TECHNICAL EFFICIENCY OF IMPROVED EXTENSIVE SHRIMP FARMING IN CA MAU PROVINCE, VIETNAM

By

PHAM BA VU TUNG

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The Norwegian College of Fishery Science

University of Tromso, Norway

&

Nhatrang University, Vietnam

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DECLARATION

This thesis has composed in its entirety by the candidate and no part of this work has been submitted for any other degree.

Candidate:

Pham Ba Vu Tung

Abstract

The purpose of this thesis is to measure the mean technical efficiency of improved extensive shrimp farming in Cai Nuoc and Dam Doi districts, Ca Mau Province, Vietnam.

Data Envelopment Analysis Input-oriented variable return to scale were used in this thesis and estimating technical super-efficiency was regressed to the pond area, farmer experiences, black tiger shrimp, mud crab stocking density and education of farmers. Technical efficiency of observation farms was the identified determinant factor, results indicated that pond area, experience and education of the owners of the shrimp farms were the mainly positive factors that influence efficiency of improved extensive shrimp farming in both districts. Nevertheless, only in Dam Doi district shrimp stocking density have a negative relationship with technical efficiency. A comparison between the technical efficiency results of the two districts showed that the farms in Cai Nuoc were more highly efficient than farms in Dam Doi District.

To improve technical efficiency, the government should conduct training on techniques in shrimp polyculture, establish farmers' organization should assist to help farmers share their experiences and provide mutual help. In addition, extension officers should organize regular training courses in shrimp polyculture model to help farmers in both districts increasing productivity.

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Abbreviations

DOA	Department of Aquaculture, Ministry of Agriculture and Rural Development
NACA	Network of Aquaculture Centers in Asia-Pacific
GSO	General Statistic Office
VIFEP	Vietnam Institute for Fisheries Economics and Planning
VND	Vietnam dongs
SPF	Stochastic Production Frontier
DEA	Data Envelopment Analysis
MRC	Mekong River Commission
IE	Improved Extensive
SI	Semi Intensive
H	Hypothesis
DMUs	Decision Making Units
OLS	Ordinary Least Squares
SUPEFF	Super-efficiency
PA	Pond Area
EXP	Experience
SDEN	Shrimp Stocking Densities
MDEN	Mud Crab Stocking Densities
EDU	Education
SC	Scale Efficiency
CRS	Constant Return to Scale
VRS	Variable Return to Scale
S.D	Standard deviation
No	Number
Eff	Efficiency
CRSTE	Constant Return to Scale Technical Efficiency
VRSTE	Variable Return to Scale Technical Efficiency
SCALE	Scale Technical Efficiency
Coeff	Coefficiency
NGOs	Non Government Organization
Mill.vnd	Million Vietnamese dongs

Chapter 1: Introduction

1.1 Problem statement

In recent years, high value market demand by mainly affluent consumers in developed countries have lead to a rapid expansion of shrimp aquaculture throughout Asia and Latin America. In 1999, shrimp aquaculture only represented 2.6 percent of the total global aquaculture, but accounted for 16.5 percent of the total revenue at a value of $6.7 billion (World Bank et al. 2002). Considerable private and public sector investment induced an annual average increase in cultured shrimp production of 5-10 percent since the 1990's.

Vietnam's aquaculture is the fastest growing sector of food production in the world and aquaculture gradually plays an important role in the fishery sector (DOA, 2008). Thus, the aquaculture sector is considerably contributors to the economy of Vietnam.

The culture of shrimp in Vientam has developed mainly over the last decade, especially since the Government resolution No. 09/NQ-CP which allows transferring ineffectively used agriculture land to aquaculture development from 2000. This has been a major factor leading to increasing aquaculture area and production in the period of time. Shrimp culture is believed to be the most economically important sector within the aquaculture industry. In 2009 the total aquaculture area in the south of Vietnam was 926,770 ha, comprising 79 percent of the area under aquaculture and 80 percent total production in comparison with total production in whole country. In which, the aquaculture area south-west of Hochiminh accounted for 823,835 ha with 1,962,970 tonnes production obtaining and it amounted to 89 percent area and 92,5 percent production within the region. Black tiger shrimp was the main species under production with 653,374 ha producing 307,713 tones.

Based on General Statistics Office of Vietnam, 2008). The total fishery production was 4.6 million tonnes, of which aquaculture contributed 2.44 million tonnes (53 percent) in 2008. Aquaculture has become a significant source of income contributing to national economy as well as a valuable source of protein for local provinces and Vietnam (Vu and Phan, 2008; Phan et al., 2008). According to NACA, 2006, Vietnam had not only fishery production increasing yearly but also that from aquaculture and shrimp culture.

White-leg shrimp production was 71,008 tonnes from 14,383 ha. The area under production of mollusks was 20,885 ha with 67,552 tonnes produced, Tra fish had 6.788 ha and produced 998,255 tonnes, fresh water prawn had 11,713 ha with 9,298 production and exported value obtaining 4,65 billion USD in 2009 (General Statistics Office of Vietnam, 2009).

