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Economic Efficiency of Extensive and Intensive Shrimp Production under Conditions of Disease and Natural Disaster Risks in Khánh Hòa and Trà Vinh Provinces, Vietnam

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Abstract: Uncertainty about efficiency and sustainability of shrimp production due to diseases and climatic events may prevent Vietnam from attaining US \$10 million target from shrimp exports by 2025. We surveyed 120 and 159 shrimp farmers from Khánh Hòa and Trà Vinh provinces, respectively, to obtain information on their input use, production levels and the effects of diseases and climate change events on their farm profitability. Stochastic production frontier analysis (SFA) discovered that the number of workers, crops and seed costs positively influenced farmers' profits, while cost of chemicals and labour negatively affected the profit of Khánh Hòa farmers. The number of workers and chemical costs positively affected profits in Trà Vinh, while cost of labour and energy, the number of crops and average stocking density negatively influenced farmer profit in Trà Vinh. Number of years of schooling, experience and average size of ponds positively influenced economic efficiency, while the number of ponds and climatic change events negatively influenced efficiency in Khánh Hòa province. Age and alternative power source positively affected economic efficiency, while disease prevalence affected efficiency of Trà Vinh. All farms practicing intensive or extensive shrimp production achieved 90% efficiency. The government should encourage the wise use of resources, high-quality seeds and a sensitive balance between intensive and extensive culture to sustainably attain its national production and export goals.

Keywords: intensive; extensive; shrimp; economic; efficiency; disease; climate; Khánh Hòa; Trà Vinh; Vietnam

1. Introduction

Many developing countries embrace shrimp farming as a strategy to promote economic growth and development [1]. Developing countries like Vietnam have encouraged shrimp production and exports as a main tool for securing foreign exchange, bolstering rural employment, and income distribution [2]. Shrimp production is included in Vietnam's agricultural action plan as the leading driver to boost exports and increase contribution to the gross national product (GDP) [3,4]. The tactic for attaining the goal of maximum shrimp production and advancing exports is production intensification [2]. Although shrimp production intensification has raised Vietnam to third place in the international shrimp trade [5,6], recently there has been doubt about the sustainability of Vietnam's

shrimp exports. Among Vietnamese producers' many concerns about achieving export and production sustainability are logistics including infrastructure development, the large number of fragmented small-scale producers and lower quality of the product in terms of size and environmental degradation of production intensification [7]. The common, unproven beliefs are that small-scale shrimp producers are unable to farm as efficiently as large-scale ones, and intensive shrimp production is more efficient than extensive shrimp production. Hence, the path to national goal attainment is not clear given the looming environmentally negative effects of shrimp production intensification and the low output of extensive shrimp production.

Efficiency is commonly evaluated through the technical allocation of resources in the production process. Farms' technical efficiency (TE) has been measured using the difference between actual farm production and expected maximum production along the production frontier, while allocative efficiency (AE) reflects the ability to use inputs in optimal proportions given their respective prices [8–10]. However, the use of TE has been criticized as inefficient for determining efficacy in generating information for farm decision making, while AE generates inaccurate measurements among limited resource farmers, and resource use estimation may differ from one farmer to another. Hence, researchers have proposed using the profit function, which encompasses both the TE and AE measurements, as an alternative for measuring economic efficiency related to farm decision making. Although researchers [11–17] have examined factors influencing shrimp profit efficiency among limited-resource farmers engaging in intensive and extensive shrimp production, none has considered the effects of climatic and risk conditions on farmer decision making. While there is optimism about shrimp production intensification as a means of enriching limited-resource farmers, doubts also persist about its sustainability because of associated risks related to production efficiency and losses resulting from diseases and natural disaster events. In this paper, we examine the efficiency of intensive and extensive shrimp production and the effects of farmer perception of climatic events and disease risks on their farm income and prospects of national goal attainment.

Shrimp farms in Vietnam, using current farming practices, occupy a total surface area of 700,000 ha, and they generated more than US\$3 billion in export revenue in 2017. Shrimp has been one of the largest agricultural export products in Vietnam, accounting for 37% to 51% of total animal-based aquatic food exports, followed by pangasius (23–31%) [18]. Vietnam shrimp exports reached US\$3 billion in 2013 and increased at an annual growth rate of 26.9% to peak at US\$3.85 billion by 2017. Vietnam is currently a leading exporter of shrimp to Japan, Europe and the United States [19]. Shrimp production and exports generate a significant portion of income for the thousands of limited-resource farmers producing on less than 1.0 ha of land [20]. However, the sustainability of limited-resource farmers is questioned since they are susceptible to disasters from climatic change events and disease risks [21].

Disease outbreaks have been the primary cause of shrimp production loss during the last two decades [18]. Shrimp diseases are associated with polluted water in the pond itself. Farmers usually discharge wastewater and contaminated sediment from shrimp ponds into receiving rivers and streams that become the source of water for other shrimp ponds. Without proper treatment, the pathogens from infected ponds are likely to spread to other ponds. The above claim matches the finding of Dhar et al. [22] that white spot syndrome virus (WSSV) occurrence in improved extensive farming using untreated water from contaminated streams is more prevalent than in semi-intensive farming [23] where water is treated before use. However, scientists have argued that intensive systems with a higher input result in significantly more income, but the farms also face high risks associated with shrimp mortality [24].

A majority of local experts have claimed that shrimp diseases relate to climatic change events. High rainfall events over large areas can engender reduction of water quality, high toxicity and conditions conducive to outbreaks of infectious diseases for shrimp [25]. These claims corroborate the findings of Tendencia and Verreth [26] and Waibel et al. [27] that the main factors affecting shrimp production and fluctuation of physical and chemical parameters of the water are variations in rainfall, temperature,

salinity and pH. These climatic factors are precursors to shrimp disease outbreaks [25]. However, Tendencia et al. [28] claimed that intensive production is able to minimize shrimp disease risks because of less exposure to the vagaries of the climate and weather. Aquaculture production intensification may be associated with increased costs but also higher production efficiency and higher profits [29]. In spite of the assertion that higher profits are associated with technical efficiency conditions and shrimp intensification's relationship to disease triggered by climatic changes, there are no known studies that investigate the effects of climate change and disease risk factors on technical efficiency, its effects on firm profitability and national production goal attainment. Furthermore, studies on economic efficiency omit the effects of disease and climatic events perception on farm profitability. In this paper, results of a stochastic production function measured economic efficiency of two shrimp-producing provinces: one where farmers used an extensive production system and state that climatic change and disease affect their shrimp farm revenue and one where farmers practice intensive shrimp production and state that only diseases affect their farm revenue. The main objective of the paper is to investigate economic efficiency distribution among intensive and extensive shrimp-producing farmers and the profit–risk relationship for farmers in shrimp-producing provinces in Vietnam affected by disease and natural disaster events.

