output model used to estimate the production efficiency among firms. The CCR model was discussed and well developed in literature. Recently, DEA has be applied to measure a firm's efficiency in different industries and issues, such as the banking system (Sherman and Gold 1985; Vassiloglou and Giokas, 1990; Yue, 1992; Grifell-Tatjé and Lovell, 1997; Paradi, Rouatt, and Zhu, 2011), hospitals (Syst, 2008; Fixler, Paradi, and Yang, 2014; Asandului, Roman, and Fatulescu, 2014), energy and environmental issues (Fried et al., 2002; Zhou, Ang, and Poh, 2008; Song et al., 2012). Many studies have also used DEA to measure the production efficiency in the hog industry. Rowland et al. (1998) used data from hog farms in Kansas to examine the impacts of hog farm and farmer's characteristics on production efficiency. Somwaru, Zhang and Tuan (2003) used 2,500 individual hog farms' data and applied DEA to measure production efficiency and scale elasticity in China. Their results show that large scale hog farms are most efficient in production and middle size hog farms, with increasing returns to scale, are the most profitable. Yang and Hsiao (2008) adapt the DEA method with undesirable output and discuss hog production efficiency in Taiwan while also taking hog waste into consideration. Their results show that 60% of the hog farms in Taiwan exhibit diminishing marginal returns and that large hog farms are more efficient than the small ones.

The goal of this study is to examine the impacts of PED on the hog industry in Taiwan. The first section estimates production efficiency of the hog industry before and after the PED and examines how the impact of PED would be different among hog farms of different scale, age and location. Section II discusses methodology and data, section III focuses on empirical results and discussion, and the last section draws conclusions and implications from the analysis.

## Methodology and Data

The literature suggests that the DEA method can be used not only estimate a firm's production efficiency (including technical efficiency and scale efficiency) but also the change of production efficiency. Chang, Hwang, and Cheng (1995) use the DEA method to examine the development and efficiency change of 23 different districts in Taiwan. Their results and policy applications can be shared with urban planning division for consideration. Sufian (2004) examines the efficiency change of commercial banks in Malaysia before and after mergers. These results show that mergers benefit small and medium sized banks through economies of scale and that large commercial banks should decrease their scale in order to improve efficiency. Wang and Wang (2005) combine the application of DEA method and the heuristic technique to analyze the efficiency change of 22 integrated circuit (IC) design companies in Taiwan before and after a merger. Results suggest the most efficient scenarios among the possible merging alternatives. Hashimoto and Haneda (2008) study Japanese medical companies' R&D efficiency change during 1983-1992 and show that the R&D efficiency decreased by 50% during that time.

Since PED caused a supply shock in the production system, it is difficult to use cost and production functions to estimate the production efficiency. Different from Chen et al. (2009), which uses accounting data such as costs and revenues from hog operations and management systems under animal technology laboratories in Taiwan, this analysis employs DEA method to calculate production efficiency based on inputs used and outputs produced during the production process. In the survey design, we include questions such as number of hired labor hours, number of sows on the farm, number of hogs produced and the loss caused by PED, as well as the hog farmers who were willing to answer these kinds of questions.

### *Theoretical Model*

Production efficiency in the DEA method is defined from Farrell (1957) and is estimated through mathematical programming to obtain the efficiency frontier. The DEA method has developed from single output to multiple-inputs and multiple-outputs, and general mathematical models are built. In this study, we use the traditional CCR model and BBC model (Banker, Charnes and Cooper, 1984) to estimate technical efficiency (TE) first, and then derive pure technical efficiency (PTE), scale efficiency (SE) and the distribution of returns to scale[1].

The difference between the CCR and BCC models is the setting of returns to scale. The CCR model calculates technical efficiency of all decision making units under the assumption of constant returns to scale (CRS). However, not all of the decision making units are with the same scale and different scales could be the reason for technical inefficiency. The BCC model then was developed under the assumption of variable returns to scale (VRS) to estimate the technical efficiency of different decision making units. In the BBC model, technical efficiency is the product of pure technical and scale efficiency. To obtain the scale efficiency of different decision making units, we divide the technical efficiency estimated in the CCR model by the pure technical efficiency calculated in the BCC model.

There are two ways to measure efficiency in the DEA method, input-orientation and output-orientation. In this study, since the impacts of PED on outputs of hog farms are different and inputs for hog farms would not change much in the short term, we choose output orientation mode to calculate the production efficiency. This means that given the input level, an increase in outputs will increase production efficiency. The empirical model is as following:

i. The Evaluation of Technical Efficiency

Given the input prices, we assume the hog farm will minimize costs to produce hogs, which means allocation efficiency will be equal to 1 and technical efficiency will be equal to production efficiency. The TE in the CCR model under output-orientation mode would be equal to equation (1).