The Mekong Delta is by far the largest shrimp production area in Vietnam, there are 8 coastal provinces having a total of 584,000 ha of shrimp farms and a production of 293,829 tonnes. The area accounted for 75 percent of total shrimp industry in Vietnam of which more than 80 percent were exported (Sources: GSO, 2008 and VIFEP, 2008 & 2009). Hao et al., (2008) mention that international have high requirements for imported black tiger shrimp and other species, with respect to environmental protection and social responsibility

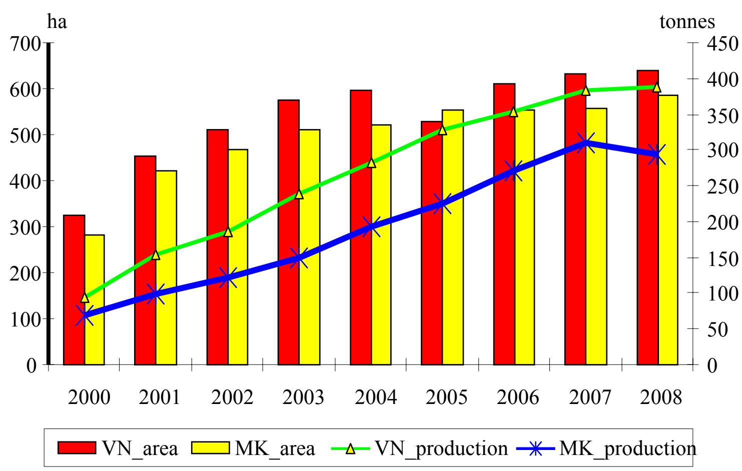


Figure 1. Culture area and production of coastal shrimps in Viet Nam & the Mekong Delta (Sources: GSO, 2008 and VIFEP, 2008 & 2009)

The trend of shrimp farming in Vietnam and in the Mekong Delta from 2000 to 2008 is shown in Figure 1 (GSO, 2008; VIFEP, 2008 & 2009). It is important to note that the area used for most of the production being conducted in improved extensive (IE) systems and intensive and semi-intensive (SI) shrimp farming in 2008 was about 10.5 percent of the total cultured area in the Mekong Delta. According to Estelles et al. (2002) and Lu et al. (2002), in Ca Mau Province has several types of aquaculture such as semi-intensive, intensive shrimp culture, shrimp-mangrove farming, shrimp crab-mangrove farming, alternate rice/shrimp farming are found. Black tiger shrimp culture in particular has been playing a determinant economic role for the last two decades, thus contributing to poverty alleviation, employment and foreign currency earning. Before making the strategic development plans, the total shrimp culture area occupied 204,381 ha in 2000, after conversion of poor quality rice fields and one part of garden area to shrimp culture. Currently, the total aquaculture area in Ca Mau is 293,223 ha of which 266,577 ha was used for shrimp culture in 2008. Improved extensive shrimp culture accounted for 90 percent and semi-intensive, intensive shrimp culture amounted for 10 percent of the total area (Ca Mau statistic department, 2009). At the moment, black tiger shrimp is one main strategy for economic development in Ca Mau and the shrimp production is improving people's living conditions.

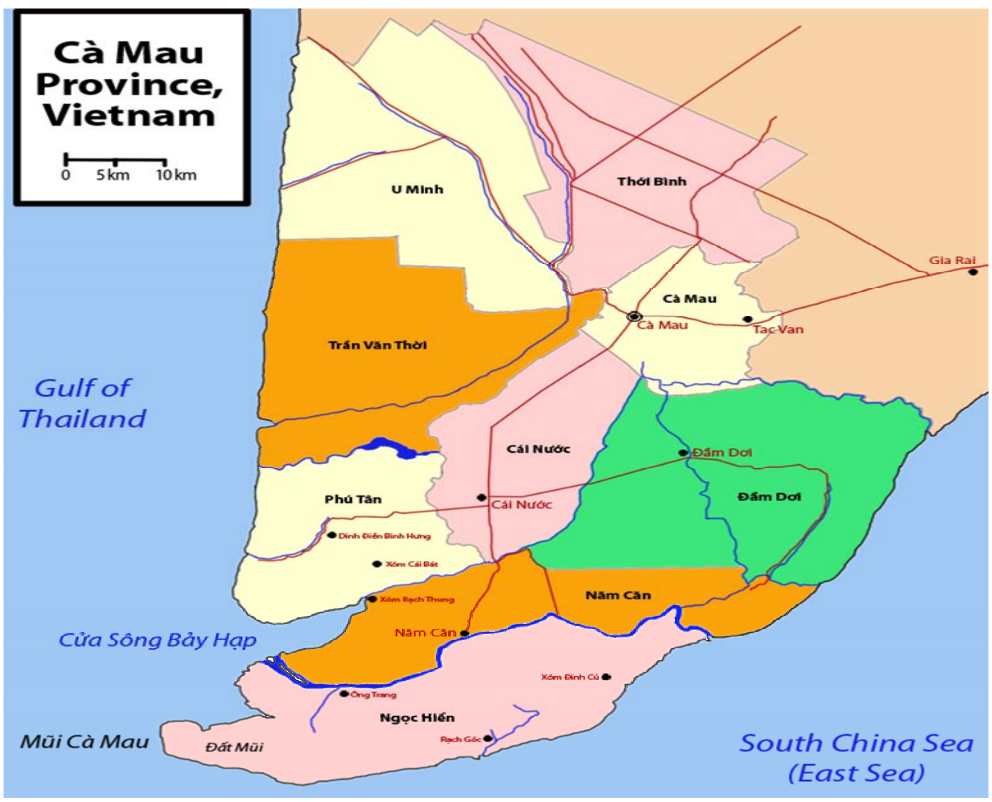


Figure 2: Ca Mau Province map

Source:http://upload.wikimedia.org/wikipedia/commons/f/f1/Ca_mau_province_map.sm.png