The specific objectives of this study are the following:

1. Measure the levels of efficiency of shrimp farmers in Khánh Hòa province, where farmers practice extensive production and claim that climatic change events and disease risks influence their income, and Trà Vinh province in the Mekong Delta, where farmers practice intensive production and state that disease risks affect their income but there is no effect of climatic change events on shrimp production income;
2. Evaluate the influence of shrimp disease on shrimp profit efficiency in both provinces;
3. Determine the other factors that affect shrimp profitability efficiency in the two provinces.

The organization of the paper continues with a literature review, followed by theoretical models of economic efficiency. Then there is a description of an implicit model, followed by a section on data sources, data collection, and the development of an empirical model. The paper ends with the results, discussion and conclusion.

2. Literature Review

Various techniques, cost, revenue, production factor productivity and profit ratios have been used to measure the technical efficiency of agricultural production [8–10]. All these scores are included in two main methods commonly adopted by researchers in measuring economic efficiency. The two most prominent methods of measuring technical efficiency are production data envelopment analysis (DEA), a mathematical approach, and stochastic frontier analysis (SFA), an econometric approach [30–32]. Researchers commonly use DEA in efficiency analytical studies, but its nonstochastic nature prevents attainment of comprehensive and sustainable results in many cases. A comparative analysis of the two main methods used for different production systems was conducted by Iliasu et al. [33], and in both their strengths and weaknesses were outlined. Hence, the SFA approach is preferred to measure technical efficiency, owing to its ability to distinguish the impact of variation in technical efficiency on the firm output from external stochastic error [34].

Akter [35] used DEA to evaluate the effects of financial and environmental factors on production of whiteleg shrimp, *Litopenaeus vannamei*, in Khánh Hòa province, Vietnam, and found that socioeconomic factors such as education and experience positively influenced technical efficiency, while environmental factors such as distance from water source had negative impacts on shrimp production efficiency. Financial factors, such as the total costs to total income ratio, the ratio of variable costs relative to fixed costs, sales margin and return on assets had positive effects on production efficiency. Reggo et al. [36] evaluated the technical efficiency of production cycles of *L. vannamei* in conventional and biofloc technology (BFT) systems in Brazil using DEA and found that there was a greater influence of

management inefficiency on the conventional system, whereas production scale influenced reduction in the technical efficiency score of the BFT system.

Tung [37] specified a two-stage DEA to estimate the technical efficiency of black tiger shrimp (*Penaeus monodon*) mixed culture with mud crab (*Scyllaserrata*) in Cai Nuoc and Dam Doi districts, Ca Mau province, Vietnam. In this study, he estimated super-efficiency scores and found that pond area, farmer experience and education, and black tiger shrimp and mud crab stocking density influenced technical efficiency. Thap et al. [38] used double-bootstrap DEA to estimate and explain the technical efficiency of intensive whiteleg shrimp farming in Ninh Thuan, Vietnam. The analysis revealed that the factors that enhanced technical efficiency were education, extension training, farming using earthen ponds and the increased size of farms. The variables that negatively related to technical efficiency and, hence, hampered farm performance were financial stress, farmer experience and a longer cultivation period.

Coelli et al. [9] employed SFA to measure total factor productivity for crop husbandry in Bangladesh for the period 1961–1992. The SFA model has also been widely used to study animal production, including aquaculture production efficiency. Reinhard et al. [39] studied the technical efficiency of Dutch dairy farms; Sharma et al. [40] evaluated the swine industry in Hawaii; Dey et al. [10] used SFA to evaluate the technical efficiency of tilapia grow-out operations in the Philippines; and Sharma and Leung [8] used SFA to measure the technical efficiency of carp production in India. These researchers organized their studies by the type of data used, the different crops, and the socioeconomic factors applied in the different models. The results show that technical efficiency is dependent on resource allocation and input management.

Begum et al. [41] used SFA to find that technical inefficiency is influenced by education, age, nonfarm income and distance of the farm to markets. Gazi et al. [42] used SFA to investigate the technical efficiency of brackish water shrimp farms and found that, on average, 65% of the sampled shrimp farms were technically efficient. The results suggest high degrees of technical inefficiency exist among shrimp farmers. Sivaraman et al. [43], on the other hand, analyzed the technical efficiency of shrimp farmers in the East Godavari district of Andhra Pradesh using SFA and found that they were 93.06% technically efficient in producing shrimp. Age, education and experience of the farmers, as well as their membership in farmers' associations and societies, significantly affected technical efficiency.

SFA is a commonly used method for measuring efficiency and generates consistent results, but this technique might not provide all the answers as to why farmers decide to remain in production or not. Profit or economic efficiency, defined as the ability to attain the highest possible profit, given prices of inputs and levels of fixed factors, may generate better information on the decision to engage in farming as a business. Ali and Flinn [11] suggested that production levels might provide inaccurate measures of efficiency decisions, since farmers face different prices of inputs and outputs and varying levels of resource endowments in the production process. Upon this criticism, the stochastic profit frontier emerged as an alternative and was applied in a number of studies to estimate economic efficiency of individual farms [11,12,14,15]. The major advantage of using such restrictive profit functions lies in the ease of obtaining closed-form algebraic formulae for costs of technical and allocative inefficiencies that are of primary concern to the producers. The disadvantage is that the production functions for which cost or profit functions are explicitly derivable are quite restrictive in nature [16,17].

There is some degree of correlation between risk and profit. The traditional, modified rule of thumb is "the higher the risk, the higher the potential return, and the less likely it will achieve the higher return" [44]. The risk of disease in shrimp farming often increases with culture intensity and high stocking densities and also when polyculture is replaced by monoculture [45]. Extensive or traditional systems, with lowest yields, are gradually being replaced by improved extensive and semi-intensive and intensive systems in Vietnam. The government of Vietnam is emphasizing increased production through increases in production intensification and yields of shrimp [4]. A study in Vietnam and Thailand showed that, in most cases, intensive operations used land much more efficiently, yielding at least eight additional tons per hectare. They also reduced the costs of land use by more than 90%

per kilogram of shrimp. The most intensive farms made efficient use of energy as well, with energy costs that were 74% to 89% lower than the least intensive operations [46]. Intensification can also have negative implications such as concentrated wastes in effluent and the potential to stress shrimp to the point that disease outbreaks, and increase in chemical use may lead to discharge in the environment if such wastes accumulate too quickly. A study conducted in West Java [47] showed that feed, disinfectant, probiotics and season increased *L. vannamei* productivity of shrimp fry and were risk inducing, but probiotics, diesel fuel and season were risk reducing. Sanchez-Zazueta and Martinez-Cordero [48] used a stochastic bio-economic model to analyze the economics of farm management adjustments as a response to disease risks. The study results showed that reducing stocking density was important in reducing risks. Hence, in this study, the levels of efficiency between intensive and extensive production may serve as the guide to determine the levels of economic and environmental risks faced by government policy makers in attaining national production and export goals.