$$\begin{aligned} &Max \quad \mathrm{TE_k} = \theta_k + \varepsilon\left(\sum_{i=1}^{m} s_i^+ + \sum_{r=1}^{s} s_r^-\right) \qquad (1)\\ &s.t. \quad \sum_{j=1}^{n} x_{ij}\lambda_j - x_{ik} + S_i^+ = 0\\ &\sum_{j=1}^{n} y_{rj}\lambda_j - \theta_k y_{rk} - s_r^- = 0\\ &\lambda_j, s_i^+, s_r^- \geq 0\\ &i=1,\ldots,m,\ r=1,\ldots,s,\ j=1,\ldots,n \end{aligned}$$

where $\mathrm{TE}_k$: technical efficiency of the hog farm $k$;

$x_{ik}$: $i$th input of the hog farm $k$;

$x_{ij}$: $i$th input of the hog farm $j$;

$y_{rk}$: $r$th output of the hog farm $k$;

[1] We focus on the overall production efficiency change before and after PED. If you are interested in the distribution of returns to scale, please contact corresponding author.

$y_{rj}$: $r$th output of the hog farm $j$;

$\theta_k, \lambda_j$: lagrange multiplier;

$\varepsilon$: non-archimedean number and assumed to be $10^{-6}$.

$S_r^-$ and $S_i^+$ are Slack variables in equation (1). The DEA method will search among feasible solution sets of the decision making units and solve the multipliers to maximize the efficiency. In the model, TE will be equal to the product of PTE and SE. PTE measures the allocation efficiency of technical resources used by decision making units. SE measures the efficiency of decision making units' scale. When the product of PTE and SE is equal to 1, it means that the decision making unit achieves relative efficiency not only in technical efficiency but also in scale efficiency. When the product of PTE and SE is less than 1, it means that the decision making unit is relatively inefficient either in technical efficiency or scale efficiency.

ii. The Evaluation of Pure Technical Efficiency

The CCR model assumes that all firms are under constant returns to scale to measure the production efficiency. The BCC model relaxes this assumption and allows for variable returns to scale but all decision units need to be under the same returns to scale. The pure technical efficiency in the BBC model could be written as the following.

$$Min \quad \mathrm{PTE_k} = \theta_k + \varepsilon\left(\sum_{i=1}^{m} s_i^+ + \sum_{r=1}^{s} s_r^-\right) \tag{2}$$

$$s.t. \quad \sum_{j=1}^{n} x_{ij}\lambda_j - x_{ik} + S_i^+ = 0$$

$$\sum_{j=1}^{n} y_{rj}\lambda_j - \theta_k y_{rk} - s_r^- = 0$$

$$\sum_{j=1}^{n} \lambda_j = 1$$

$$\lambda_j, s_i^+, s_r^- \geq 0$$

$$i=1,\ldots,m,\ r=1,\ldots,s,\ j=1,\ldots,n$$

where PTE$_k$ is the hog farm $k$'s pure technical efficiency and other variables are with the same definitions of equation (1).

iii. The Evaluation of Pure Technical Efficiency

Each decision making unit's SE can be calculated by TE/PTE. The value of SE will be between 0 and 1 and can be used to justify the returns to scale of firms. When SE is equal to 1, it means that the decision making unit is under CRS and is achieving its best scale efficiency. When SE is less than 1, it means that the decision making unit is under decreasing returns to scale or increasing returns to scale and should either decrease or increase its production to achieve its best scale efficiency.

In the empirical DEA studies, it is a two-stage process to analyze factors affecting production efficiency. In the first stage, the PE values of each decision making unit are estimated. In the second stage, the estimated PE's are set to be the dependent variable and regressed against explanatory variables to estimate the marginal effects. The estimated PE values are between 0 and 1, and therefore are limited variables. If ordinary least squares were used, the estimation would be biased or asymptotic to zero (Greene, 1981). To deal with the censored variable, we use the Tobit censored regression model in the second stage through STATA 13.0 to calculate efficiencies for each hog farms and marginal effects of each factor.

The change of production efficiencies before and after PED can be estimated by kernel density estimation, which is a non-parametric method to estimate the density function of the continuous random variables. The function estimated in this study is $\hat{f}_{\lambda}(x) = \frac{hv}{n\lambda}\sum_{i=1}^{n} K_0(\frac{x - x_i}{\lambda})$ , where $K_0(\cdot)$ is the kernel density function, $\lambda$ is the bandwidth, $n$ is the number of observations , $x_i$ is the $i$ th observation, and $v$ is a vertical scale factor defined as the following: $v = \begin{cases} n \rightarrow v\ Scale = frequency \\ 100 \rightarrow v\ Scale = percentage \\ 1 \rightarrow v\ Scale = proportion \end{cases}$. In this study, frequency scale is used to present results from the kernel density estimation, which are illustrated in Figure 1. The figure shows that frequency is highest in the range from -5 to 0 and the kernel density curve is also in a higher level. This is useful to exhibit the distribution of efficiencies and how the efficiencies changed after PED.

