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Environmental Efficiency of Intensive Shrimp Farming in Transforming Areas of The Coastal Mekong Delta

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Efficient use of environmentally detrimental inputs in agricultural production activities in general and intensive shrimp farming in particular is very important for achieving sustainable development goals, especially for the vulnerable coastal areas of the Vietnamese Mekong Delta. In order to provide solutions for improving the environmental efficiency of intensive shrimp farmers who recently transformed their farming systems, the study conducted face–to–face interviews with 160 farmers in Kien Giang and Soc Trang provinces. The study employed one–step stochastic frontier analysis to estimate the output–oriented technical efficiency, then measure the environmental efficiency for each shrimp farmers. Besides, the study also employed Tobit regression to investigate the factors affecting the environmental efficiency. The study found that the average output–oriented technical efficiency of shrimp farmers is 92.32%. The average efficiency scores in Soc Trang and Kien Giang are 90.54% and 96.89%, respectively. The study also found that the average environmental efficiency of the converted shrimp farmers in the study sites is 91.77%, specifically 89.73% in Soc Trang and 97.02% in Kien Giang. This result indicates that the shrimp farmers in Soc Trang and Kien Giang provinces can reduce by 10.27% and 2.08%, respectively, of the total environmentally detrimental inputs (feed, medicine, and fuel) without compromising output level while keeping normal inputs constant. The Tobit regression indicated that there are five factors having significant effects on the environmental efficiency. Of which, experience, pond area and density have positive effects while location and number of ponds have negative effects on the environmental efficiency.

Key words: Environmental efficiency, Shrimp farming, The Mekong Delta, Transformation

INTRODUCTION

Agricultural production is a key economic sector in the Mekong Delta (MD). During the period 2016–2018, the agricultural sector of the MD achieved a GDP growth rate of 3%/year, which is higher than the national average growth rate at 2.67%/year. The agricultural production of the MD contributed about 34.6% of total GDP of the national agricultural sector and 33.5% of the total GDP of the whole region (General Statistical Office of Vietnam – GSO, 2019). Under the context of implementing drastically the scheme on restructuring agricultural sector towards increasing value–added and sustainable development based on the Prime Minister's Decision 899/QĐ–TTg released on June 10, 2013, the crop and livestock sectors in the MD have been restructured and transformed rapidly. In addition, due to the impact of climate change and the instability of input and output markets of some key agricultural products, the restructuring situation of crop and livestock sectors has been carried out remarkably in the coastal regions.

The MD is the largest "rice bowl" and a key agricultural producer in Vietnam. However, the MD is one of the three mega deltas in the world being affected most seriously by climate change and sea level rise (IPCC, 2014). In fact, as of recent years, climate change and sea level rise have wreaked havoc on the areas, which has caused a large shift in the agricultural and economic of the region. Particularly, the coastal provinces in the MD are considered as the most vulnerable areas. For instance, in 2016 and 2020, seven coastal provinces in the MD declared natural disasters due to drought and salinity intrusion.

According to IPCC (2014), the MD is one of the three deltas most affected by climate change and sea level rise. If the sea level rises by one meter, about 38,9% of the total land and 10% of the population of the MD will be directly affected (MONRE, 2016). Previous studies show that the sea level in the MD has increased by an average of 20 cm over the past 50 years (MONRE, 2016; Nguyen Huu Ninh, 2007). These studies also predicted that the sea level rise could increase by 25–33 cm in 2050 and 73–75 cm in 2100 (MONRE, 2016; Nguyen Huu Ninh, 2007). Wassman (2004) predicted that sea levels would rise by 14–20 cm by 2030 and 32–45 cm by 2090. These authors also indicated that about 0.6 to 1.6 million ha in the MD will be inundated due to sea level rise and saline water will intrude inland about 10 km in 2030 and 20 km in 2090. This projection implies that the current farming systems and farmers' livelihoods will be seriously affected, especially in coastal areas. Changing to appropriate farming practices is one of the possible solutions to adapt to the climate change. However, this conversion is associated with high risks

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due to limited management capacity, which probably result in inefficient use of inputs, particularly environmentally detrimental inputs.

Since the implementation of Decision 899/QĐ–TTg, the rice cultivation area has decreased remarkably by approximately 194 thousand hectares from 4.302 million hectares in 2015 to 4.107 million hectares in 2018. Similarly, the sugarcane area also decreased sharply, from 55 thousand hectares in 2015 to 36 thousand hectares in 2018. As opposite, the aquaculture area increased by 64.6 thousand ha, from 742.7 thousand hectares to 807.3 thousand hectares, leading to the share of aquaculture in the total agricultural value increased from 35.4% to 42% during the same period (GSO, 2019). Of which, the majority of area was shifted to intensive shrimp farming in the coastal regions.

However, the process of transformation requires high investment costs, good preparation of production techniques as well as market outlets, so the risk of the conversion process is quite high (Le Anh Tuan *et al.*, 2015; World Bank, 2016). One of the risks of converting agricultural production activities to intensive shrimp is that farmers have poor experiences in production techniques, which may lead to inefficient use of environmentally detrimental inputs and then cause environmental pollution. According to the World Bank (2016), shrimp farming is one of the farming practices that has significantly severe impacts on the water environment and emit a lot of greenhouse gases due to overuse of inputs. Therefore, it is necessary to measure the environmental efficiency of shrimp farming in transforming areas.

To measure the environmental efficiency, the literature review shows two main approaches: Data Envelopment Analysis (DEA) and Stochastic Frontier Analysis (SFA). The DEA method estimates the efficiency based on mathematic programming and non–parametric approach, which is impossible to separate noise effects from the deterministic frontier. Thus, the estimated results from DEA may be biased. As opposed to DEA, SFA method is based on econometric model so it can overcome the disadvantages of DEA (Tu & Yabe, 2015). Therefore, the current study employed SFA method to measure environmental efficiency for each shrimp farmer.

Recently, the one–step SFA is recommended by econometric experts instead of the two–step estimation approach in order to control estimation biases (Caudill & Ford, 1993; Wang & Schmidt, 2002; Caudill, 2003; Greene, 2005; Belotti *et al.*, 2013; Kumbhakar *et al.*, 2015). Thus, in this current study, we employed the one–step SFA to measure the environmental efficiency for shrimp farmers in transforming coastal areas, then investigating the factors affecting the gaps in environmental efficiency scores among farmers.

LITERATURE REVIEW

Pittman (1983) is probably considered to be the first who concerned about environmental issues when estimating the efficiency for production activities. In that study, he considered the environmental aspect as an unexpected output from production process. The author modified the index from the term "*translog multilateral productivity index*" proposed by Caves *et al.* (1982). This efficiency index took into account of the pollution problem of two unexpected outputs: water pollution and air pollution caused by manufacturing process. The study defined an efficiency index as the minimum proportional decrease/increase in desirable output and increase/decrease in undesirable output. It is crucial for policy makers to control pollution under the context of trade–offs between undesirable and desirable outputs. However, in reality, it is quite difficult to measure the unexpected outputs in agricultural production.