Climate change events may cause more frequent flooding and expand the area of salinity intrusion in the dry season in shrimp-producing areas [49,50]. To mitigate the effects of climate change, farmers may have to build their ponds with surrounding protective dykes or reduce the number of crops produced per year. A study by Nguyen et al. [51] showed that farms affected by salinity intrusion had a lower scale efficiency, as they reduced stocking rate and frequency.

3. Theoretical Model

One of the basic assumptions in the estimation of a production function is that all firms are technically efficient, and the representative firm defines the production frontier. Another assumption underlying the specification of a production frontier is that the firm engaged in production is applying “best management practices”, and it receives the maximum potential output for a given set of inputs, employing a specific production process. Failure to attain this maximum is deemed inefficient; therefore, based on the observed output of a firm, one is able to measure its level of efficiency [52]. The measurement of firm-specific technical efficiency is based upon deviations of observed output from the best production or efficient production frontier. Here, we are not measuring the technical efficiency of the firm but the economic efficiency or profit function, and from here on, we will specify economic efficiency or profit function and not technical efficiency.

Suppose that the profit function for a farm is defined by $f(P_i, F_i)$, farm i achieves profit:

$$\pi_i = f(P_i, F_i; \beta) \quad (1)$$

where π_i is the restricted normalized profit of farm i defined as gross revenue less variable costs divided by output price received by the farm. P_i is the vector of input costs faced by farm i divided by output price. F_i is the vector of normalized fixed factors utilized by farm i , and β is a vector of unknown parameters to be estimated. Stochastic profit frontier analysis assumes that a farm potentially obtains less than maximum profit based on its degree of inefficiency. According to Ali and Flinn [11], profit efficiency is defined as the ability of a farm to achieve the possible highest profit (which is the profit frontier), given prices and a level of fixed factors. Profit inefficiency is the loss of profit from not being on the frontier. Specifically,

$$\pi_i = f(P_i, F_i; \beta) \xi_i \quad (2)$$

where ξ_i is written in the form of $\xi_i = (v_i - u_i)$, the level of efficiency for farm i varying strictly between zero and one. If $\xi_i = 1$, farm i achieves the possible highest profit. When $\xi_i < 1$, farm i is inefficient or not making the most from inputs used. Let the profit be subject to random shocks; where v_i represents the random factors outside the farmer’s control and is assumed to be independently and identically, non-negative, normally distributed, $N^+ \sim (0, \sigma_v^2)$; and u_i is non-negative variable and normally distributed. The u_i is a one-sided disturbance term ($u_i \geq 0$) functioned to capture the effects of the inefficiency model [53] and guarantees that all observations lie on or beneath the stochastic

production frontier. Hence, u_i captures the economic inefficiency in production and is assumed to be firm specific [54]. The stochastic profit frontier that takes into account inefficiency is given by

$$\pi_i = f(P_i, F_i) \exp(v_i - u_i) \quad (3)$$

The random variable v_i is independent of u_i ; and u_i represents the economic efficiency and can be presented as $\mu_i = Z_i \delta_i + \Omega_i$ and variance $\sigma_u^2 \left(\left[N(u_i, \sigma_u^2) \right] \right)$ [54], where Z_i is the set of explanatory variables that may influence profit efficiency on farm i , Ω_i represents the truncation of the normal distribution with mean 0 and variance σ_u^2 , and δ_i are a set of parameters to be evaluated [55]. Within this context, profit efficiency is estimated by

$$\pi EF_i = E \left[\exp(-u_i) \right] \quad (4)$$

The use of the maximum likelihood (ML) to estimate Equation (1) results in simultaneous estimators for β , λ and σ^2 , where β is a vector of unknown parameters; $\lambda = \sigma_u / \sigma_v$ and $\sigma^2 = \sigma_u^2 + \sigma_v^2$ [54,56]. The coefficient $\lambda = \sigma_u / \sigma_v$ shows the relative variation of the standard error of u to the standard error of v . When λ is zero, the error v dominates the one-sided error, which is an indication that the difference between the observed profit and the frontier profit is insignificant. When λ is large, the one-sided error u dominates the error v , which implies that the difference between the observed and the frontier output is the consequence of technical inefficiency. An EF_i of one indicates that the farm is generating maximum profit given the level of inputs. Thus, the profit efficiency shortened to EF_i for each individual farm is given by

$$EF_i = E \left[\exp(-u_i) \right] \quad (5)$$

The stochastic profit frontier and profit efficiency, which are estimated simultaneously by maximum likelihood estimation, generate the total variance $\sigma^2 = \sigma_u^2 + \sigma_v^2$ and $\gamma = \sigma_u^2 / \sigma^2$, where γ is bounded between 0 and 1. A value of γ close to 1 suggests the existence of inefficiency, while a value close to 0 indicates the absence of inefficiency. (If γ is not significantly different from zero, σ_u^2 is 0, and the model reduces to a mean response function in which the inefficiency term enters directly (Battese and Coelli, 1995) [54].) For simplicity, we do not present the expression for the log likelihood function here.

Production Inefficiency

Economic inefficiency is an unobserved variable. Inefficiency is assumed as a component of the error term that consists of two parts: The random factors V that are outside the farmer's control. It is assumed that $F(\cdot)$ and $f(\cdot)$ in Equation (3) are the standard normal distribution and the standard normal density functions, respectively. These are evaluated at $\varepsilon_i \lambda / \sigma$ to be independently and identically normally distributed, $N \sim (0, \sigma_v^2)$ and independent of u_i and u_i is a one-sided component ($u_i \geq 0$), represents the economic efficiency relative to the stochastic frontier, and is the non-negative random errors independently $N^+ \sim (\mu, \sigma_u^2)$ distributed [56]. Inferences about the economic efficiency for individual farmers can be made by using the conditional distribution of u , given the error term ε from Equation (1) [57].

The formula for calculating the economic inefficiency for individual farmers is then given in Equation (3).

$$E[u_i | \varepsilon_i] = \frac{\sigma_u \sigma_v}{\sigma} \left[\frac{f(\varepsilon_i \lambda / \sigma)}{1 - F(\varepsilon_i \lambda / \sigma)} - \frac{\varepsilon_i \lambda}{\sigma} \right] \quad (6)$$

where $\sigma^2 = \sigma_v^2 + \sigma_u^2$ and $\lambda = \sigma_u / \sigma_v$.