*Relative DEA Variables*

Two important indicators are often used to evaluate the productivity of the swine industry: the one is litters per sow per year (LSY), and the other is litter size at weaning (LSW). Following the LSY calculation from Yen (2001), LSY is about 2.4 litters per year, but the average LSY in Taiwan is less than 2.4 litters. According to the estimation of LSY from Lo and Chen (2008), the LSY of a commercial hog operation should be around 2.1 to 2.2 litters, and the LSW is about 8.7 heads in Taiwan. Furthermore, Huang, Roan, and Lee (1998) used Jan's pig farm as the research sample. They found the LSY on Jan's pig farm to be about 2.01 litters during 1996, and the LSW to be about 8.85 heads. Meanwhile, Huang (2009) studied 168 Taiwanese hog farms from 2002 to 2006 and found that the LSY, on average, was about 2.12-2.24 litters, and the LSW, on average, was about 7.17-

9.84 head. In another study, Huang (2012) used another 33 traditional hog farms' records in order to distinguish the top 25% and the bottom 25% in productivity. The LSY for the top 25% was 2.25 litters and 1.99 litters for the bottom 25%. Therefore, the productivity (LSY) of Taiwanese sows is about 2 litters per year or one every six months.

In order to understand how PED events affected the productivity of the Taiwanese swine industry, this study attempts to apply DEA method to evaluate technical efficiency with two different stages: Before PED event and After PED event. The fundamental calculation for technical efficiency uses pig numbers in input and output for each hog farm. The pig number in input measures how many pigs were produced during a certain time period, which relates directly to sow numbers. The pig number in output measures how many pigs were sent to markets during a certain period, primarily relates to monthly output for each farm. Therefore, the DEA method used in this study is slightly different from previous studies which utilized costs and profits, etc. Since pig numbers in input and output are different for every hog farm, the concept of using pig numbers in DEA method seems feasible and will allow us to determine if technical efficiency could be distinguished between larger/smaller farms, old/young farms, or regions. One advantage of using pig numbers to calculate technical efficiency is that the data records would be more reliable and producers could more easily respond the questionnaire.

Table 1. Variables Setting in Two Different Estimations

| | | Variables | Unit | Description |
|---|---|---|---|---|
| Before PED | Output | $O_{11}$ | head per six months | average monthly pigs sold*6 |
| | Input | $I_{11}$ | head per six months | sow number; an indication of pig inventory input for half year |
| | | $I_{12}$ | persons per six months | average monthly laborers*6 |
| After PED | Output | $O_{21}$ | head per six months | average monthly pigs sold*6 minus the accumulated pig deaths from PED |
| | Input | $I_{21}$ | head per six months | sow number; an indication of pig inventory input for half year |
| | | $I_{22}$ | persons per six months | average monthly laborers*6 |

The input and output variables used in this study are shown in Table 1. In order to calculate a consistent period for input and output, each variable is set to a half year base. The output before PED ($O_{11}$) is set to be the number of pig sold per half year, which is simply six times the average monthly pig sold. The output after PED ($O_{21}$) is set to be a deduction of half year output from the total death number during PED events. The inputs are set to be sow numbers and labor numbers per half year and this is assumed to be the same before and after the PED events. Technical efficiency can be calculated from each input / output set, so two different technical efficiency estimates can be made before and after PED. In order to further understand the changes in technical efficiency with regard to different factors, a simple *t* test was applied to test for differences by farm size, farm age, and farm regions.

*Data Source and Sample Distribution*

Common research sampling and implementation challenges include questionnaire quality, ethnic issues, representation issues, matches with respondents' interest, etc. Even response time has been found to result in lost interest if they are too long (Dillman, 2007). Farmer respondents in particular need an extra patient person to explain the potential benefits of the research that is being conducted. Thus, the best sampling strategy for farmer respondents is typically as short as possible.

The sampling method in Chen et al. (2009) and Chen (2012) utilized the bookkeeping records of the management system from Animal Technology Laboratories in Taiwan which allowed them to use every cost and benefits to evaluate technical efficiency via DEA method. However, information about costs and benefits are often in short supply, inaccurate, and difficult to obtain during the PED events. Therefore, this study attempts to utilize hog inventory input and output to evaluate technical efficiency in order to ease the challenges of the data accuracy and shortages during the PED events. With this method of hog input and output numbers, only a few questions were needed in the questionnaire: average monthly farm laborers, sow numbers, average number of pigs sold per month, and the total number of confirmed deaths from PED. These questions are typically easier for farmers to answer since hog farmers tend to focus on mortalities during PED scares.

Implementing a survey during a PED event was challenging because hog farmers had been quarantined and were unlikely to welcome unfamiliar faces on their farm. Since many Taiwanese hog farmers, especially the second generation, were involved with a closed group through Facebook which allowed them to share and discuss hog production issues, this also became a feasible way to collect the necessary information. Since many hog farmers expressed difficulty in dealing with PED during the outbreak in spring of 2014, a survey was implemented to collect information and share with those farmers. The web-based survey was only open from March 7, 2014 to March 21, 2014. With this web-based survey method, many hog farmers were self-motivated to respond this questionnaire.