Färe *et al.* (1989) proposed the term "*enhanced hyperbolic productive efficiency measure*". This term considers simultaneously the difference among the maximum equiproportional increase in desirable outputs, the maximum equiproportional decrease in undesirable outputs and the maximum equiproportional decrease in inputs. Besides, the authors also took into account strong and weak disposability of all inputs, desirable and undesirable outputs, from which they measured potential losses in outputs and revenue caused by regulations that prevent the strong disposability. However, the study measured the efficiency indexes by using nonparametric approach, which can't separate noise effects apart from the deterministic frontier and did not consider separately environmentally detrimental inputs as well.

In order to overcome the drawbacks of the previous studies and respect the material balance principle, Reinhard *et al.* (1999) treated environmental pollution as input surpluses (e.g., fertilizers, pesticides, energy) to estimate environmental efficiency (EE). As the environmentally detrimental inputs such as chemical fertilizers, pesticides, fuels, ... have a close relationship with the unexpected output (pollution), minimizing the unexpected output can be achieved through minimizing the environmentally detrimental inputs. Thus, the environmental efficiency index explicitly reflects the level of overuse or the ability to reduce the environmentally detrimental inputs, given output and other normal inputs fixed. The process of estimating the environmental efficiency is similar to that of the input–oriented technical efficiency but the difference is that the environmental efficiency only considers the environmentally detrimental inputs.

To provide better understanding on the measurement of environmental efficiency, Figures 1 and 2 describe the graphical illustrations of the production frontier and the measures of such efficiency indexes in surface and cross–section, respectively.

Suppose that a farm uses two inputs X (normal inputs) and Z (environmentally detrimental inputs). Thus, the production frontier can be expressed by the surface $OX_RR^FZ_R$. Farm R is the observed point that produces output level at Y_R using X_R and Z_R. ABCR is the surface of identical output quantity at Y_R. In other words, every input combination in this surface will produce the same output level, and farm R is also on this

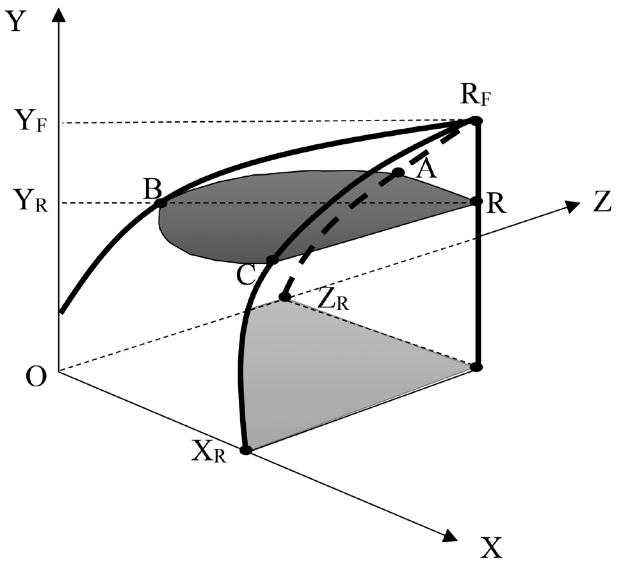

Fig. 1. Graphical illustration of measuring technical and environmental efficiency.
Source: Tu *et al.*, 2015

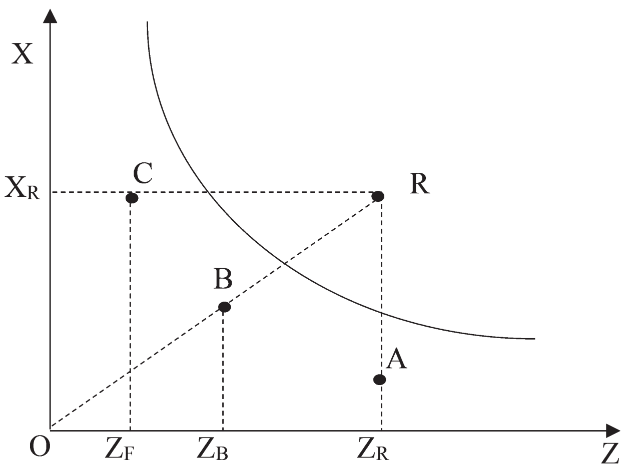

Fig. 2. Cross–sectional illustration of measuring environmental efficiency.
Source: Tu *et al.*, 2015

surface. From Figure 1, it is easily to measure the output–oriented technical efficiency for farm R by the ratio $|OY_R|/|OY_F|$. It is also possible to estimate the input–oriented technical efficiency as a radial contraction by the ratio $|Y_RB|/|Y_RR|$.

To make Figure 1 easily understandable, we derive Figure 2 as a scross–sectional production frontier with two inputs X and Z. From Figure 2, one can obtain the environmental efficiency by the ratio $|OZ_F|/|OZ_R|$. In fact, farmer R and farmer C have the same output level but use different levels of environmentally detrimental input Z, so the farmer R can reduce Z by a distance Z_FZ_R.

METHODOLOGY

Data collection

The process of collecting data is described in four main steps. First, we collected the secondary data from local agricultural organizations to capture the current situations of the farming system's changes to intensive shrimp farming. Second, we conducted focus group discussions and in–depth interviews with key informant panels. This step helps provide the overall picture of changes in the farming system, opportunities and obstacles, as well as policy interventions in the study sites. Third, the study designed questionnaires for trial interviews, then consulted experts to complete the questionnaires that meet the objectives of the study. Finally, we used the designed questionnaires to directly survey farmers in two provinces (Soc Trang and Kien Giang province). The survey collected information on four main aspects: production and conversion status, production technology, risks in model conversion, characteristics of farming households. Data on the production and conversion status were collected to reflect the general situations of the production and transformation. Data on production technology were used for analysis of technical and environmental efficiency. Data on the third and fourth aspects were used in the analysis of difficulties and challenges of the converted shrimp farming, as well as the factors that influence the efficiency gaps of the transformed intensive shrimp farming.

The sample size was 160 households who recently transformed to intensive shrimp farming in Kien Giang and Soc Trang province. Of which, the study interviewed 90 shrimp farmers in Cu Lao Dung district of Soc Trang province where the farmers transformed from sugarcane to intensive shrimp farming. In Kien Giang, we conducted interviews with 70 farmers who transformed from rotated rice – shrimp to intensive shrimp farming.

Empirical model

Reinhard *et al.*(1999) evaluated the environmental efficiency of a dairy production. The study considered the ability of reducing environmentally detrimental inputs such as nitrogen fertilizer, phosphate fertilizer and fuel while outputs and other normal inputs (labor, capital inputs) remain constant.