Battese and Corra [58] used γ , which is defined in Equation (5) as the ratio of variability of u to the total variability ($u + v$), to measure the difference in the observed profit and the frontier profit.

$$\gamma = \frac{\sigma_u^2}{\sigma^2} \quad (7)$$

where $\sigma^2 = \sigma_v^2 + \sigma_u^2$. The mean economic efficiency for the population is given by Equation (6).

$$E[\exp(-u)] = 2 \exp\left(\frac{\sigma_u^2}{2}\right) [1 - F(\sigma_u)] \quad (8)$$

where $F(\cdot)$ is the standard normal distribution function evaluated at σ_u .

Hence, to determine the level of inefficiency, the economic inefficiency score is first calculated, and then the score determines the economic inefficiency (πIE), and Equation (6) is the basis for the calculation:

$$\pi IE = 1 - \exp(-E[u_i|\varepsilon_i]) \quad (9)$$

where ε_i is the error term.

4. Method

4.1. Research Areas

4.1.1. Khánh Hòa Province

Khánh Hòa province is located in the coastal southern central part of Vietnam. There is 385 kilometers of seashore as well as rivers, ponds, bays and canals along the coastline. The coastal terrain and hydrographic conditions are ideal for shrimp farming. Khánh Hòa province is considered a cradle of the shrimp farming movement thanks to its successful experiment in artificially producing shrimp fry in the 1980s [19]. Today, Khánh Hòa is still a well-known center for shrimp hatcheries in the country [4] and is the largest producer of shrimp on the South Central Coast of Vietnam. Whiteleg shrimp are produced by 16%, 57% and 27% of farms using intensive, semi-intensive and extensive systems, respectively. Farmers are gradually adopting VietGAP, biofloc technology and farming in cement tanks with yields 20%–30% higher than normal farming. Most ponds have 2.0 crops/y, with some up to 3.0 crops/y; average productivity is 15.0 tons/ha/crop. Production has varied from year to year because of diseases and natural disasters.

Disease epidemics in 2012 led to the financial collapse of a large number of small farms. Farmers sought various means of survival, and in some cases, they mortgaged their shrimp ponds to manage their debts. In 2012, the shrimp farm area declined by 50%. In 2012, there was 1090 ha infected with diseases; in 2013 the infected area was 173.0 ha, and by 2014 it was 493 ha. About 44.2% of farmers revealed that diseases had a high impact on their income, while 32.5% and 33.3% stated that it had medium and low effect, respectively (Table 1).

Whiteleg shrimp culture practiced in Khánh Hòa province is an important, commercially feasible activity because of the favorable climatic conditions. Climate factors, including temperature, humidity and rainfall, have a great influence on the development of shrimp. Shrimp production in this province is highly susceptible to droughts and floods from climatic events. The typhoon Damrey in 2017 caused heavy losses to Khánh Hòa shrimp farmers. An estimated 1475 ha of shrimp ponds was affected, resulting in the loss of 2949.0 tons of shrimp valued at 1,094,724.9 million VND or US\$47,596,735. Most of these heavily damaged facilities are in shrimp farms in Nha Trang City [59]. About 99.9% of sampled farmers practiced extensive shrimp culture in mud bottom earthen ponds. Approximately 7.5% of sampled farmers reported that natural disasters had a high impact on their income, while 22.5% and 70.0% stated that they had a medium and low effect, respectively (Table 1).

Table 1. Perception of farmers in Khánh Hòa and Trà Vinh provinces on the impact of disease and natural disasters on their shrimp income.

Evaluation Criteria	Khánh Hòa Province			Trà Vinh Province		
	Disease Impact			Disease Impact		
	Frequency	%	Cumulative	Frequency	%	Cumulative
High	53	44.2	44.2	1	0.63	0.63
Medium	39	32.5	76.7	46	28.93	29.57
Low	28	33.3	100.0	112	70.44	100.00
	Natural disaster impact			Natural disaster impact		
	High	9	7.5	7.5	N/A	N/A
	Medium	27	22.5	30.0	N/A	N/A

4.1.2. Trà Vinh Province

Trà Vinh is a coastal province in southern Vietnam, located in the Mekong Delta region of the country. It borders Ben Tre and Vinh Long provinces in the north and Soc Trang province on the west, and has an eastern coastline 65 km long. Trà Vinh suffers from difficulties such as strong wind, high level of evaporation and low rainfall. Temperatures in Trà Vinh range from a minimum of 18.5 °C to a maximum of 35.8 °C, with an average of 26.6 °C. The Trà Vinh climate is divided into two main seasons: dry and rainy. The rainy season lasts from May to November and the dry season from December to April.

Aquaculture in Trà Vinh province is divided into two types: fresh water and brackish water. In 2015, brackish water farms occupied 25,648 ha, approximately 83% of the total aquaculture area [59,60]. Shrimp farming in brackish water in the province includes intensive, semi-intensive, improved extensive and mixed mangrove–shrimp systems. The mixed mangrove–shrimp farms include production and protected forest areas. From 2005 to 2012 the productivity of tiger shrimp (*P. monodon*) fluctuated between 410 and 810 kg/ha.

The goal set for 2020 by the province is to mobilize more than VND 5000 billion (US \$217,391,304) to invest in developing sustainable shrimp farming. The aim is directed toward high technology, with construction planning for irrigation, transportation and electricity production; investment in infrastructure, strengthening management capacity and supporting production development for farmers; and offering incentives to attract enterprises to produce and process [61].

Farming of whiteleg shrimp (*L. vannamei*) started in 2008; at that time, *L. vannamei* productivity was higher than that of *P. monodon*. However, *L. vannamei* productivity has recently declined due to disease, particularly in 2012 [61]. Unstable weather leads to the spread of various diseases, including pancreatic diseases in black tiger shrimp and white spot syndrome in whiteleg shrimp. The main shrimp diseases in the district are white spot disease, yellow head disease, white scour and early mortality syndrome (acute hepatopancreatic necrosis). In 2014, disease outbreaks affecting *L. vannamei* (72% of the 500 ha) in intensive, semi-intensive and extensive shrimp production involved over 3000 households and approximately 3500 ha [61]. In 2017, over 987 households lost 44 million black tiger shrimp and 75 million whiteleg shrimp [62]. About 0.63% of farmers reported that disease had a high impact on their income, while 28.93% and 70.44% stated that it had a medium and low effect, respectively (Table 1). Farmers reported no negative impact of climate change events on their shrimp revenue. All farmers stated that they were engaged in intensive shrimp farming.