A total 96 hog farmers responded to the survey during the two-week period. The sample distribution is shown in Table 2. A total 67 hog farmers confirmed that they were dealing with a PED occurrence. The average PED occurrence period is about two months (the shortest period was 10 days, and the longest period was about five months) among these 67 hog farmers. The average losses per farm from PED were about 650 head. Regarding farm size, about 48% of respondents managing less than 1999 head, about 30% managed 2000-4999 head, approximately 12% managed 5000-9999 head, and about 10% were managing over 10000 head. Regarding the age of the farm operation, about 10% of respondents had been operating for less than 10 years, about 19% had been in operation for 10-19 years, about 35% had been operation for 20-29 years, and approximately 36% had been in production over 30 years. Regarding farm region, about 57% of respondents were from central area, about 34% were from south area, and approximately 9% were from rest regions. The sample distribution for the average sow numbers per farm were about 457 head. The minimum number of sows was 75 head, and the maximum number of sows was 2250 head. Therefore, the sample distribution covers all of Taiwanese hog farm scales. On average, each farm sold 402 hogs per month and employed five laborers. It was determined that this sample appropriately represented the Taiwanese swine industry.

**Empirical Results**

This study attempts to understand how the PED events affected the Taiwanese swine industry. With the survey sampling method, a DEA method is further adopted to evaluate the TE, PTE, and SE which is shown in Table 3. On average, TE before PED was about 0.56, PTE was about 0.78, and SE was about 0.73. The impacts of PED are directly related to mortality so the number of pigs sold per month is expected to decrease. As expected, values for TE, PTE, and SE is, in general, decreased after PED. After PED, TE decreased 8.6%, PTE decreased 6.6%, and SE declined about 2.8%. T tests confirmed that the changes in TE and PTE were significant at the 5% level in explaining that the PED significantly influenced the production efficiency of swine industry.

The distribution for the values of TE, PTE, and SE can be illustrated via the kernel density lines, as shown as in Figures 2, 3, and 4. Figure 2 shows two distributions, which are based on before (solid line) and after (dashed line) PED, for the TE values of the entire hog farms. As mentioned previously, TE declined 8.6%, which can be observed via the movement of the distribution lines. Therefore, the peak of the distribution line also moves upper and to the left. Furthermore, this outcome also corresponds to previous outcomes as is shown in Table 3.

Figure 3 illustrates the distribution of PTE values for all hog farms. Note the distributions of the PTE values have two different peaks which imply that Taiwanese hog farms may not have a consistent PTE. Also note that after PED, the left curve of the distribution lines expands, meaning that most farms saw a decrease in PTE. It is interesting that so much difference exists in the reproductive in Taiwan. This also implies that farms with low reproduction rate should improve management their skills and adopt new techniques to improve reproductive rates. Figure 4 demonstrates the distributions for the SE values for all hog farms. Note the distribution line shifts to the left following PED, but it is not hard to notice that most Taiwanese hog farms have higher scale efficiencies.

This study also attempts to explain the value changes of TE, PTE, and SE resulting from farm scale, farm age, and region by using *t* tests to determine if differences are significant. Changes in TE reveal a significant decrease of about 13% for the 2000-4999 head scale and a significant decrease of about 9% for those over 10000 head. Changes in PTE suggest a statistically significant decrease about 21% for operations over 10000 head and a significant decrease of 8% for those between 2000-4999 head. This finding suggests that larger scale farms are likely to face higher mortality rates as a result of PED. Changes in SE values reveal a significant decrease of about 5% for 2000-4999 head operations and a 15% increase for those over 10000 head. The decease associated with farms between 2000-4999 head was not a surprise, but the increase for larger operations clearly was. There are likely two possible explanations: first, it is possible that larger scale Taiwanese hog farms may be operating above their optimal scale. If so, it is also possible that the increased mortality associated with PED could have actually improved scale efficiency. A second explanation might be that larger scale farms are under financial pressure each month such that they are purchasing piglets to be resold later.

The problem solving ability of a hog operation is likely highly related to experience, so it is worthwhile to consider farm experience when examining changes in TE, PTE, and SE. Changes in TE reveals a significant decrease of about 18% for farms in existence between 10-19 years and an 11% decrease for farms in production over 30 years. However, the changes in PTE show a significant decrease of about 10% decrease for farm tenure between 10-19 years and farm tenure over 30 years. As for regional differences, changes in TE values exhibit a significant decrease of about 12% decrease in central area and changes in PTE suggested a significant 10% decrease. This suggests that some areas in Taiwan may potentially face greater challenges resulting from PED.

While *t* tests provide a good level of understanding about PED impacts with regard to different factors, it is still worthwhile to examine how these factors jointly affect the changes of TE, PTE, and SE values individually via Tobit censored regression model. The outcomes of Tobit censored regression are shown in Table 4. The overall examination is consistent and robust. Three different dependent variables are individually examined to determine any impact from independent variables such as Total days with PED, Total head loss, Farm age, Farm scale, and Regions. Results reveal that the changes of TE values are impacted by mortality rate, the farm tenure, and farm Scale. Farms that experienced higher hog mortality had greater TE and PTE values. Farms that had been operating over 30 years were more likely to experience a decrease in PTE than farms that had been operating less than 9 years. Overall, larger scale farms (5000 and larger) were more likely to see negative impacts on TE, PTE, and SE than were smaller scale farms (less than 1999 head). Respondents from the central area were more likely to experience negative impacts on PTE than respondents from the northern and eastern regions. In sumary, large scale farms, farms that had been in operation longer, those with greater mortality losses, and farms in the central area experienced more negative impact on TE, PTE, and SE.