In the case of the shrimp farming, the environmentally detrimental inputs include feed, medicines and fuel. Shrimp feed is considered as a bad input because excess protein from shrimp feed may pollute the water during the decomposition of anaerobic microorganisms and is a favorable condition for pathogens to grow. During the shrimp farming process, most of the feed that farmers use to feed shrimp is rich in protein. In the process of metabolism, a part is excreted from the manure, and part of the excess feed decomposes and causes water pollution in the pond. This is a very favorable condition for toxic algae, parasites as well as microorganisms harmful to shrimp to develop, thereby causing dangerous diseases such as curved body disease, opaque body disease, white spot syndrome virus, luminous bacteria disease, etc. These dangerous diseases may reduce significantly the productivity and quality of shrimp (Le Manh Tan, 2006; Research Institute of Aquaculture 1, 2013). According to Le Thanh Hung and Ong Moc Quy

(2010), the shrimp feed factories have been following the standards set by the Ministry of Agriculture and Rural Development to produce feed for each stage of shrimp development. Each factory has 6–8 types of feed, in which the protein ranged from 36 to 42%. This fluctuation in terms of nutrient content is not significant, so the differences in protein content between feed types is also insignificant. Especially, according to the study of Do Minh Vanh *et al.* (2016), there are 4 main feed brands used in white–leg shrimp farming in the MD, including UP, CP, Grobest and TongWei companies. Therefore, the current study used the feed variable that measured in kilogram and didn't considered the nutrient content in 1 kg of feed.

According to Le Manh Tan (2006), shrimp ponds also contain a little residue of medicines. Due to limited knowledge of shrimp farming techniques, the shrimp farmers, particularly the recently transformed shrimp farmers use medicines inefficiently. The use of medicines, including antibiotics has caused drug resistance in the microorganisms. In addition, the disease treatment with antibiotics and chemicals may also destroy the majority of beneficial bacteria in shrimp ponds.

In order to obtain the accurate estimation of the environmental efficiency, it is required that the technical inefficiency (u_i) is also estimated correctly because the environmental efficiency is estimated based on u_i.

The process of estimating the environmental efficiency for the shrimp farmers in case of 5 inputs, including three environmentally detrimental inputs: feed (Z_1), medicine (Z_2) and fuel (Z_3) ; and two normal inputs: shrimp larva (X_1) and labor (X_2) is as follows :

The translog production function with two normal inputs and three environmentally detrimental inputs is written as follows:

$$\begin{aligned} LnY_i = {} & \beta_0 + \beta_1 lnX_1 + \beta_2 lnX_2 + \alpha_1 lnZ_1 + \alpha_2 lnZ_2 \\ & + \alpha_3 lnZ_3 + \frac{1}{2}\beta_{11} lnX_1 lnX_1 + \frac{1}{2}\beta_{22} lnX_2 lnX_2 \\ & + \frac{1}{2}\alpha_{11} lnZ_1 lnZ_1 + \frac{1}{2}\alpha_{22} lnZ_2 lnZ_2 \\ & + \frac{1}{2}\alpha_{33} lnZ_3 lnZ_3 + \beta_{12} lnX_1 lnX_2 + \delta_{11} lnX_1 lnZ_1 \\ & + \delta_{12} lnX_1 lnZ_2 + \delta_{13} lnX_1 lnZ_3 + \delta_{21} lnX_2 lnZ_1 \\ & + \delta_{22} lnX_2 lnZ_2 + \delta_{23} lnX_2 lnZ_3 + \delta_{31} lnZ_1 lnZ_2 \\ & + \delta_{32} lnZ_1 lnZ_3 + \delta_{41} lnZ_2 lnZ_3 + v_i - u_i \qquad (1) \end{aligned}$$

Note: The total number of interaction variables used in the translog function is calculated by the formula: N = [k (k + 3)] /2, where k is the number of independent variables and N is total number of combinations. Thus, in this case, the total number of combinations is N = [5 (5 + 3)]/2 = 20.

From Equation 1, the environmental efficiency which reflects the ability to reduce feed, medicine and fuel is calculated by replacing Z_1, Z_2 and Z_3 with ΦZ_1, ΦZ_2 and ΦZ_3 respectively and giving u_i = 0. Note Φ is the environmental efficiency or the ratio of possible minimum amount and the observed amount of environmentally detrimental inputs. After replacements and setting u_i = 0, we get:

$$\begin{aligned} LnY_i = {} & \beta_0 + \beta_1 lnX_1 + \beta_2 lnX_2 + \alpha_1 ln\Phi Z_1 + \alpha_2 ln\Phi Z_2 \\ & + \alpha_3 ln\Phi Z_3 + \frac{1}{2}\beta_{11} lnX_1 lnX_1 + \frac{1}{2}\beta_{22} lnX_2 lnX_2 \\ & + \frac{1}{2}\alpha_{11} ln\Phi Z_1 ln\Phi Z_1 + \frac{1}{2}\alpha_{22} ln\Phi Z_2 ln\Phi Z_2 \\ & + \frac{1}{2}\alpha_{33} ln\Phi Z_3 ln\Phi Z_3 + \beta_{12} lnX_1 lnX_2 \\ & + \delta_{11} lnX_1 ln\Phi Z_1 + \delta_{12} lnX_1 ln\Phi Z_2 + \delta_{13} lnX_1 ln\Phi Z_3 \\ & + \delta_{21} lnX_2 ln\Phi Z_1 + \delta_{22} lnX_2 ln\Phi Z_2 + \delta_{23} lnX_2 ln\Phi Z_3 \\ & + \delta_{31} ln\Phi Z_1 ln\Phi Z_2 + \delta_{32} ln\Phi Z_1 ln\Phi Z_3 \\ & + \delta_{41} ln\Phi Z_2 ln\Phi Z_3 + v_i \qquad (2) \end{aligned}$$

Let (1) and (2) be equal, we have

$$\begin{aligned} & (\alpha_1 ln\Phi Z_1 - \alpha_1 lnZ_1) + (\alpha_2 ln\Phi Z_2 - \alpha_2 lnZ_2) \\ & + (\alpha_3 ln\Phi Z_3 - \alpha_3 lnZ_3) \\ & + (\frac{1}{2}\alpha_{11} ln\Phi Z_1 ln\Phi Z_1 - \frac{1}{2}\alpha_{11} lnZ_1 lnZ_1) \\ & + (\frac{1}{2}\alpha_{22} ln\Phi Z_2 ln\Phi Z_2 - \frac{1}{2}\alpha_{22} lnZ_2 lnZ_2) \\ & + (\frac{1}{2}\alpha_{33} ln\Phi Z_3 ln\Phi Z_3 - \frac{1}{2}\alpha_{33} lnZ_3 lnZ_3) \\ & + (\delta_{11} lnX_1 ln\Phi Z_1 - \delta_{11} lnX_1 lnZ_1) \\ & + (\delta_{12} lnX_1 ln\Phi Z_2 - \delta_{12} lnX_1 lnZ_2) \\ & + (\delta_{13} lnX_1 ln\Phi Z_3 - \delta_{13} lnX_1 lnZ_3) \end{aligned}$$