4.2. Study Design—Questionnaire, Interview

Data collection began in 2018 after the gathering of sufficient information from key informants during focus group discussions (FGDs). The FGDs enabled the researcher to develop questionnaires to cover all aspects of shrimp farming systems in the two provinces. The questionnaire included basic information on socioeconomic, financial and operational aspects of shrimp farming. The data collected

encompassed information on the farm physical structure, for example, pond size, proportion of pond area to total farm area, with/without reservoir or water treatment pond, with/without effluent and sludge treatment, biosecurity, seed and feed management, labor and water inlet/outlet. The survey also collected information on the farm operation, such as yields and returns data, availability, content and quality of farm records, farm assets and production loss for the most severe events since the farm started. It included questions on disease and natural disaster risks, measures undertaken to manage risky events and willingness to participate in insurance programs. Also incorporated was information on farmer participation in Vietnam Good Agricultural Practices (VietGAP), Global Agricultural Practices (GlobalGAP), or Aquaculture Stewardship Council (ASC), and levels of compliance with good aquaculture practices.

The questionnaire was tested and corrections and adjustments were made to accommodate reactions from farmers. After the correction of the questionnaire, trained interviewers conducted face-to-face interviews with farmers. Interviews took place at the disposal of the farmers and mostly on the farms.

The recruitment of farmers took place in two provinces: Khánh Hòa and Trà Vinh. The farmers were recruited from a list of aquaculture farmers producing shrimp with the following characteristics: whiteleg shrimp farming, monoculture (not integrated), no intercropping, brackish water culture, earthen pond, farming for at least five years (before 2012) and at least one successful crop in 2017.

4.3. Empirical Model

The stochastic frontier model for shrimp profits can be described as

$$\ln\pi_i = \beta_0 + \sum_{j=1}^6 \beta_j \ln P_{ji} + \sum_{k=1}^5 \beta \ln FC_{ki} + \sum_{l=1}^1 \beta \ln F_{li} + v_i - u_i \quad (10)$$

where

π_i = restricted normalized profit computed for farm, defined as gross revenue less variable costs per commodity i divided by farm specific shrimp price P_y ;

β_0 = intercept;

β_j = regression coefficients of the explanatory variable inputs j in the estimated stochastic profit function, $i = 1, 2, \dots, 6$;

P_{ji} = weighted cost of variable inputs j contributing to profit efficiency (for $i = 1, 2, \dots, 6$), consisting of

P_{1ji} = weighted cost of seed (VND/kg/crop) normalized by price of output (P_y),

P_{2ji} = weighted cost of fertilizer (VND/kg/crop) normalized by price of output (P_y),

P_{3ji} = weighted cost of energy (VND/crop) normalized by price (P_y),

P_{4ji} = weighted cost of chemical pesticides (VND/Liter/crop) normalized by price of output (P_y),

P_{5ji} = weighted cost of labor (VND/man-day/crop) normalized by price of output (P_y);

FC_{1ki} = farm characteristic, number of ponds,

FC_{2ki} = farm characteristic, average size of ponds,

FC_{3ki} = farm characteristic, average stocking density,

FC_{4ki} = farm characteristic, average crop yield,

FC_{5ki} = farm characteristic, number of workers employed;

F_{li} = value of fixed costs contributing to profit efficiency, where $l = 1, 2$;

v_i = random variable assumed to be independently and identically distributed;

(i.i.d) $N(0, \sigma_v^2)$ and independent of u_i ;

u_i = non-negative random variable that is assumed to account for profit inefficiency in shrimp production. This includes the producer perception of disease and natural disasters' effect on shrimp

revenue, which can be controlled to a certain extent through the application of improved management practices and mitigation against climate change events;

\ln = natural logarithm;

$i = 1, \dots, N$, N = number of observations.

The subscripts j or k , i refer to the j th or k th input used of i th farm.

The shrimp farm level profit efficiency (PE) or μ_i model was simultaneously estimated with the stochastic frontier profit function model. The PE model for the shrimp farm is expressed mathematically as follows:

$$PE_i = \mu_i = \delta_0 + \sum_{k=1}^7 \delta_k W_{ki} + \xi_i \quad (11)$$

PE_i = technical efficiency, δ_0 is the constant, W_{ki} is the socioeconomic and environmental characteristics (diseases and natural disaster events on revenue), and ξ_i is the error term.

4.4. Data Entry and Analysis

The questionnaires collected were reviewed for accuracy and completeness, and data were entered in an Excel spreadsheet. The data were cleaned and analyzed using the statistical analytical system (SAS) and SPSS software. The software Frontier and maximum likelihood regression assisted in the development of the profit models. Tobit regression was employed to develop the efficiency model. Descriptive statistics and cross-tabulations were performed.

5. Results

Table 2 presents some farm statistics and selected variables used in the development of the SFA. The farmers interviewed ranged in age from 26 to 68 y, with the farmers in Khánh Hòa having an average age of 51.6 y and those in Trà Vinh 42.9 y. The average number of years of schooling for farmers in Khánh Hòa province was 10.2, whereas the average for Trà Vinh was 4.2. Shrimp farmers from Khánh Hòa province also had more experience, 12.6 y, versus 11.0 for Trà Vinh farmers. The number of children per household in Trà Vinh (2.4) was, however, higher than that for Khánh Hòa (1.7).

Table 2. Descriptive statistics of selected variables of Khánh Hòa and Trà Vinh provinces.

Variable	Khánh Hòa Province			Trà Vinh Province		
	Sample = 120			Sample = 159		
	Mean	Minimum	Maximum	Mean	Minimum	Maximum
Age	51.6	33.00	68.0	42.9	26.0	63.0
Years of schooling	10.2	5.00	14.0	4.2	2.0	9.0
Years of experience	12.6	3.00	32.0	11.0	2.5	27.5
No. of children	1.7	0.00	4.0	2.4	0.0	4.0
Average size of pond	0.55	0.15	1.80	0.26	0.11	1.0
No. of ponds	1.25	1.0	3.0	2.8	1.0	10.0
No. of crops	2.0	1.0	3.0	2.8	1.0	4.0
No. who worked on the farm	2.8	1.00	6.0	1.8	1.0	5.0
Average stocking density	27.0	17.00	40.0	89.9	75.0	90.00
Seed cost US\$	521.03	260.87	1,000.00	3,910.92	1,086.96	27,173.91
Chemical cost US\$	480.54	291.30	695.65	10,089.96	2,608.70	17,391.30
Energy cost US\$	521.03	291.30	1000.00	2532.95	1304.35	6521.74
Labour cost US\$	557.79	391.30	652.17	2420.56	521.74	5217.39
Total Var. Cost US\$	5337.73	3327.83	8157.04	44,965.00	1284.58	140,130.43
Total Fixed costs US\$	577.03	247.83	739.13	2775.77	652.17	9782.81
Total costs US\$	5,914.76	3,575.66	8,896.17	47,740.77	1936.75	149,913.24
Yield /crop/ha (tons)	1.900	1.200	2.635	17.725	5.000	56.000
Feed conversion ratio (FCR)	1.13	0.70	1.40	1.12	1.00	1.20
Price of shrimp US\$	4.37	3.75	5.97	7.14	3.95	9.36
Total revenue US\$	10,056.44	4,155.93	22,9321.73	95,883.03	18,434.00	526,086.00
Net income US\$	4,142.19	-23,615.65	20,642.96	48,142.26	-58,043.50	460,956.50