*An Alternative Approach to Estimate the Economic Loss*

From the previously discussed results, the impacts of PED events on mortality are clear. Many experts were trying to estimate the total economic loss as a result of a PED outbreak (Schulz and Tonsor, 2015; Paarlberg, 2014). While the DEA method is not designed for prediction or estimation of economic losses, it does provide an opportunity to examine changes in TE and PTE values in relation to what was reported by the government. The Taiwanese Council of Agriculture (COA) reports total inventory of hogs on farms annually and estimated about 5,806,237 head[2] at the end of 2013. Their estimate on total hog inventory was 5,422,399 head in April, 2014. This time period represented a time when PED severely impacted the Taiwanese hog sector. If all of this decrease in inventory was due to PED and the auction market value was $6000NT per head, then the total economic loss to the Taiwanese hog sector would be around NT$2.3 billion. However, the accuracy of this number is clearly very assumption dependent.

On a percentage basis, the mortality loss suffered during this period was 6.6%[3] decrease during this period. It is noteworthy that the sampling period used in this study was very similar to COA reporting period, and the percentage of loss at 6.6% is very close to the 8.6% decrease in TE found in this study. This result seems to suggest that the DEA method may be a reasonable approach to estimate economic losses from PED. However, for this to be true, there are many assumptions that must hold. Key factors that warrant further discussion are the sample representation via Facebook closed group, the application of using pig numbers as inputs and outputs for the DEA method, the reliability of using DEA method to calculate economic losses.

[2] Total heads on farms: http://agrstat.coa.gov.tw/sdweb/public/inquiry/InquireAdvance.aspx
[3] 6.6% = (5,422,399-5,806,237) / 5,806,237

## Conclusion

Highly contagious diseases often create tremendous impacts on agricultural and food production and PED events have created severe impacts around the world. The impacts of PED were serious in Taiwan and most farmers questioned how best to handle this unfamiliar disease since approximately 70% of hog farms in Taiwan dealt with its impacts.

Compared to previous applications of the DEA method, this study adopts pig numbers as input and output sources to evaluate the efficiency values of TE, PTE, and SE. Overall, the examination of TE, PTE, and SE was explained reasonably well by sow number, laborers per six months, and head sold per six months. As a result of PED, TE and PTE, on average, declined 8.6% and 6.6%, respectively. These percentage changes were very similar to the percentage changes (6.6%) in total losses (in number of head) on farms reported by COA. While the DEA method was not designed for this type of estimation, it is interesting that the percentage changes from this study are so similar to those from COA's reports. However, this study is not trying to conclude that the DEA method can be used as an estimation of economic loss. But, if these values are not just a coincidence, it likely does provide evidence that the sample in this study was representative, PED primarily lead to losses related to mortality, and there was little difference from the structure of hog farms. Basically, the structure of most hog farms in Taiwan is still farrow-to-finish farms and this represented that majority of respondents in this study. Therefore, the outcomes of this work suggest further discussion and studies are warranted.

Although PED events influence the entire Taiwanese swine industry, many influences can be found, particularly, on total mortality, larger scale farms, farms that had been in operation longer, and farms in the central area. In particular, the distribution of kernel density revealed that the PTE lines were not normal. This suggests that the reproduction rate for each hog farm is different with some farms operating at high efficiency and others that still have a lot of room for improvement. It was also interesting that some larger farms (scale over 10000 heads) actually experienced better scale efficiency after PED; this may imply that larger farms may have been operating at above their most efficient levels prior to PED. If so, PED may have actually improved the scale efficiency for some of the larger farms. It is also possible that these larger farms imported farrowing sows in order to sell more hogs in the future. This point is likely easier to deny since PED primarily impacted farrowing herds.

In sum, the PED events in Taiwan not only have affected the production efficiency, but also led to large economic losses. If the value per her for hogs at the auction market value were NT$6000, then the farm-based losses would be aroundNT$2.3 billion. Although smaller scale farms were impacted, the impacts on larger scale farms appeared even greater. Smaller scale farms were likely able to recover easier from PED than larger scale farms. Therefore, if the government wishes to influence the market and see supply return to normal levels, they should consider assisting larger scale operations as quickly as possible.