After the government expanded the shrimp culture area in the years from 2000 to 2008 with changing land uses with the resolution No. 09/2000/NQ-CP, brackish shrimp culture got the key position, not only in term of from economic point of view or inefficiency of land, water and labour resources but also in mobilizing material resources to develop post harvest service of brackish shrimp (Phi *et al.*, 2007). However, one of the most recent and significant causes of mangrove forest loss in the past decades has been the consumer demand for shrimp and the corresponding expansion of unsustainable production methods of export-oriented industrial shrimp aquaculture The great earnings of shrimp culture are short-lived, while the real costs in terms of consequent environmental impact are high and long-lasting. While the immediate profits from shrimp farming may satisfy a few, the vast numbers of coastal dwellers, once dependent on healthy coastal ecosystems for fishing and farming, are being displaced and impoverished. Thus, the brackish shrimp culture is limited to the extend that it is not sustainable and bears a high rate of risk. Lu et al, (2005) stated that improved-extensive shrimp farming monoculture, with only one species, tiger shrimp (*Penaeus monodon)* suffer environmental problems, with large region affected by virus outbreak and subsequent impact of farmer's income. Shrimp diseases usually occurred in this system from 30 to 60 days after seed stocking. The most frequent disease outbreaks involved white spot virus and red body bacteria diseases. Shrimp diseases appear to be transmitted from one farm to another via water in canals because farmers let out diseases water into the river and it caused contaminant to another farmer when they let in water into their pond. Disease outbreaks can and often lead to major decreases in the farmers income to the extent that they are unable to repay all of their debt. Practical experiments in 2003 and 2004 showed that appropriate stocking density would control shrimp diseases, crab mixed shrimp culture would increase farmers' income and limit environmental pollution (Lu et al, 2005).

According to http://www.Ca Mau.gov.vn, (2009) Dr. Hao director of Research Institute for aquaculture Number 2 (RIA2) (2007) suggested a method of polyculture such as shrimp mixed with mud crab in the same pond to reduce those problems. This model of combined production of the two species is more sustainable than only monoculture shrimp production. Hao and Phi, (2007) assessment that shrimp mixed with mud crab culture had low effect on soil and water pollution, and they recommended that Ca Mau should apply this model linking with natural ecology as there is a big demand in the global market for organically cultured shrimp. In addition, improved extensive shrimp culture has truly improved the efficiency in aquaculture. Moreover, most farmers in Ca Mau province applied this model because it is one of the right ways to decrease high risk in improved extensive shrimp culture in recent years. Base on the study on shrimp in Mekong delta, Dr. Ly Thi Thanh Loan concluded that improved extensive shrimp culture in Ca Mau had improve household income with net profit 32 – 37 million VND/ha/crop.

The main objective of this study was to determine the technical efficiency of improved extensive shrimp farming in Ca Mau province, Vietnam. The study not only intends to explain why this improved extensive shrimp culture is an efficient model but also understand the technical efficiency levels, how much inputs were really used and how much should be used, particularly in the situation of limited resources such as pond area, pond preparation cost, capital for seeds, owner education, experiences and skills of labours. Other questions addressed in this study are: (a) Which factors should be controlled to improve technical efficiency? (b) Are there any differences in the level and determinants of technical efficiencies between pond culture of Cai Nuoc and Dam Doi district? This study also intends to examine some socio-economic characteristics of the giant prawn growers in two districts in Ca Mau. As a result, recommended measures to achieve long-term sustainability including improved farm management for not only farmers, officials at different levels and policies makers, will be put forward.

Four methodological approaches to measure and estimate technical efficiency stand out. These are: (a) the deterministic statistical approach, (b) the stochastic frontier production function approach, (c) the parametric programming approach, and finally (d) the nonparametric programming approach. Following Dey, Paraguas et al. (2005); Den, Ancev et al. (2007), the technical efficiency of Vietnam aquaculture used stochastic production frontier approach (SPF) for multi-input and only one output. The Data Envelopment Analysis (DEA) is a more popular approach than stochastic production frontier because it is able to analyze multi-output production situations based on multi-input (Herrero 2003; Pascoe 2003; Timothy J. Coelli, D.S. Prasada Rao et al. 2005). In this thesis the two-stage Data Envelopment Analysis (DEA) approach will be applied. The technical efficiency score of improved extensive shrimp farming are estimated in the first stage to identify how efficient those farms are, and which type of production environment, Cai Nuoc or Dam Doi farms, is more efficient. The results of estimating regressed to some characteristics of the farmers, shrimp and mud crab stocking density and pond area variables to determine which factor impacts on technical efficiency of these farms.

1.2 Objectives of this thesis

Based on the problems stated in the above section, the following three objectives are envisaged by this reasearch:

i) To study the existing aquaculture production in Ca Mau Province.

ii) To measure the technical efficiency of improved extensive shrimp farming in Cai Nuoc and Dam Doi districts in Ca Mau Province.

iii) To investigate the main factors affecting the technical efficiency of improved extensive shrimp farming in Cai Nuoc and Dam Doi districts in Ca Mau Province.

1.3 Hypotheses of this thesis

The hypothesis that the characteristics of each farmer's operations affects their technical efficiency or operation year of improved extensive shrimp farming will be tested. Based on the results, recommendation in decision making will be given. In addition, the effects of getting shrimp diseases situation of those farms last year will be tested.

- H1: The higher improved extensive shrimp farming area, the more efficient the production.
- H2: Farmer's characteristics of shrimp farming such as pond area, experience and education are significant factors affecting the technical efficiency of improved extensive shrimp farming production.
- H3: Stocking densities of shrimp *(Penaeus monodon)* and mud crab (*Scylla paramamosain*) species in this model have no effect on the technical efficiency.

1.4 Organization of the study

This thesis includes the following chapters:

Chapter 1 provides the introduction with the problem statement, the objectives and hypotheses.

Chapter 2 contains an overview about aquaculture in Ca Mau Province: it covers the whole picture of Ca Mau aquaculture including a general introduction on the allocation of what? and characteristics of the area, aquaculture labour, and the aquaculture production.

Chapter 3 empirical studies related to technical efficiency in aquaculture are reviewed.

Chapter 4 describes the methods used for data collection and the sample sizes. It also includes definitions of technical efficiency approaches and its measurements. The use of the Data Envelopment Analysis in the first stage and the Ordinary Least Square regression in the second stage are mentioned.

Chapter 5 presents the results of performance analysis on estimated technical efficiency scores and which factors effecting on this efficiency. The results are discussed

Chapter 6 concludes the main point of the analysis and recommendations to improve the technical efficiency in this study area.