The average pond size was 0.55 ha for Khánh Hòa and 0.26 ha for Trà Vinh, while the average number of ponds was 2.8 in Trà Vinh and 1.25 in Khánh Hòa. However, the average stocking density in Trà Vinh, 90 m², was much higher than that for Khánh Hòa (27m²). This partially resulted in higher average net profits per crop per year: US \$48,142.26 for Trà Vinh farmers versus US \$4142.19 for Khánh Hòa farmers. The higher net profits partly were due to higher average prices received by Trà Vinh farmers of US \$7.14 per kg compared to US \$4.37 per kg for Khánh Hòa farmers, as well as the nature of the farming systems practiced in both provinces. Farm leaders from Trà Vinh stated during a group discussion that they sold their shrimp to Cambodian traders who sold to China; therefore, they received higher than average prices from this market channel. The profit density functions in Figure 1a,b show that Khánh Hòa farmers had a negatively skewed distribution (that is the distribution of profits was concentrated to the left or less than zero) than that of Trà Vinh farmers. The mean profit was larger for Trà Vinh farmers than those from Khánh Hòa as seen in the longer tail to the right in Figure 1b that shown that Trà Vinh had more farmers who received \$10,000 and above. The feed conversion ratio (FCR) was about the same for Khánh Hòa (1.13) as that of Trà Vinh (1.12), but there were major differences in chemical costs per ha per crop, US \$480.54 for Khánh Hòa but US \$10,089.96 for Trà Vinh.

The estimated results for the mean response for shrimp profit function are given in Table 3. The test statistic $H_0 : \beta_{jk} = 0$, $H_1 : \beta_{jk} \neq 0$ has a log likelihood ratio value of -967.03 ($N = 120$) and -1653.7 ($N = 159$) for Khánh Hòa and Trà Vinh provinces, respectively. This implies a rejection of the null hypothesis at the 5% significance level. In other words, the stochastic production frontier model is appropriate to capture the production behavior of shrimp farmers in the two provinces. The presence or absence of technical inefficiency was tested in the study using the important parameter of log likelihood in the half-normal model $\lambda = \sigma_u / \sigma_v$. If $\lambda = 0$, and the null hypothesis that there was no inefficiency effect was accepted. The Z-statistic of 0.16712 ($Pr(> |z|) = 0.862$) for Khánh Hòa farmers and 0.0149 ($Pr(> |z|) = 0.814$) for Trà Vinh suggests the absence of inefficiency effects for shrimp farmers in both provinces, and any deviation from the maximum is due to noise [53].

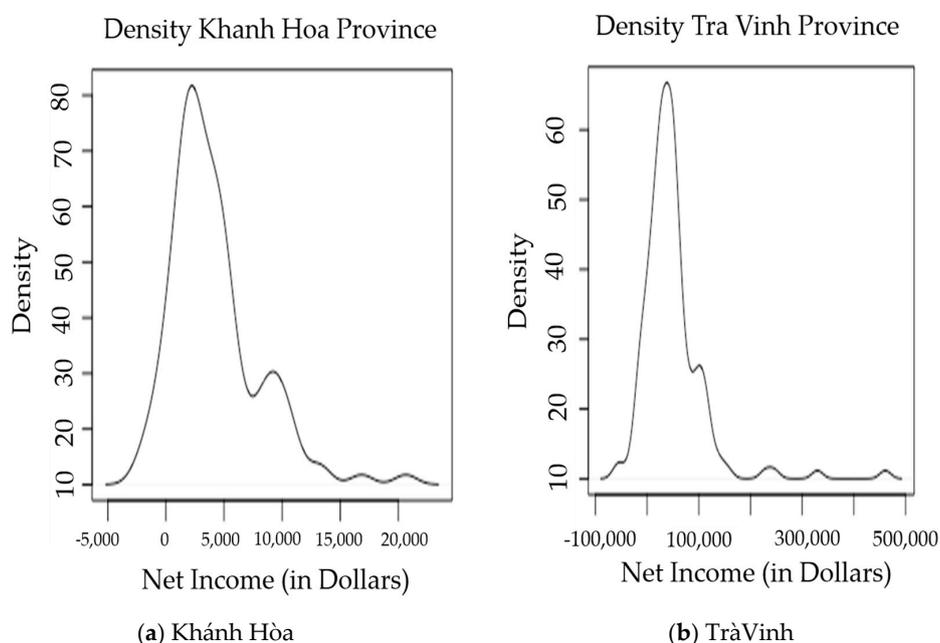


Figure 1. Profit density functions for Khánh Hòa and Trà Vinh provinces.

The factors positively influencing shrimp farm profits were yield, number of workers, the number of crops and cost of seeds, while cost of chemicals and labour negatively affected the profit of Khánh Hòa farmers. On the other hand, the number of workers and chemical costs positively affected profits in Trà Vinh province, while cost of labour and energy, the number of crops and average stocking density

negatively influenced farmer profit in Trà Vinh province. The elasticities related to the variables are seen in Table 4. Profits in Khánh Hòa province were highly elastic for the cost of labour and chemicals, that is, if the costs increased by 1.0%, profits were likely to decline by 2.11% and 1.61%, respectively. The profits for Trà Vinh farmers will decline by 1.40% for a 1.0% increase in average stocking density, while profits will increase by 1.09% for a 1.0% increase in the use of chemicals.

Table 3. Factors influencing profit of shrimp production of Khánh Hòa and Trà Vinh provinces.

Variable	Khánh Hòa Province		Trà Vinh Provinces	
	Estimate	Std. Error	Estimate	Std. Error
Intercept	140,425.78	2.07	14,042.55	1.08
Avg. stocking density			−1.691 *	1.00
Yield per crop	41.78 *	10.32		
No. Workers	8,252,825 *	1.00	2,417,199 *	1.00
Cost of chemicals	−5.12 **	3.29	5.12 **	1.00
Cost of Energy	−9.30 *	4.29	−6.610	5.91
Cost of Labour	−1.57 *	7.01	−7.214 **	3.88
Cost of seed	5.88 *	2.02	−1.097	2.278
No. of crops	1.00 *	1.00	−106,246 *	1.000
σ^2	6,039,615 *	1.00	65,333,330 *	1.00
γ	0.019,269,000	0.15	0.0149	0.063
$\sigma^2\mu$	11,654.6000	0.00	970,856	4,139,012
$\sigma^2\nu$	59,230.069 *	0.00	63,436,244 *	4,139,012
σ	771.4960 *	0.00	8082.90 *	6190000
λ	0.1403	0.43	0.0122	0.0267
Log likelihood	−967.03		−1653.7	
N	120		159	

* significant at the 1.0%, ** significant at the 5.0% and *** significant at the 10% levels.