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Table 2. Variable Definitions and Summary Statistics ($N$ = 96)

| Variables | Definition and Variable Description | Mean | Std. Dev. | Min. | Max. |
|---|---|---|---|---|---|
| Sow number | Continuous variable; respondents' sow numbers on farm | 457 | 567 | 75 | 2250 |
| Laborers | Continuous variable; respondents' laborers on farm | 4.81 | 2.91 | 2 | 12 |
| Head sold per month | Continuous variable; respondents' head sold per month | 402 | 394 | 25 | 1450 |
| TE | Continuous variable; the average technical efficiency before PED events | 0.56 | 0.24 | 0.04 | 1 |
| PTE | Continuous variable; the average pure technical efficiency before PED events | 0.78 | 0.23 | 0.33 | 1 |
| SCALE | Continuous variable; the average scale efficiency before PED events | 0.73 | 0.23 | 0.08 | 1 |
| Total days with PED | Continuous variable; respondent reports total days of PED occurrence on their farm | 63.52 | 26.69 | 10 | 150 |
| Total head loss | Continuous variable; respondent reports total head loss since the PED event | 642.6 | 882.4 | 50 | 4000 |
| Farm tenure 10-19 years | Binary variable=1 if respondent's farm tenure is within 10-19 years | 0.19 | 0.40 | 0 | 1 |
| Farm tenure 20-29 years | Binary variable=1 if respondent's farm tenure is within 20-29 years | 0.35 | 0.48 | 0 | 1 |
| Farm tenure over 30 years | Binary variable=1 if respondent's farm tenure is over 30 years | 0.36 | 0.48 | 0 | 1 |
| Scale 2000-4999 head | Binary variable=1 if respondent's farm scale is between 2000-4999 heads | 0.30 | 0.46 | 0 | 1 |
| Scale 5000-9999 head | Binary variable=1 if respondent's farm scale is between 5000-9999 heads | 0.12 | 0.33 | 0 | 1 |
| Scale over 10000 head | Binary variable=1 if respondent's farm scale is over 10000 heads | 0.10 | 0.30 | 0 | 1 |
| Central | Binary variable=1 if respondent's farm locates at central area in Taiwan | 0.57 | 0.49 | 0 | 1 |
| South | Binary variable=1 if respondent's farm locates at south area in Taiwan | 0.34 | 0.47 | 0 | 1 |

Table 3. The Value of TE, PTE, SE with Comparison under Different Circumstances and *t* Test

| | | TE | | | | PTE | | | | SE | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | **Before PED** | **After PED** | **% Change** | ***t*-test** | **Before PED** | **After PED** | **% Change** | ***t*-test** | **Before PED** | **After PED** | **% Change** | ***t*-test** |
| Average Total Efficiency | | 0.567 | 0.519 | -8.6% | ** | 0.782 | 0.731 | -6.6% | ** | 0.738 | 0.717 | -2.8% | - |
| Farm scale | Below 1999 head | 0.533 | 0.494 | -7% | - | 0.843 | 0.820 | -3% | - | 0.634 | 0.589 | -7% | - |
| | 2000~4999 head | 0.565 | 0.494 | -13% | ** | 0.627 | 0.579 | -8% | * | 0.897 | 0.849 | -5% | ** |
| | 5000~9999 head | 0.710 | 0.702 | -1% | - | 0.821 | 0.762 | -7% | - | 0.844 | 0.883 | 5% | - |
| | Over 10000 head | 0.553 | 0.502 | -9% | * | 0.911 | 0.720 | -21% | *** | 0.613 | 0.706 | 15% | *** |
| Farm tenure | Below 9 years | 0.569 | 0.531 | -7% | - | 0.874 | 0.839 | -4% | - | 0.665 | 0.666 | 0% | - |
| | 10 to 19 years | 0.579 | 0.473 | -18% | * | 0.797 | 0.720 | -10% | * | 0.751 | 0.690 | -8% | - |
| | 20 to 29 years | 0.543 | 0.538 | -1% | - | 0.734 | 0.728 | -1% | - | 0.746 | 0.734 | -2% | - |
| | Over 30 years | 0.582 | 0.518 | -11% | * | 0.799 | 0.720 | -10% | * | 0.738 | 0.721 | -2% | - |
| Farm region | Rest of area | 0.620 | 0.558 | -10% | - | 0.765 | 0.771 | 1% | - | 0.780 | 0.681 | -13% | * |
| | Central area | 0.547 | 0.483 | -12% | * | 0.784 | 0.702 | -10% | ** | 0.710 | 0.700 | -1% | - |
| | South area | 0.587 | 0.549 | -6% | - | 0.783 | 0.757 | -3% | - | 0.772 | 0.741 | -4% | - |