Chapter 2: Overview of aquaculture in Ca Mau Province

Ca Mau province was created on 01 January, 1997 from the separating of Minh Hai province. Ca Mau is a low lying coastal region and southernmost part of the Mekong Delta, Vietnam. It consists of eight districts and one city: Ca Mau City, U Minh, Thoi Binh, Phu Tan, Nam Can, Ngoc Hien, Tran Van Thoi, Dam Doi and Cai Nuoc. It is bounded by the South China Sea and the Gulf of Thailand. The province has a natural area of 5,331 km^2 and a population of 1,261,971 people (Statistical Yearbook of Ca Mau, 2008). The province possesses a coastline of 170 km, elaborated waterways and many water transition areas. The Figure 2 show that the spatial extent of Ca Mau Province is as follows:

- North bordering with Kien Giang Province
- East bordering with Bac Lieu Province
- West bordering the West Sea
- South bordering the East Sea

Ca Mau is the only province in the country regulated by two conflicting tidal regimes. The East Sea has a large amplitude semidiurnal tide, while the West Sea has a diurnal tide of smaller amplitude. The farming systems in the buffer area of Ca Mau Province are influenced by the tide pattern of Eastern Sea with a high amplitude 2 to 3m (Tran Thanh Xuan, 2001).

According to MRC (2007), Ca Mau Province is suited for aquaculture activity due its large network of canals, sluices and dams, which allowed farmers to control water availability and quality.

Lu *et al*. (2002) concluded that the application of management techniques such as rotation of shrimp-crabs and fish culture, using disease-free shrimp post larvae; suitable shrimp and crab density, adjustment of environmental factor play a role in limitation of limiting shrimp disease occurrences in the cultured crop of 2006 when shrimp diseases did not happen. In addition, black tiger shrimp and mud crab are a key species in the improved extensive shrimp farming and are mainly used in coastal of Ca Mau provinces. Therefore, improved extensive shrimp farming plays an important role in the alleviation of poverty and the achievement of food security in many parts of the world. Shrimp production in Ca Mau has significantly contributed to national economy.

2.1. Aquaculture labour

Ca Mau Province encompasses one city, 8 districts and 81 communes. There are 610,096 labourers, accounting for 50.62 percent of the province's population with Cai Nuoc and Dam Doi district contributing 27.62 percent of the labour force within the whole of Ca Mau province (Table 1).

Table 1: Distribution of communes and labourer by district in Ca Mau Province

Districts	**Number of communes**	**Distribution of labour**	
		Number labourers	**Percent (%)**
Total	**81**	**610,096**	**100**
Ca Mau city	7	84,637	13.87
Thoi Binh rural district	11	74,034	12.13
U Minh rural district	6	51,572	8.45
Tran Van Thoi rural district	11	116,300	19.06
Cai Nuoc rural district	10	76,972	12.62
Phu Tan rural district	8	50,619	8.30
Dam Doi rural district	15	91,586	15.01
Nam Can rural district	7	23,449	3.84
Ngoc Hien rural district	6	40,927	6.71