Table 1. Description of variables used in estimating environmental efficiency

Variable name	Symbol	Unit	Variable description
Yield	Y	Kg/ha/season	Harvest yield per season
Feed	Z_1	Kg/ha/season	Feed amount
Medicine	Z_2	Thousand/ha/season	Total expense on medicine
Fuel	Z_3	Thousand/ha/season	Total expense on fuel
Larva	X_1	Head/ha/season	Number of shrimp larva
Labor	X_2	Day/ha/season	Number of working days

$$+(\delta_{21} lnX_2 ln\Phi Z_1 - \delta_{21} lnX_2 lnZ_1)$$
$$+(\delta_{22} lnX_2 ln\Phi Z_2 - \delta_{22} lnX_2 lnZ_2)$$
$$+(\delta_{23} lnX_2 ln\Phi Z_3 - \delta_{23} lnX_2 lnZ_3)$$
$$+(\delta_{31} ln\Phi Z_1 ln\Phi Z_2 - \delta_{31} lnZ_1 lnZ_2)$$
$$+(\delta_{32} ln\Phi Z_1 ln\Phi Z_3 - \delta_{32} lnZ_1 lnZ_3)$$
$$+(\delta_{41} ln\Phi Z_2 ln\Phi Z_3 - \delta_{41} lnZ_2 lnZ_3) + u_i = 0 \quad (3)$$

By some manipulation, we get

$$\alpha_1 lnEE_i + \alpha_2 lnEE_i + \alpha_3 lnEE_i$$
$$+[\frac{1}{2}\alpha_{11}(lnEE_i)^2 + \frac{1}{2}\alpha_{11} lnEE_i (lnZ_1 + lnZ_1)]$$
$$+[\frac{1}{2}\alpha_{22}(lnEE_i)^2 + \frac{1}{2}\alpha_{22} lnEE_i (lnZ_2 + lnZ_2)]$$
$$+[\frac{1}{2}\alpha_{33}(lnEE_i)^2 + \frac{1}{2}\alpha_{33} lnEE_i (lnZ_3 + lnZ_3)]$$
$$+\delta_{11} lnX_1 lnEE_i + \delta_{12} lnX_1 lnEE_i + \delta_{13} lnX_1 lnEE_i$$
$$+\delta_{21} lnX_2 lnEE_i + \delta_{22} lnX_2 lnEE_i + \delta_{23} lnX_2 lnEE_i$$
$$+[\delta_{31}(lnEE_i)^2 + \delta_{31} lnEE_i (lnZ_1 + lnZ_2)]$$
$$+[\delta_{32}(lnEE_i)^2 + \delta_{32} lnEE_i (lnZ_1 + lnZ_3)]$$
$$+[\delta_{41}(lnEE_i)^2 + \delta_{41} lnEE_i (lnZ_2 + lnZ_3)] + u_i = 0 \quad (4)$$

From equation (4), we get

$$(\frac{1}{2}\alpha_{11} + \frac{1}{2}\alpha_{22} + \frac{1}{2}\alpha_{33} + \delta_{31} + \delta_{32} + \delta_{41})(lnEE_i)^2$$
$$+[\alpha_1 + \alpha_2 + \frac{1}{2}\alpha_{11}(lnZ_1 + lnZ_1)$$
$$+\frac{1}{2}\alpha_{22}(lnZ_2 + lnZ_2) + \frac{1}{2}\alpha_{33}(lnZ_3 + lnZ_3)$$
$$+\delta_{11} lnX_1 + \delta_{12} lnX_1 + \delta_{13} lnX_1 + \delta_{21} lnX_2$$
$$+\delta_{22} lnX_2 + \delta_{23} lnX_2 + \delta_{31}(lnZ_1 + lnZ_2)$$
$$+\delta_{32}(lnZ_1 + lnZ_3) + \delta_{41}(lnZ_2 + lnZ_3)] \, lnEE_i$$
$$+u_i = 0 \quad (5)$$

From the equation (5), we can obtain the environmental efficiency by solving the quadratic function. So the environmental efficiency of the shrimp farming model is calculated by the following formula:

$$EE_i = exp\left(\frac{-b_i + \sqrt{b_i^2 - 4a_i u_i}}{2a_i}\right) \quad (6)$$

where $a_i = \frac{1}{2}\alpha_{11} + \frac{1}{2}\alpha_{22} + \frac{1}{2}\alpha_{33} + \delta_{31} + \delta_{32} + \delta_{41} \ \forall a_i \neq 0$;

$$b_i = \alpha_1 + \alpha_2 + \frac{1}{2}\alpha_{11}(lnZ_1 + lnZ_1) + \frac{1}{2}\alpha_{22}(lnZ_2 + lnZ_2)$$
$$+\frac{1}{2}\alpha_{33}(lnZ_3 + lnZ_3) + \delta_{11} lnX_1 + \delta_{12} lnX_1$$
$$+\delta_{13} lnX_1 + \delta_{21} lnX_2 + \delta_{22} lnX_2 + \delta_{23} lnX_2$$
$$+\delta_{31}(lnZ_1 + lnZ_2) + \delta_{32}(lnZ_1 + lnZ_3)$$
$$+\delta_{41}(lnZ_2 + lnZ_3)$$

RESULTS AND DISCUSSIONS

Changes of farming systems in the coastal MD

Farming transformation is an inevitable phenomenon, particularly in the coastal regions with the expectation of higher profits from the new farming practices. The general picture of the changes in farming systems in the coastal area of the MD in general and in the study sites in particular is described in Figure 3.

Figure 3 shows that in the freshwater area, the farmers mainly produce rice and grow sugarcane. In the brackish water zone, also known as the transforming area, due to the influence of salinity intrusion, many farmers have changed their farming practices from sugarcane to intensive shrimp in Soc Trang province and from rice–shrimp to intensive shrimp monoculture in Kien Giang province. This shows that salinity intrusion is an important factor affecting the transformation of agricultural production activities.

Regarding to the conversion time, the research results show that the majority of farmers in the study sites changed the farming systems during the period from 2013 to 2017 for various reasons. The specific conversion time is presented in Figure 4.

Figure 4 shows that since 2013, the increasingly adverse impacts of salinity intrusion and the higher expected profit from intensive shrimp farming have induced many farmers convert their farming systems.