Table 4. The Outcomes of Tobit Censored Regression for Regarding Factors

| Dependent Variable | ∆TE | ∆PTE | ∆SCALE |
|---|---|---|---|
| Total days with PED | 3.1e-03 | 0.001 | 4.9e-04 |
| | (2.4e-03) | (0.000) | (4.0e-03) |
| Total head loss | 8.4e-04*** | 1.7e-03*** | 1.9e-04 |
| | (1.1e-04) | (1.2e-04) | (2.0e-04) |
| Farm tenure 10-19 years | -0.043 | -0.043 | -0.030 |
| | (0.028) | (0.054) | (0.030) |
| Farm tenure 20-29 years | -0.041 | -0.077 | 0.004 |
| | (0.027) | (0.053) | (0.028) |
| Farm tenure over 30 years | -0.065** | -0.082 | -0.017 |
| | (0.024) | (0.056) | (0.028) |
| Scale 2000-4999 head | -0.014 | 0.044 | -0.009 |
| | (0.015) | (0.027) | (0.025) |
| Scale 5000-9999 head | -0.067*** | -0.019 | -0.050* |
| | (0.022) | (0.035) | (0.029) |
| Scale over 10000 head | -0.182*** | -0.084** | -0.217*** |
| | (0.035) | (0.041) | (0.071) |
| Central | -3.8e-03 | -0.100** | 0.034 |
| | (0.013) | (0.043) | (0.038) |
| South | 0.003 | -0.048 | -0.000 |
| | (0.011) | (0.043) | (0.037) |
| Constant | 0.078*** | -0.014 | 0.059 |
| | (0.025) | (0.067) | (0.045) |
| /sigma | 0.045*** | 0.060*** | 0.073*** |
| | (0.006) | (0.007) | (0.008) |
| Observations | 64 | 67 | 64 |
| Adjusted $R^2$ | -0.298 | 2.087 | -0.393 |
| Log-Likelihood | 89.88 | 20.05 | 46.65 |

Notes: Asterisks indicate levels of significance: * = 0.10, ** = 0.05, and *** = 0.01.

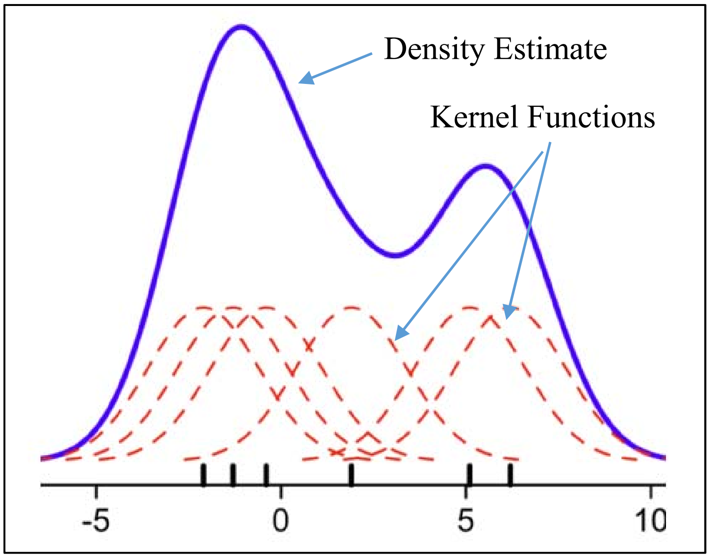


Figure 1. The Illustration of Kernel Density Estimation

Source: http://cdn.spiderfinancial.com/sites/all/files/KDE-Tutorial-101.pdf

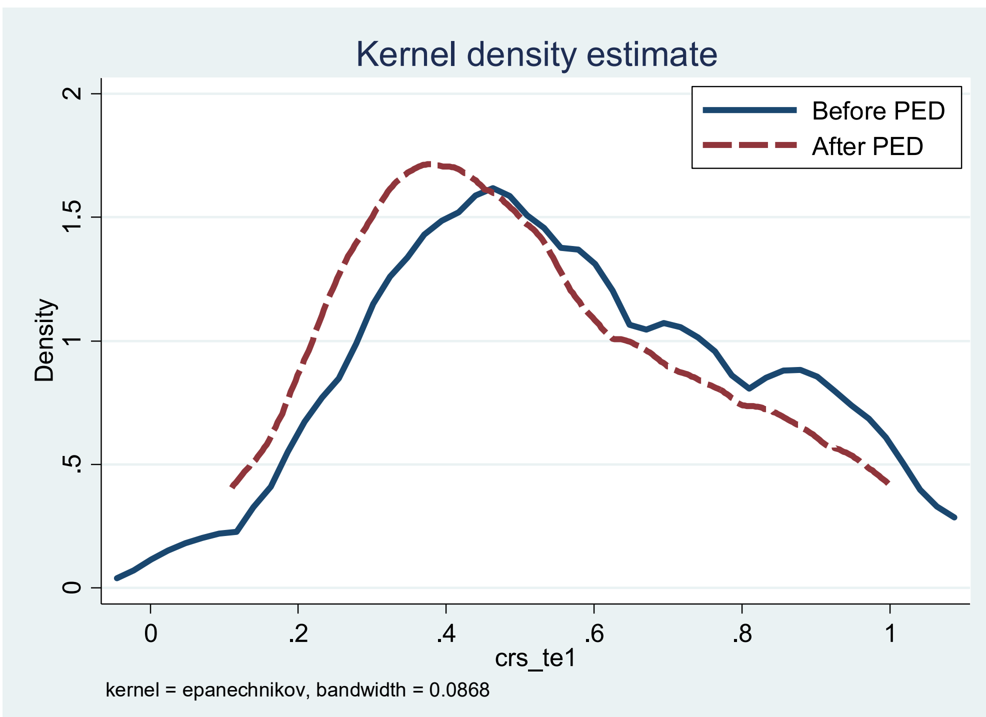


Figure 2. The Illustration for the Movement of Technical Efficiency before and after PED