Source: Statistical Yearbook of Ca Mau, 2004

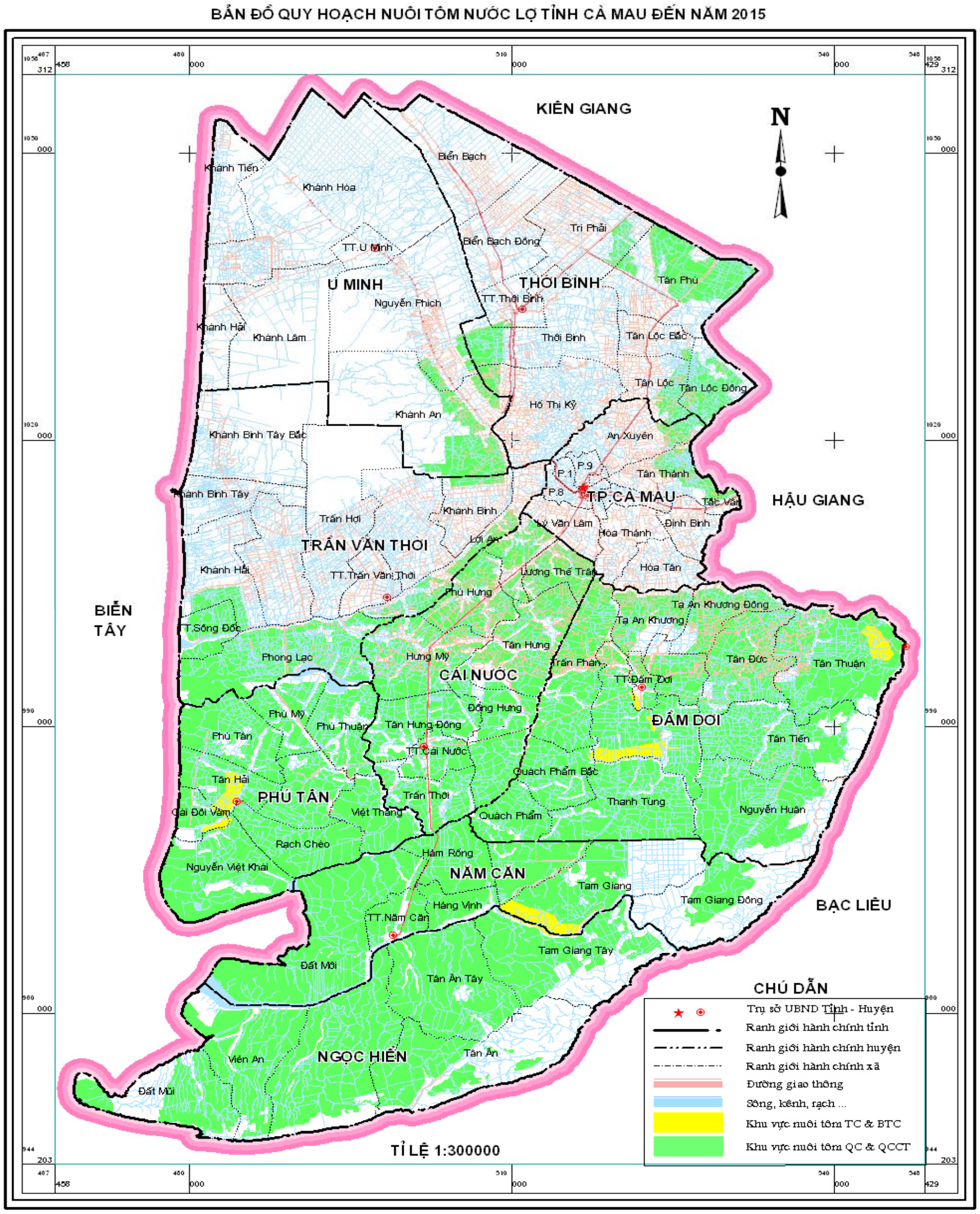


Figure 3: Improved extensive shrimp farming plan in Ca Mau Province
Source: (Nguyen Thanh Tung, 2008)
Note: The green colour shows the areas identified for improved extensive shrimp farming

Table 2 shows that labourer employed in the fishery sector counted for 64.26 percent of the total population employed in the province. Almost 19 percent of the labour force is working in agriculture and forestry. Thus, more than 80 percent of the population living in Ca Mau is employed in the fishery, agriculture or forestry sector.

Table 2: Distribution of employee by kind of economic activity in Ca Mau Province

No.	**Economic sectors**	**Number of labourers**	**Percent (%)**
	Total	**664,807**	**100**
1	Agriculture and Forestry	124,223	18.69
2	Fishery	427,224	64.26
3	Mining and Quarrying	194	0.03
4	Manufacturing	25,875	3.89
5	Electricity, Gas and Water supply	881	0.13
6	Construction	2,574	0.39
7	Wholesale and retail Trade; Repair of motor vehicles, motor cycles and personal goods	32,029	4.82
8	Hotels and Restaurants	10,671	1.61
9	Transport; Storage and Communications	7,743	1.16
10	Financial Intermediation	668	0.10
11	Scientific activities and Technology	49	0.01
12	Real estate; Renting business activities	1,583	0.24
13	Public Administration and Defence; Compulsory social security	6,926	1.04
14	Education and Training	14,841	2.23
15	Health and Social work	3,584	0.54
16	Recreational, Culture and Sporting activities	1,220	0.18
17	Activities of Party and Activities of Membership Organisations	1,044	0.16
18	Community, Social and Personal service activities	1,876	0.28
19	Private households with employed persons	1,602	0.24

Source: Statistical Yearbook of Ca Mau, 2008

2.2. Aquaculture area and households

The area used for brackish shrimp culture in Ca Mau Province increased slightly from 2000 till present, which is mainly due to the Vietnamese diversification strategy with a shift from rice cropping to tiger shrimp culture. The Mekong Delta is the biggest brackish shrimp area in Vietnam. The total shrimp farming area in Vietnam adds up to 560,201 ha (89.7 percent of the total area), of which Ca Mau Province covers 262,117 ha (46.8 percent)

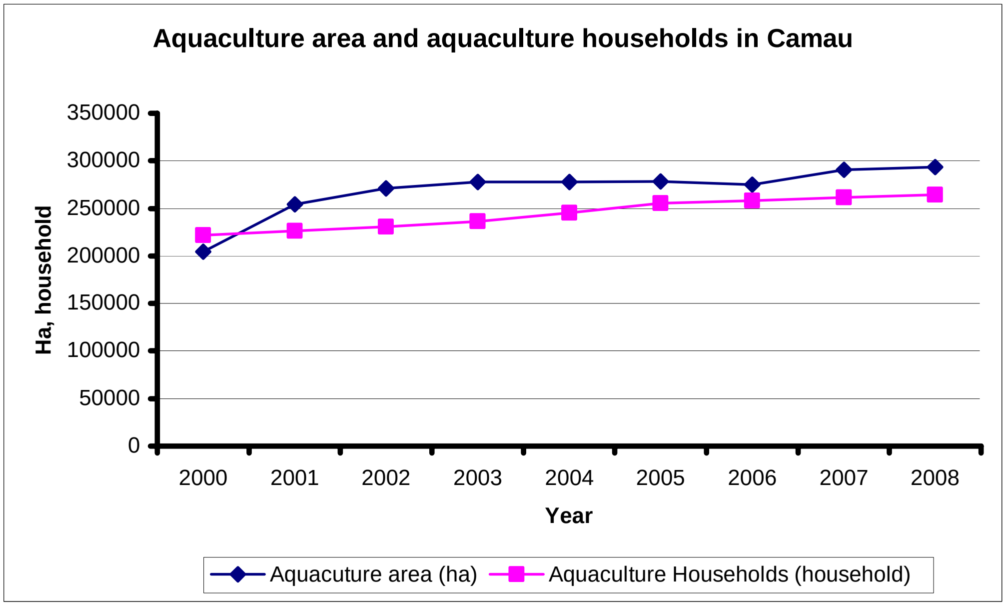


Figure 4: Aquaculture area and households in Ca Mau Province
Source: Statistical Yearbook of Ca Mau, 2008

Main livelihood of local residents is derived not only aquaculture but also earns living by fishing from sea, river and canal because there is very rich natural resource coming from Mekong river and seas. However, shrimp production was not appropriate with area in the province. For example, in 2008 total tiger shrimp production obtained 11,682 tonnes with area 293,223 ha and average yield 398 kg/ha/year (Statistical Yearbook of Ca Mau, 2008). In particular, the irrigation system in Dam Doi district has not been upgraded by the government because farmers in this area were only involved in rice cultivation long time ago. Thus, they lack knowledge in the technology of shrimp culture. As a result, they have met high risk in shrimp culture and experience low production compared with other districts.