Figure 5 shows that only 55 households (accounting for about 35.03%) have changed the farming activities based on the production plan of the local government, the rest of of farmers (more than 64.9%) transformed their farming activities spontaneously. The spontaneous conversions originated from two main reasons: the higher expected profit from the intensive shrimp farming and the adverse effects of salinity intrusion that make farmers impossible to continue the rice–shrimp and sugar cane production.

In order to provide empirical information for policy makers to propose solutions to improve production efficiency and adaptive capacity for shrimp farmers in the transforming areas in the coastal regions of the MD, the research results on the difficulties faced by the shrimp farmers are presented in Figure 6.

Figure 6 shows that the most challenging problem that the shrimp farmers have encountered is the shrimp diseases, accouting for 67.16% of surveyed households; followed by the poor quality of inputs and shirmp larva, accounting for 64.18 and 56.72% respectively.

Based on the survey, we found that some new businesses were started to sell shrimp larva and inputs (feed

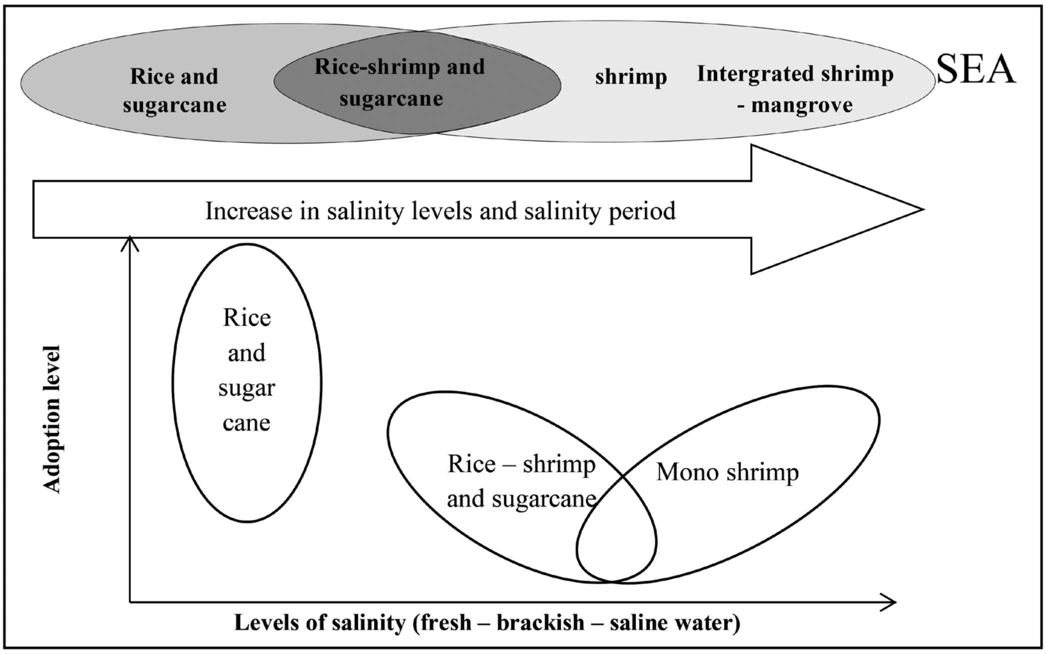

Fig. 3. Trends in agricultural production transformation in the coastal areas of Soc Trang and Kien Giang provinces.

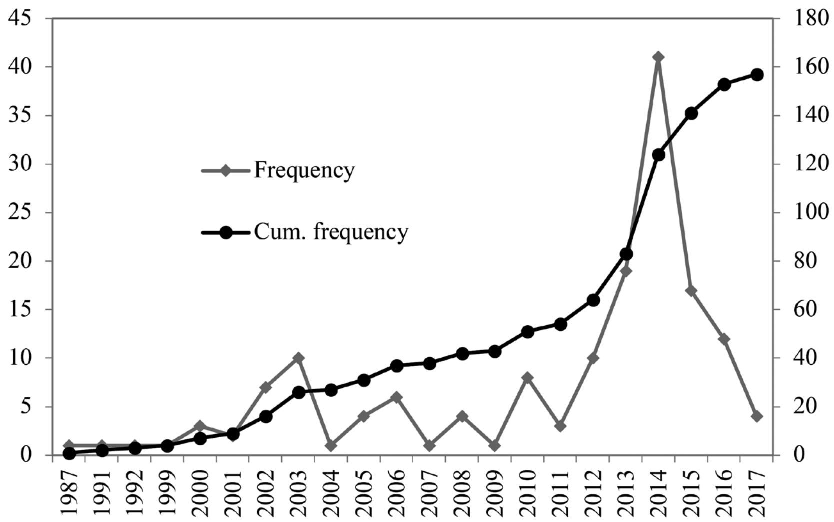

Fig. 4. Conversion time to intensive shrimp farming.
Source: Household survey, n=160

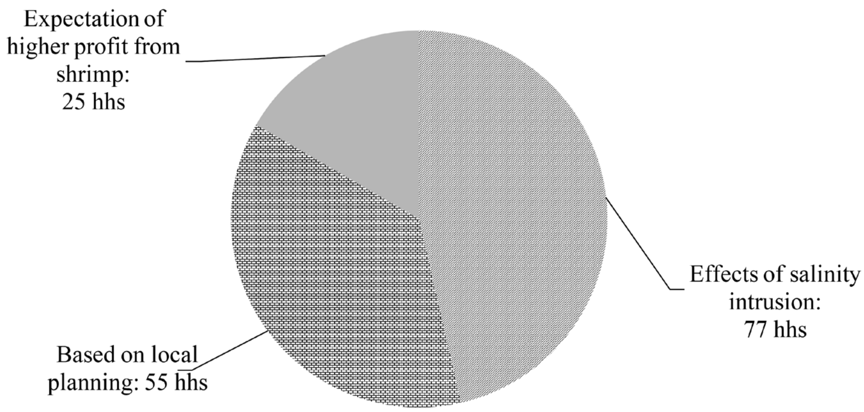

Fig. 5. Reasons for changing farming models.
Source: Household survey, n=160

and medicines) to meet the increasing demands of new shrimp farmers. To earn higher profits, some sellers supplied low quality and unknown origin of shrimp larva. The study also found some other difficulties in both production and consumption. Most farmers sell shrimp harvests to middleman, so the selling price is low and unstable.

Estimation of environmental efficiency

As we mentioned, the environmental efficiency is calculated after estimating the technical inefficiency (u_i). In order to estimate the technical efficiency for each shrimp farmers, we need to specify the production function, which reflect the relationship between inputs (including normal inputs and environmentally detrimental inputs) and output level. Table 2 presents a summary of the variables used in the one–step SFA model to estimate the technical efficiency and thereby calculate the environmental efficiency.