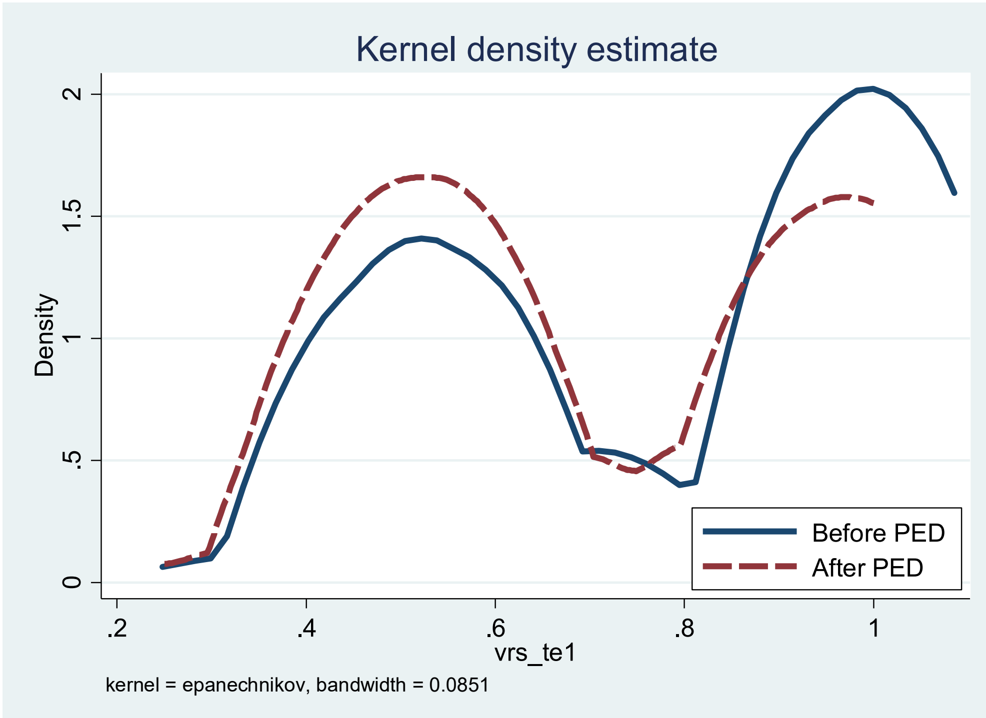


Figure 3. The Illustration for the Movement of Pure Technical Efficiency before and after PED

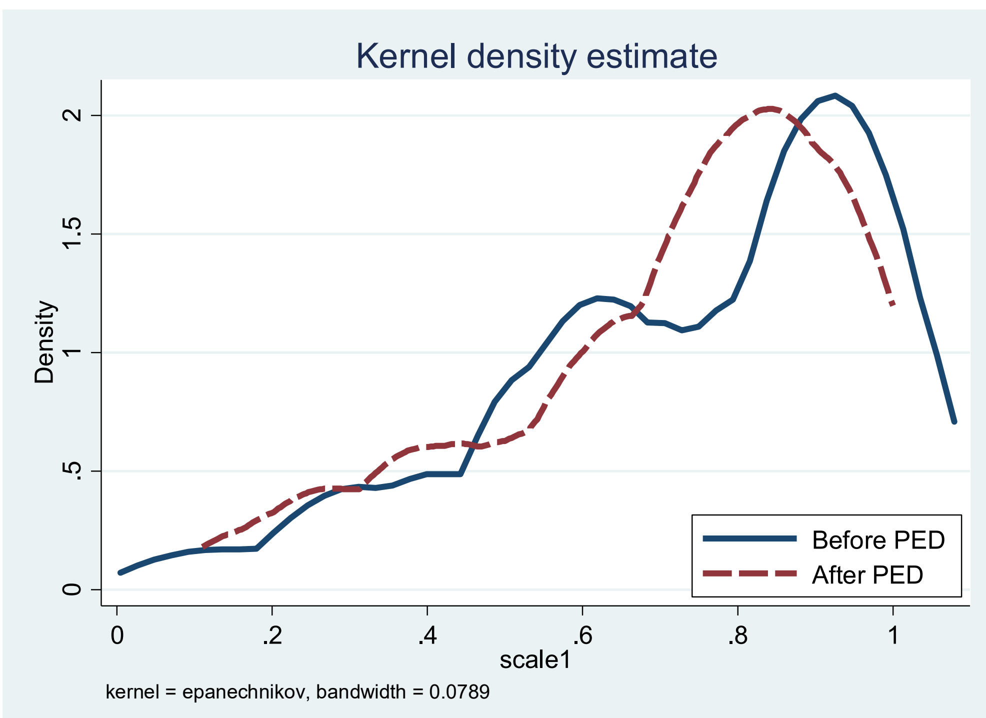


Figure 4. The Illustration for the Movement of Scale Efficiency before and after PED