Figure 4 shows that the aquaculture area as well as the amount of households engaged in aquaculture increased slightly from 2000 to 2008. Nevertheless, production of aquaculture fluctuated between 2000 and 2003 before it increased significantly from 2004 onwards.

2.3. Aquaculture production and value

According to Figure 5 shows that shrimp production increased significantly from 35,377 tonnes in 2000 to 94,291 tonnes in 2008. Other production in aquaculture went down from 28,949 tonnes in 2001 to 21,927 tonnes in 2002 and it remained stable in the two years 2003-2004 and then this production increased dramatically from 2005 with 31,530 tonnes to 70,575 tonnes in 2008.

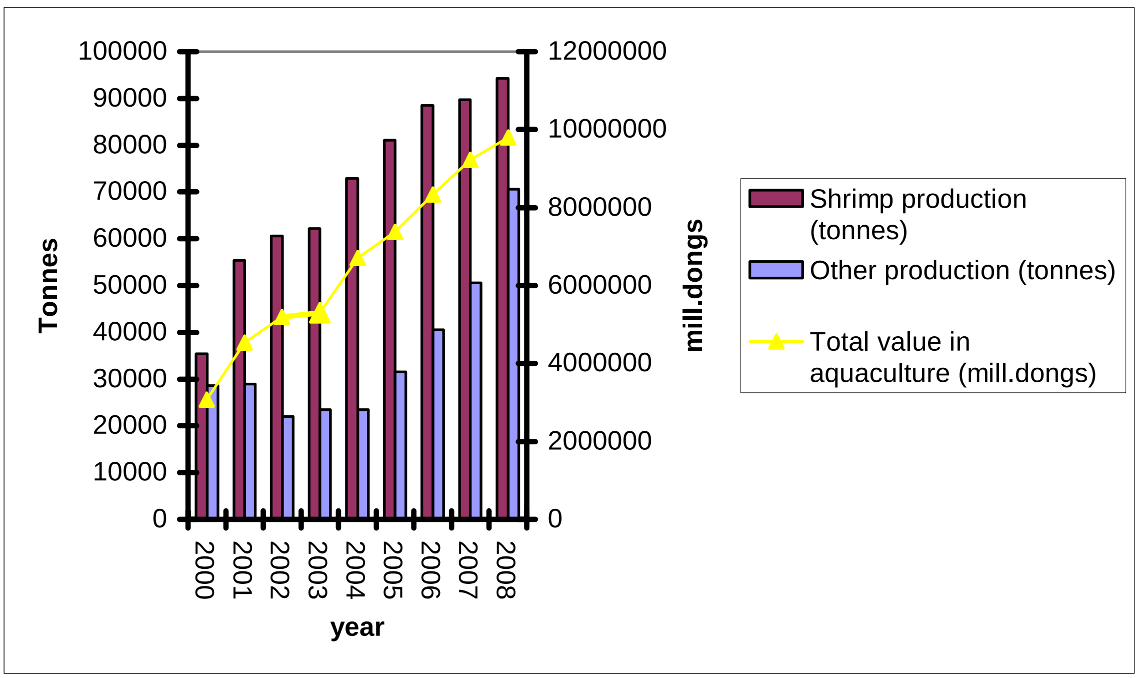


Figure 5: Aquaculture production and total value in Ca Mau Province

Source: Statistical Yearbook of Ca Mau, 2008

importance very important fact is that the total value of aquaculture production also produced high economic returns. The total value of aquaculture production indicates that it was a big contributor to social economic development, not only for the people living in the districts but also for the Ca Mau government finance. In 2008, the total value in aquaculture was 9,795,435 million dong and it was triple this figure in 2000 (3,071,724 million dongs). Shrimp production was the main contributor to the total value.

Chapter 3: Literature review on efficiency of aquaculture

3. A valuable literature survey

In 2008, Dipeolu et al. and Kareem estimated the economic efficiency of fish-farms in Ogun, Nigeria using the stochastic frontiers production approach. They used cross section data of 85 fish farming grouped into concrete and earthen pond type. The research was based on the Cobb Douglas production function involving fish production in kilogram and five inputs, including pond area. Using this method, they analyzed labour, lime, fingerlings, feed and other materials (Table 3). The technical inefficiency function involved experience such as age and education of the owners as well as household size. The empirical results revealed that the mean technical efficiency of earthen pond and concrete pond type were about 0.88-0.89 with no statistical significant difference between the two pond types (Table 3).

Experience of the owner had negative effect on inefficiency of concrete pond (Kareem, Dipeolu et al. 2008). For evaluating the resource allocation efficiency of prawn-carp poly-culture systems in Bangladesh using the DEA approach, cross-section data of 105 prawn-carp farms were used. The efficiency estimation was based on two outputs prawn and carp and four inputs such as fingerlings, labour, organic fertilizer, inorganic fertilizers and feeds. The main results of this study indicated that the mean technical, allocative, cost and scale efficiency of prawn-carp poly-culture in Bangladesh were 0.85, 0.58, 0.49, and 0.88 respectively. Pond size was found to have a positive effect on technical and cost efficiency. Nevertheless, there was a negative relationship between pond size and allocative efficiency, and between feed application and technical, allocative and cost efficiency (Alam and Murshed-e-Jahan 2008) (see also Table 3).