The output variable in this study is the shrimp yield per hectare. In this sudy, to ensure the homogeneity in output quantity, we excluded farmers who culture many types of shrimp together and intergrate shrimp with crab in Kien Giang province because the shrimp farmers in Soc Trang only culture intensively white–leg shrimp. So the total valid sample used for estimating the production function is 125.

For the quantity of shrimp larva, the study found that the average stocking density in Soc Trang province and Kien Giang province is about 92 heads/m^2 and 46 heads/m^2, respectively. These densities are similar to the findings of Do Minh Vanh *et al* (2016) at 77–84 heads/m^2, but they are much lower than the findings of Phung Thi Hong Gam *et al*. (2014) at 152 heads/m^2 ; Briggs (2006) from 120 to 200 heads/m^2 and Nguyen Sy Minh (2012) at 115 heads/m^2.

For the feed quantity, the results show that the average amount of feed used per ha per season is 11.15 tons in Soc Trang province with feed conversion ratio (FCR) of 1.14 and only 8.49 tons/ha/season in Kien Giang province with FCR of 1.19. This feed amount is lower than the study results of Do Minh Vanh *et al*. 2016) at 10.2–11.8 tons/ha/season and FCR of about 1.19–1.28. The result of the current study is also lower than previous studies by Phung Thi Hong Gam *et al*. (2014) with FCR of 1.32 and the study of Briggs *et al*. (2004) with FCR of 1.2 and Nguyen Sy Minh (2012) with FCR of 1.21.

For the medicine and fuel inputs, the study show

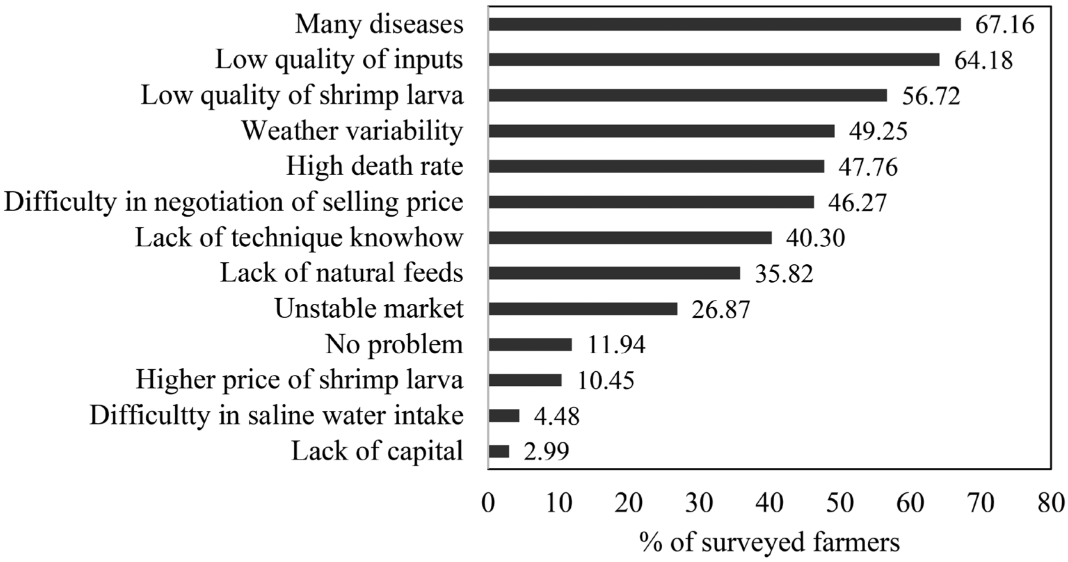

Fig. 6. Difficulties in transformed shrimp farming.
Source: Household survey, n=160

Table 2. Inputs and outputs of intensive shrimp culture

Indicator	Unit	Soc Trang		Kien Giang		Difference
		Mean	SD	Mean	SD	
Yield	Kg/ha	9,781.9	6,346.8	7,129.5	11,158.9	2,652.4**
Feed	Kg/ha	11,149.1	7,008.1	8,490.5	14,727.9	2,658.6
Medicine	1,000 VND/ha	63,900.5	68,366.7	19,241,2	29,972.0	44,659.3***
Fuel	1.,000 VND/ha	35,918.1	25,854.6	22,773.3	29,197.6	13,144.8***
Larva	Heads/ha	927,907.4	321,257.6	607,420.0	732,635.3	320,487.4***
Labor	Manday/ha	347.5	228.0	182.4	166.3	165.1***

Source: Household survey, n=125
Note: ** & *** indicate the significant differences at 5% and 1%, respectively.

that there is a large variation among households with a significant difference between Soc Trang and Kien Giang. The total expenses on medicines on the average for farmers in Soc Trang province is 63.9 million VND/ha/season, which is significantly higher from that of Kien Giang province at 19.24 million VND/ha/season. The total expenditure on medicine in Soc Trang is much higher than that in the previous study of Do Minh Vanh *et al* (2016) at 56.98 million VND/ha/season, but the case in Kien Giang is much lower. Regarding to the fuel cost, the study found that the total expense on fuel is about 35.9 million VND/ha/season in Soc Trang province and 22.77 million VND/ha/season in Kien Giang province, which is lower than the previous study of Do Minh Vanh *et al* (2016) at 38 million VND/ha/season.

As the study employed the one–step SFA to estimate of production function, it is necessary to consider independent variables affecting the output–oriented technical efficiency for the shrimp farmers. The independent variables affecting the technical inefficiency used in the current study are summarized in Table 3 below:

Education is expected to be positively correlated with the environmental efficiency. As we assume that the higher educational level the shrimp farmers have, the more knowledge and technical knowhow the shrimp farmers can access, which probably result in the better environmental efficiency. From the descriptive statistics in Table 3, the educational level of the shrimp household head on the average is still low at 7.71.

Regarding to the experience variable, we assume that the effect can be either negative or positive. Some previous studies found that when more experience is accumulated, farmers tend to be more "conservative" with new technology. On the other hand, some studies found that accumulating more experiences will help farmers easily adapt or handle problems in production. The results showed that on the average the shrimp farming experience in Soc Trang is about 5 years, while the experience in shrimp farming of the farmers in Kien Giang is about 9 years. The farmers in Kien Giang have more experiences than those in Soc Trang because they had cultured the rice–shrimp cultivation before transformation. The difference in shrimp experiences in the two areas is significantly differenct at 1%.

Joining in associations is one of the most important factors is expected to have a positive affect on the environmental efficiency because farmers may have more opportunities to contact and share information. However, the results showed that the percentage of shrimp farmers joining in organizations in the study areas is quite low, only about 7% in Soc Trang and 12% in Kien Giang.

Similarly, we also expect training to have a positive effect on the environmental performance. The study results showed that 71% of shrimp farmers in Soc Trang participated in the training while this value is only about 42% in Kien Giang province.