5.1. Distribution of Technical Efficiency

The distribution of efficiencies for all farmers in both provinces was similar, with minima of 0.492 and 0.458 for farmers in Khánh Hòa and Trà Vinh, respectively. The distribution of efficiencies of all farmers in the first quartile, median and mean were similar (Table 5) in both provinces. Almost all farmers had a level of efficiency greater than 89.0%. The average levels of efficiency were 90.5% for farmers in Khánh Hòa, with median of 91.8% and 88.9% for Trà Vinh farmers with median of 89.3%, indicating that all farms achieved approximately 90% of the maximum possible output from a given set of inputs. The distribution of the various percentages of efficiencies indicates that Khánh Hòa had 30.67% of farmers in the 80%–90% economic efficiency range and 67.22% within the 90%–100% range, while 62.021% of Trà Vinh farmers were within the 80%–90% range and 36.07% within the 90%–100% range.

Table 4. Elasticities of variables for Khánh Hòa and Trà Vinh provinces.

Variables	Khánh Hòa Province	Trà Vinh Province
Average stocking density	−	−1.40
No. of workers	0.24	0.39
Cost of chemicals	−1.61	1.09
Cost of energy	−1.17	−0.33
Cost of labour	−2.11	−0.35
Cost of seed	0.73	−0.09
No. of crops	2.15	−0.28
Yield	3.43	−

5.2. Economic Efficiency of Shrimp Profit

The to bit results for factors affecting profit efficiency are seen in Table 6. Average size of ponds, years of schooling and experience positively influenced economic efficiency in Khánh Hòa province, while number of ponds and perceived impacts of natural disasters on farm income negatively influenced it. Number of ponds, farmer age and purchase of electric motors positively influenced economic efficiency in Trà Vinh, while impact of disease perception on farm income negatively influenced it. Trà Vinh, where farmers practiced intensive shrimp production, revealed during the FDG that they required constant electricity for water aeration; if not, they may suffer huge losses from mortality from low levels of dissolved oxygen and disease incidence. Hence, they had to have a backup of an electric generator to supplement the electricity supplied by the public grid. Farmers also expressed the need for chemical use to reduce the incidence of diseases on their farms. Hence, they perceived diseases had a major effect on their farm's economic efficiency. In Khánh Hòa province, farmer's economic efficiency was reduced by the number of ponds but increased with the average pond size since farmers were engaged in extensive shrimp production and required larger ponds for the low stocking rates to increase their profits. Elasticities of efficiency are seen in Table 7.

Table 5. Statistical distribution of efficiency of Khánh Hòa and Trà Vinh provinces.

Statistics	Khánh Hòa	Trà Vinh
	Efficiency Distribution	Efficiency Distribution
Minimum	0.492	0.458
1st quartile	0.894	0.878
Median	0.918	0.893
Mean	0.905	0.889
3rd Quartile	0.930	0.907
Max	1.00	0.990

6. Discussion

Farm sizes were small in both provinces, and all farms on average had positive net profits, but the farms in Trà Vinh using intensive production system had significantly (11.62 times) higher profits per crop per ha than farms in Khánh Hòa province. Farmers from Khánh Hòa engaged in extensive shrimp production and had lower profits but relatively larger numbers in the 89%–100% efficiency range than Trà Vinh farmers. The cost of inputs (chemicals, labor and energy) negatively influenced profits, while yield, number of crops, the number of workers and the cost of seeds positively influenced profits of Khánh Hòa farmers. The cost of seeds positively relates to the intrinsic quality of seeds [19], indicating that higher quality seed is sold at a higher price, and if the farmer increases the quality of seeds, the yield and generated profits are likely to improve. The elasticities for the costs of seeds were 0.73 for Khánh Hòa farmers, and that means that a 1.0% increase in seed cost (seed quality) will result in a 0.73% increase in profits. This result is similar to the findings of a study by Ghee-Thean et al. [63], who found that the input elasticity of seed was 1.52. The positive value of seed elasticity is in line with previous findings of Begun et al. [64]. Singh et al. [65] reported that seed quality was an important determinant of TE, and Ghee-Thean et al. [63] reported that shrimp seed size was a significant factor for TE. This result indicates that shrimp seed is an important input in shrimp production in Khánh Hòa province. In Trà Vinh province, the cost of labor and the number of crops negatively influenced profits, while the number of workers and the cost of chemicals positively influenced profits. The cost of chemicals positively influenced profits in Trà Vinh province, while the average stocking density negatively influenced profits, and these are contrary to intuition. This phenomenon may be due to the high stocking densities in Trà Vinh province and the increase in recent disease outbreaks requiring greater investment in chemical prevention and control. As noted in the results, the cost of chemicals for Trà Vinh was 20 times that for Khánh Hòa farmers, and this should be an environmental concern for policy makers who aim at sustainable shrimp increase through production intensification. The results,

therefore, suggest that aquaculture extension agencies need to educate farmers on selection of quality seed, adoption of chemical cost-reducing methods [66], monitoring of disease outbreaks, improvement of energy use and better management practices to sustain economic efficiency.

Table 6. Factors influencing efficiency of shrimp profit in Khánh Hòa and Trà Vinh provinces.

Variable	Khánh Hòa		Trà Vinh Province	
	Estimate	Std. Error	Estimate	Std. Error
Intercept 1	0.889	0.016	0.9190	0.032
Intercept 1	0.090	3.826	−3.9810	0.059
No. Ponds	−0.001	0.005	0.0059 *	0.001
Avg. size of pond	0.033 *	0.012	−0.0021	0.016
Years of schooling	0.002 ***	0.001		
Years of experience	0.0009 **	0.0004		
Impact of natural disaster	−0.0274 *	0.0082		
Impact on diseases	−0.002	0.0052		
FCR			−0.0250	0.0233
Age			0.0008 *	0.00019
As a factor of disease			−0.0946 *	0.0279
Buy PI (Process Integration pump for the reduction of energy)			0.0442 **	0.0204
Statistics				
Log -likelihood	129.63		344.05	
Pseudo R ²	0.014		0.369	

* significant at the 1.0%, ** significant at the 5.0% and *** significant at the 10% levels.