In 2008, Au estimated the technical efficiency of prawn poly-culture in Tam Giang lagoon, Vietnam. The evaluation of the resource allocation efficiency of the poly-culture systems was also done using the DEA approach and cross-section data of 44 poly-culture farms in Tam Giang lagoon were used for the analysis

Table 3: Summarizing the result of the survey of the literature

Study	Name	Year	Country	Method	No. inputs	No. outputs
Estimated the economic efficiency of fish-farms in Ogun	Dipeolu et al and Kareem	2008	Nigeria	Stochastic frontiers production approach	labour, lime, fingerlings, feed and materials	Fish production in kilogram
Evaluating the resource allocation efficiency of prawn-carp poly-culture systems	Kareem, Dipeolu et al	2008	Bangladesh	Data Envelopment Analysis (DEA) approach	Fingerlings, labour, organic fertilizer, inorganic fertilizers and feed	Prawn and carp
The technical efficiency of prawn poly-culture in Tam Giang lagoon	Au	2008	Vietnam	DEA	Working hours, seed cost and feed	Prawn, fish and other
The impact of financial variables on the production efficiency of Pangasius farms in An Giang province	Hanh	2008	Vietnam	Ordinary Least Square and DEA	Labour, Fuel and oil, Electricity, Chemicals, Seed and Feed	Pangasius production
The technical efficiency analysis for commercial Black Tiger Prawn (*Penaeus monodon*) aquaculture farms in Nha Trang city, Vietnam.	Huy	2008	Vietnam	DEA	Labour, pond area, machine, pond depth and activities cost	Size of shrimp, total shrimp production

The productivity and technical efficiency of crustacean in Nigeria	Amos	2007	Nigeria	Stochastic production frontier (SPF) approach	Labour, cost of feed, equipment, foundation stock, and other cost	The value of crustacean produced per hectare
The technical efficiency of black tiger farming in the Mekong Delta	Den	2007	Vietnam	Stochastic production frontier (SPF) approach	Pond area, experience, age, education	Kilogram prawn per hectare per year
The cost efficiency of trout farms in the Black Sea Region	Den, Ancev et al	2007	Turkey	Stochastic production frontier (SPF) approach	Feed and labour	Trout production
The productive efficiency of catfish farms in Chicot	Kaliba and Engle	2006	Arkansas	DEA	Labor, energy, quantity of fingerlings, quantity of feed & other costs	Live catfish in kilogram per hectare
The technical efficiency of smallholder farmers in Southern	Mussa	2006	Malawi	Stochastic production frontier (SPF) approach & Translog production function	Land, assets, labour, and others	Value

Estimated the technical efficiency and its determinants of freshwater pond poly-culture in selected Asian countries	Dey et al	2005	Asian countries	Stochastic production frontier (SPF) & Cobb Douglas function	Stocking density, feed, labour, and chemicals	Farm yield in kilogram per hectare
The technical efficiency of milkfish in Taiwan	Chiang et al	2004	Taiwan	Stochastic production frontier (SPF) approach	Pond area, fry, feed, water, electricity cost and other costs	Milkfish production quantity
Implemented the input-oriented Malmquist productivity index to aquaculture farms in Greek	Pantzios et al	2004	Greek	Stochastic production frontier (SPF) approach & DEA	Labour, stocking rate, fish feed and cages area	The total annual production of sea-bass and sea-bream
The technical efficiency of carp production in India	Sharma and Leung	2000	India	Stochastic production frontier & Cobb Douglas production frontier	Seed, labour, chemical fertilizer, organic manure, feed, and other	Quantity of fish production in kilogram per hectare

Linuma, Sharma and Leung assessed the technical efficiency of carp pond culture in Peninsula Malaysia	Sharma and Leung	1999	Malaysia	Stochastic production frontier (SPF) approach	Seed, seed ratio, feed, feed ratio, labour and other	Total quantity of fish harvested
The economic efficiency of fish poly-culture in China	Linuma, Sharma et al	1999	China	DEA	Seed, feed, and labour	Black carp, grass carp, silver carp and common carp
The economics analysis of carp culture in Thanjavur district, Tamil Nadu state, India	Jayaraman	1997	India	Ordinary Least Square method and Probabilistic frontier production function model (PFPF)	Pond size, stocking ration, labour, feed cost, and average price of fish	The mean yield of carp

The efficiency estimation was based on three outputs such as prawn, fish and other as well as three inputs such as working hours, seed costs and feeds. The main results of this analysis showed that there were 18 out of 44 farms (over 40 percent of the whole sample) being variable return to scale (VRS) technically efficient. The experience of shrimp poly-culture farmers, different stocking densities, their access to extension services as well as the production environment were significant factors affecting the technical efficiency. On the other hand, the education level of shrimp poly-culture farmers and stocking density of rabbit-fish had no explanatory effect on technical super-efficiency (Au, 2008) (Table 3).

Hanh (2008) analyzed the impact of financial variables on the production efficiency of Pangasius farms in An Giang province, Vietnam. She used cross section data of 61 pangasius farms. The analysis was based on the average production function estimated by Ordinary Least Square method on some financial variables (debt - to - asset ratio; bank debt - to - asset ratio; debt - to - asset ratio) in addition to other specific factors. She used the DEA with using the mean yield of pangasius and six inputs (labour, fuel and oil, electricity, chemicals, seeds and feeds) and one output (pangasius production). Here, the technical efficiencies of Pangasius farming in Vietnam was estimated under the assumption of constant returns to scale and variable returns to scale as 0.595 and 1.058 respectively. The group with the largest ponds area (>7000 m^2) achieved the highest scale efficiency score and the group with the smallest sized ponds (< 4000 m^2) achieved the lowest scores (Hanh, 2008).

Huy, (2008) examined the technical efficiency analysis for commercial Black Tiger Prawn (*Penaeus monodon*) aquaculture farms in Nha Trang City, Vietnam. Cross section data of 64 samples of black tiger shrimp farming were used. The efficiency estimation was based on two outputs such as the size of the shrimp, the total shrimp production and five inputs such as labour, pond area, machine, pond depth and activities cost. The main results indicated that the area of the technical efficiency ponds for Black Tiger Prawn (Penaeus monodon) aquaculture in Nha Trang is within the range of 0.08 - 2.5 ha and pond size was found to have positive effect on the technical and cost efficiency (Huy, 2008).