The stocking density is expected to have a positive effect on the environmental performance since a higher stocking density may result in higher output level under proper input conditions. The results also showed that the stocking density of the converted shrimp farmers in Soc Trang province is much higher and statistically significant at a level of 1% compared with that in Kien Giang province. The average stocking density in Soc Trang province is about 92 heads/m^2 while that in Kien Giang province is only about 46 heads/m^2.

The times of water intakes are expected to have an negative effect on the environmental performance as farmers normally exchange water when the water is polluted and contains many pathogens. The research results in Table 3 also showed that the proportion of shrimp households who have the clarifying ponds is quite high, about 67% in Soc Trang province and 55% in

Table 3. Independent variables affecting technical and environmental efficiency

Variable name	Explanation	Soc Trang		Kien Giang		Difference
		Mean	SD	Mean	SD	
Education	Years of schooling	7.71	3.64	9.59	4.23	1.88***
Extension	1 = Yes; 0 = No.	0.26	0.44	0.48	0.51	0.22**
Experience	Years of shrimp farming	5.28	5.20	8.94	4.97	3.66***
Association	1 = Yes; 0 = No.	0.07	0.25	0.12	0.32	0.05
Training	1 = Yes; 0 = No.	0.71	0.45	0.42	0.49	–0.29
Density	Head/m^2	91.96	36.45	46.53	60.71	–45.43***
Area of pond	1000 m^2	3.18	2.16	11.40	11.53	8.22***
Labor	People	1.88	1.11	1.84	0.82	–0.04
Number of ponds	Pond	1.92	1.15	1.76	1.05	–0.16
Distance	m^2	54.42	134.91	12.04	236.56	42.38**
Water intakes	Times	1.22	1.38	2.98	2.01	1.76***
Clarifying Pond	1 = Yes; 0 = No.	0.67	0.47	0.55	0.50	–0.12
Location	1 = Soc Trang;	1.00	0.00	0.00	0.00	

Source: Household survey, n = 125
Note: SD represents the standard deviation; *** and ** indicate significant differences of 1% and 5%, respectively.

Kien Giang province.

Prior to specifying the production function, it is necessary to perform a test to select the the best fit production function (Cobb–Douglas or translog function). To perform this test, the current study employed the LR test (Coelli *et al*., 2005; Greene, 2012; Kumbhakar *et al*., 2015). The LR test shows that the value of χ^2 = 23.80, which is much higher than the critical χ^2 value at 10% (see Table 4 for more details of the test results). This result shows that the observed data is best fit with the translog production function.

The research results in Table 4 also show that as compared to the two–step estimated production function, the one–step translog production function is accepted through the value χ^2 = 14.97, which is greater than the critical value of χ^2 at 10%.

In addition, since data were collected in two different provinces (Soc Trang and Kien Giang), it is necessary to test whether there is any difference in the production function between the two study sites. To test the differences, we performed the t–test by adding dummy variables (representing for the study sites) along with the interaction variables (interaction between the study site and the price variables). The results showed no significant differences between the two datasets, except for feed and labor variables. Thus, it is possible to pool the data and to estimate the common production function of both shrimp farmers in Kien Giang and Soc Trang. The estimates of production function are presented in Table 5 below:

Based on the estimates of the production function in Table 5 and the equation (6), we can calculate the output–oriented technical efficiency and the environmental efficiency. The technical and environmental efficiency are summarized in Table 6 and Table 7 below:

The research results in Table 6 show that the average output–oriented technical efficiency of shrimp farmers in Soc Trang province is 90.54%, which means that at the current input levels, the shrimp farmers in Soc Trang can increase the yields by 9.46%. The average output–oriented technical efficiency of shrimp farmers in Kien Giang province is 96.89%, which is much higher than that in Soc Trang. The difference in the environmental efficiency scores between the two study sites is statistically significant at 1%.

The output–oriented technical efficiency in the study sites has a large variation among shrimp farmers.

Table 4. Results of testing production function

Criteria	Cobb–Douglas function	Translog function	
		Two–step	One–step
Log–likelihood	–78.6452	–66.7451	–59.2113
χ^2		23.8000	14.9700
Prob> χ^2		0.0686	0.0918

Table 5. Estimation of the translog production function by MLE

Production function parameters			Factors affecting efficiency (M_u)		
Variable	Coefficient	Standard error	Variable	Coefficient	Standard error
lnZ_1	1.492 **	0.584	*Education*	–0.035	0.079
lnZ_2	0.559	0.495	*Experience*	–0.307	0.198
lnZ_3	1.209	0.808	*Credit*	0.903	1.022
lnX_1	–0.296	1.315	*Density*	–0.045 **	0.022
lnX_2	0.185	1.033	*Location*	4.255	2.844
$(lnZ_1lnZ_1)/2$	0.003	0.084	*Labor*	0.375	0.306
lnZ_1lnZ_2	0.057	0.044	*Number of pond*	0.680 *	0.370
lnZ_1lnZ_3	–0.095	0.060	*Water intakes*	0.123	0.153
lnZ_1lnX_1	–0.032	0.053	Intercept	–3.494	3.062
lnZ_1lnX_2	0.031	0.084	u_{sigma}	–1.794	0.834
$(lnZ_2lnZ_2)/2$	–0.104 **	0.044	v_{sigma}	–1.908	0.133
lnZ_2lnZ_3	–0.028	0.042	σ_u	0.407	0.170
lnZ_2lnX_1	0.023	0.038	σ_v	0.385	0.025
lnZ_2lnX_2	–0.005	0.050	Lamda	1.058	0.173
$(lnZ_3lnZ_3)/2$	–0.037	0.051	L–likelihood	–59.21	
lnZ_3lnX_1	–0.012	0.042	Wald χ^2 value	519.76	
lnZ_3lnX_2	0.089	0.059	Prob> χ^2	0.0000	
$(lnX_1lnX_1)/2$	0.061	0.073	Observations	125	
lnX_1lnX_2	–0.098	0.075			
$(lnX_2lnX_2)/2$	–0.002	0.042			
Intercept	–7.847	10.766			

Source: Household survey, n = 125

Note: *, ** and *** represent the significant level of 10%, 5% and 1%, respectively.

The highest technical efficiency is 98.97% while the smallest one is only about 29.59%. This result partly shows that shrimp famers face high risks in the production process. The majority of shrimp farmers have technical efficiency distributed above 80%, accounting for 100% of the total sampled households in Kien Giang province and 88.89% in Soc Trang province.

Next, we turn to estimate the environmental efficiency for shrimp farmers. The results are shown in Table 7.