Farmers in both provinces attained high efficiency rates, though Khánh Hòa farmers had a larger number of farmers in the 90%–100% range. A study conducted by Kumaran et al. [67] in India also showed that the mean technical efficiency of *P. vannamei* farms in the country was 0.9013. A study conducted by Rashid and Chen [68] in Bangladesh showed that technical efficiency was 0.82, 0.85, and 0.93 for extensive, improved extensive and semi-intensive farming methods, respectively. These figures are high, but one must remember that these are based on technical efficiency and not on economic efficiency. The statistical analysis shows that there is no inefficiency, which means all farmers are nearing maximum efficiency practices, and deviations from maximum efficiency are due to noise [53]. The results imply that small-scale producers, whether practicing intensive or extensive shrimp farming, are capable of operating efficiently.

Table 7. Elasticities of profit efficiency of Khánh Hòa and Trà Vinh provinces.

Variable	Khánh Hòa Province	Trà Vinh Province
No. of ponds	−0.002	0.0191
Avg. size of ponds	0.020	−0.0066
Years of schooling	0.002	
Years of experience	0.012	
Age		0.051
BuyPI (Process Integration pump)		0.042

The factors affecting efficiency varied for both provinces, but what was most striking was the years of schooling and experience in Khánh Hòa province and age in Trà Vinh province. The results are similar to those of a study by Sivaraman et al. [42] in Ahndra Pradesh, India, which found that age, education and experience of the farmers and their membership status in farmers' associations and societies had a significant effect on technical efficiency. The possession of a motor pump affected farm efficiency in Trà Vinh province; motor pumps are essential in Trà Vinh province, since farmers

complained that power shortages in the area were frequent, and they needed a motor or improvement in the power grid for production intensification [2].

Khánh Hòa farmers “perceived the effects of disease prevalence on their shrimp revenue” had no effect on their profits. Though farmers revealed that diseases had an impact on their farm income, the to bit model showed that the impact was insignificant. This could be due to the remediation made after the 2012 to 2013 disease attacks. However, the perceived effects of natural disasters on income of the Khánh Hòa farmer negatively affected economic efficiency as a result of flooding and infrastructure damages. This could be due to the recent effects of Damrey that farmers are still mindful of the severe damages to ponds in Khánh Hòa province caused by the typhoon [69,70]. Trà Vinh farmers reported that climate change events had no effect on their shrimp farm revenue. This might not be completely true, since saltwater intrusion is a major problem in this province. However, farmers might be taking precautions in their pond design and constructing dykes to minimize the effects of saltwater intrusion [71]. This could be reflected in the high capital costs expended per ha, which is about 4.8 times larger than that of Khánh Hòa farmers. The perceived effects of disease on farm revenue affected economic efficiency for farmers in Trà Vinh province, since recent outbreaks had negative effects on farm profits. Intensive shrimp production is associated within creased drug and chemical use. As is noted in the results, an increase in the use of chemicals by 1.0% for Trà Vinh farmers will increase profits by 1.09%. This measure of elasticity sends a message to farmers to increase chemical use. Hence, Anh et al. [66] have suggested ways in which farmers can reduce chemical use without affecting production.

7. Conclusions

The study showed that farmers in both provinces achieved high levels of economic efficiency in *L. vannamei* production. Khánh Hòa farmers practicing extensive shrimp culture had significantly lower profits but higher levels of economic efficiency than Trà Vinh farmers using intensive production systems. This finding may unravel the confusion in the literature between production intensity and efficiency, since the results suggest that farmers practicing extensive shrimp farming can be as efficient as farmers practicing intensive culture, even though at lower yields and profits. However, in an attempt to meet national production and export goals, the government will move towards intensive shrimp production in spite of its associated risks of environmental pollution. As is shown in the case of Trà Vinh, diseases have a major perceived impact on farm profits, and farmers tend to increase chemical use to control disease proliferation. Hence, policy makers should provide information on proper and optimal chemical use to minimize environmental pollution. There was absence of inefficiency, and deviations from maximum attainable profits were merely noise. This phenomenon could serve as an indicator of how well farmers are adopting Best Management Practices (BAPs) and Vietnam Good Aquaculture Practices (VietGAPs) on their farms and send a signal to policy makers and extension agents. The factors influencing profits varied in both provinces. In general, the major input cost factors had negative effects on farmer profits. Yield, quality of seeds and the use of a motor pump had positive effects on profits. Demographic variables such as average years of schooling and experience positively influenced economic efficiency in Khánh Hòa province, while the number of ponds and the perceived impacts of natural disasters on farm income negatively influenced economic efficiency. The number of ponds, farmer age and the purchase of electric motors positively influenced economic efficiency in Trà Vinh, while perceived impact of disease on farm income negatively influenced economic efficiency.

The study contributes to the body of knowledge by showing that the cost of inputs influenced profits, but farmers were unsure as to whether they used the optimum levels to maximize profits. The study suggests that efficiency and profitability may differ for production systems, but small-scale intensive and extensive shrimp farming can attain maximum efficiency. Hence, in an effort to attain its objective of US \$10 million from exports by 2025, using intensive shrimp production, the government of Vietnam should reconsider the importance of the mix of farming systems and the various levels of efficiency for shrimp farms in different ecological zones. While intensive production may be the

best way for the government to attain its objectives of increased production and exports, it might not be the optimal way of promoting efficient shrimp production when environmental, ecological and socio-economic factors are considered. Intensive shrimp production may have negative environmental and ecological effects and may require investment capital unavailable to limited-resource farmers. Hence, careful spatial consideration and production distribution of efficiency should be included in government planning process, and policies of capital access should be reasonable to meet shrimp farmer's needs. The government has been encouraging banks to lower their lending rate to aquaculture farmers, but the process has been slow [72]; however, with the high levels of profits generated from intensive shrimp farming, the government should revisit its policy and discussion with the banks. The study also generates significant findings on the impact of diseases in Trà Vinh and natural disasters on shrimp profits in Khánh Hòa province in Vietnam. Though there is suspicion that the indirect effect of climate change events may be a problem in Trà Vinh province, the impact on income was not significant, and indeed it might not have influenced gross margin since farmers have already invested in the design of the pond system to minimize the effects of salt water intrusion. This factor should be considered in future research in the way the questions are posed to the farmers in terms of the effects of climate change events on pond design and capital costs. In the case of Khánh Hòa province, improvements could have been made if the questions on the effects of diseases on farm income were on actual expenditure rather than on the perceived effects, since perception tends to consider the present rather than the past when disease was a problem. Farmers have also made adjustments to prevent previous disease problems and, hence, a negative effect of disease on perceived income. The data collected were from a one-time survey, but the researchers believe that even if the survey was conducted at different times, the answers would have been the same.

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