Table 7 shows that the comprehensive environmental efficiency of the converted shrimp farmers in the study sites on the average is 91.77%, specifically 89.73% in Soc Trang province and 97.02% in Kien Giang province. This difference is statistically significant at the 1% level. This result shows that shrimp farmers in Soc Trang and Kien Giang provinces can reduce by 10.27% and 2.08% of the environmentally detrimental inputs (feed, medicine, and fuel) without compromising the output level. Similar to the technical efficiency, the environmental efficiency also has a large variation. In general, the environmental efficiency of the converted shrimp farmers is quite high. This result may be explained that the shrimp yield is quite high in the study sites, which result in low FCR. In addition, the shrimp farming in the study sites has lower medicine costs compared to previous studies by Do Minh Vanh *et al* (2016); Phung Thi Hong Gam *et al* (2014); Briggs *et al*. (2004); Nguyen Sy Minh (2012).

In general, the environmental efficiency of the converted intensive shrimp farming estimated by the one–step SFA method is far higher than that estimated by the

Table 6. Output–oriented technical efficiency

Technical efficiency	Soc Trang		Kien Giang	
	Number of households	%	Number of households	%
≥90	72	80.00	35	100
80–90	8	8.89	0	0
70–80	4	4.45	0	0
60–70	2	2.22	0	0
50–60	1	1.11	0	0
<50	3	3.33	0	0
Average efficiency	90.54		96.89	
Minimum value	29.59		98.97	
Maximum value	98.56		91.75	
T–test value	3.04***			
Mean efficiency	92.32			
Standard deviation	10.84			

Source: Household survey, n = 125
Note: *** represents a 1% difference

Table 7. Environmental efficiency of shrimp farmers

Environmental efficiency	Soc Trang		Kien Giang	
	Number of households	%	Number of households	%
>90	67	73.33	35	100
80–90	14	15.56	0	0
70–80	4	4.45	0	0
60–70	3	3.33	0	0
<60	3	3.33	0	0
Average efficiency	89.73		97.02	
Minimum value	27.29		92.67	
Maximum value	98.67		98.93	
T test value	3.58***			
Mean efficiency	91.77			
Mean standard deviation	10.69			

Source: Household survey, n = 125
Note: *** indicates the significant difference of 1%.

Table 8. Results of factors affecting the environmental efficiency

Variables	Coefficient	Standard error	t value
Education	0.053	0.225	0.24
Experience	0.576***	0.174	3.30
Join in associations	0.894	2.902	0.31
Extension	–0.286	1.859	–0.15
Density	0.068***	0.018	3.78
Area of pond	0.449*	0.241	1.86
Location	–5.735***	2.148	–2.67
Labor	–1.161	0.759	–1.53
Number of ponds	–2.124***	0.794	–2.67
Distance	0.00003	0.005	0.01
Clarifying ponds	2.608	1.733	1.50
Intercept	88.829***	3.851	23.06
Log–likelihood		–447.349	
LR χ^2		51.410	

Source: Household survey, n = 125
Note: *, ** and *** indicate the significant levels of 10%, 5%, and 1% respectively.

two–step approach. In fact, Nguyen Thuy Trang *et al.* (2018a); Nguyen Thuy Trang *et al.*, (2018b) estimated the environmental efficiency by using the one–step approach. They found that the average environmental efficiency scores in Soc Trang and Kien Giang were only 65.44% 52.79%, respectively.

The factors affecting environmental efficiency gaps

By using the one–step SFA approach, we can obtain simultaneouly the estimates of both production function and the factors affecting technical inefficiency. However, the current study aims at proposing solutions to improve the environmental efficiency, so the Tobit regression was employed to investigate the factors affecting the environmental efficiency. Specifically, the Tobit regression results are presented in Table 8:

The Tobit regression results in Table 8 show that there are five factors that have significant effects on the environmental efficiency. Of which, three variables *experience, area of pond* and *density* have positive effects and two variables *location* and *number of ponds* have negative effects on the environmental efficiency.

Experience is positively and significantly correlated with the environmental efficiency at the 1% level. This can be explained that farmers with more experiences will have more information and knowledge about shrimp farming, so they can manage and use the environmentally detrimental inputs more efficiently.

Pond size has a positive effect on the environmental efficiency at the significant level of 10%. This result shows that the shrimp farmers have larger pond size will have higher environmental efficiency scores. The explanation is that farmers with larger pond size will have favorable conditions to make use of natural feed, which help the farmers save the environmentally detrimental inputs.

The stocking density variable has a positive effect on the environmental efficiency at the significant level of 1%. This result can be explained that when the stocking density is high, the output will be high, which results in higher technical efficiency and environmental efficiency.

The study results also show that the number of ponds has a negative correlation with the environmental efficiency. When a farmer has one more pond, the environmental efficiency will decrease by about 2.124%. This can be explained that when a farmer has many ponds, it is difficult for them to manage and make us of environmentally detrimental inputs efficiently.

CONCLUSIONS

The current study shows that the shrimp farming in the study sites achieved an average profit of 430 million VND/ha/season in Soc Trang province and 394 million VND/ha/season in Kien Giang province. However, there is a large variation in profits between farmers, which partly reflects the high level of risk in the shrimp production process. The research results also found that farmers who get lost in their shrimp farming at least once account for a relatively high proportion, specifically 90% in Soc Trang and 42% in Kien Giang. The main reasons leading to losses in shrimp farming are disease, low quality of shrimp larva, changing weather and market volatility.

The results also show that the average output–oriented technical efficiency of shrimp farmers in Soc Trang province is 90.54%, and 96.89% in Kien Giang. The difference in the technical efficiency between the two study sites is statistically significant at 1%.

Regarding to the environmental efficiency, the average efficiency of the converted shrimp farmers in the study sites is about 91.77%, specifically at 89.73% in Soc Trang province and 97.02% in Kien Giang province. This difference is statistically significant at the 1% level. This result shows that shrimp farmers in Soc Trang and Kien Giang provinces can reduce by 10.27% and 2.08% of the total environmentally detrimental input (feed, medicine, and fuel) without compromising output level, given normal inputs constant.

For the factors affecting the environmental efficiency, the Tobit regression results show that there are five factors that have significant effects on the environmental performance. Of which, *experience, pond area* and *density* have positive effects while *location and number of ponds* have negative effects on the environmental efficiency.

AUTHOR CONTRIBUTIONS

Nguyen Thuy Trang designed the study questionnaire, collected and analyzed the data, and drafted the manuscript (the contributions account for 30%) ; Vo Hong Tu collected and analyzed the data, and drafted the manuscript (the contributions account for 25%); Nguyen Bich Hong, Le Thanh Son and Chau Thi Le Duyen drafted the manuscript (the contribution accounts for 10% for each); and Mitsuyasu Yabe supervised the research and made critical revisions to the manuscript (the contributions account for 15%) under the Technical Cooperation Project "Building capacity for Can Tho University to be an excellent institution of education, scientific research and technology transfer" of JICA. All authors read and approved the final manuscript.

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