The productivity and technical efficiency of crustaceans in Nigeria was studied by Amons (2007) who used the stochastic production frontier (SPF) approach Amos, (2007). Data from 100 crustacean farms in five villages in Ilaje Local Government Area in Nigeria were used. The analysis was based on the Cobb-Douglas frontier production function with five inputs: labour, cost of feed, equipment, foundation stock, and other cost costs as well as one output of the value of crustacean produced per hectare. The results indicate that feeds and equipment costs are significantly affecting the technical efficiency. With these empirical results, Amos proved that the mean technical efficiency of producers was 7 percent and the age of producers had a negative and family size had a positive effect on the technical efficiency (Table 3).

The technical efficiency of black tiger farming in the Mekong Delta in Vietnam was examined by Den et al. (2007) using the Stochastic Production Frontier (SPF) approach. Cross-section data from 2004 with 193 cases classified into extensive and intensive farms in this area were used for the analysis. The study was based on the Cobb Douglas production function in the first step involving one output of kilogram prawn per hectare per year and seven inputs: Postlarvae, commercial feeds, chemical, fuel, hired labour, type of shrimp. In the second step, the farm specific technical inefficiency was analysed using four inputs: pond area, experience, age and education of the owner. The mean technical efficiency obtained 46 percent, while the extensive shrimp farming was technically more efficient than the intensive shrimp farms with 48 percent and 35 percent respectively (Table 3).

Den, Ancev et al. (2007) examined that the relationship between experience and technical efficiency is positive. In contrast, when owners were younger they were more technically efficient in shrimp farming. The researchers of the cost efficiency of trout farms in the Black Sea Region, Turkey used a two-stage data envelopment analysis approach (Cinemre et al, 2006) with cross-section data of 73 trout farms. The analysis was based on two inputs (feed and labour) and a single output (trout production framework) in the first stage. In the second stage, a Tobit model with personal characteristics such as education level and experience of the operators, farm characteristics, off-farm income and pond size as well as access to credit institutions and extension services was used. The results proved that the mean technical, allocative and cost efficiencies were 82 percent, 83 percent and 68 percent respectively. In addition, farm ownership, pond tenure, experience as well as education level of the host, met with extension services, off-farm income and credit availability were found to have positive effects on cost efficiency. However, based on Cinemre and Ceyhan et al. (2006), there was a negative relationship between cost efficiency, feeding intensity, pond size, and capital intensity (Table 3).

Kaliba and Engle (2006) studied the productive efficiency of catfish farms in Chicot, Arkansas with a weight-restricted DEA approach analyzing 32 catfish farms cross section data were used in this area in 2001. The efficiency analysis was based on five inputs: labour, energy, quantity of fingerlings, quantity of feed, other costs as well as one output of live catfish in kilogram per hectare. Besides the experience of the operator, extension services and land lessee were included in the second stage of the Tobit model. The results illustrate that the mean technical efficiency under constant return to scale (CRS) and allocative scale efficiency were 57 percent, 67 percent and 77 percent respectively. Meanwhile, the technical and cost efficiency under variable return to scale (VRS) were 73 percent and 49 percent respectively. The operators' experience, extension contacts were found to have a positive effect on the level of efficiency of those farms (Table 3).

The technical efficiency of smallholder farmers in Southern Malawi was measured by Mussa (2006) who used the stochastic frontier production (SPF) function. Cross-section data in 2003 of 150 farms adopting and 150 farms not-adopting integrated aquaculture-agriculture were analysed. First of all, the analysis was based on the Translog production function. Then, it was tested against a Cobb Douglas functional form. Those factors influencing the production frontier concern the farming system output value and inputs such as land, assets, labour, and others as well as the technical inefficiency function involving age and education of the farmers, availability of credit, extension services, membership of a association, number of plots and recycling of materials. The results show that non-adopters were technically less efficient than adopters, with 49 percent and 63 percent, respectively. Further, there was a positive relationship between education, extension services, recycling of materials, number of plots and technical efficiency of adopting integrated aquaculture-agriculture farms (Mussa, 2006) (Table 3).

Dey et al. (2005) estimated the technical efficiency and its determinants of freshwater pond poly-culture in selected Asian countries using the SFP approach. The data included 409 samples from India, 300 samples from China, 180 samples from Thailand, and 120 samples from Vietnam collected by the WorldFish Center and its partner institutions. Those poly-culture farms in freshwater pond were classified into extensive, semi-intensive and intensive farming. As a production frontiers the Cobb Douglas function was used. The inputs used in those production frontiers were not only the common inputs such as stocking density, feed, labour, and chemicals but also the specific inputs, such as energy, protein, nitrogen, phosphorus, fertilizer as well as dummy variables. The farm-specific variables included age, education, experience of the farm operator, the farm size, private ownership (dummy), distance from seed supplier/market and a regional variable (dummy). The only output included was farm yield in kilogram per hectare. The results revealed that technical efficiencies of extensive and semi-intensive system were 65 percent and 86 percent in India, 77 percent and 84 percent in China, 72 percent and 91 percent in Thailand, 42 percent and 48 percent in Vietnam, respectively. The technical efficiency of intensive system in China had the highest score with 93 percent and the relationship between regional dummy, farm size, distance to seed supplier in China, education, farm size, pond owner dummy in India, farm area, pond owner dummy, distance to seed supplier in Thailand, age, education of operator, farm area, distance to nearest market in Vietnam and technical inefficiency (Dey, Paraguas et al. 2005) (Table 3).

Chiang et al. (2004) analyzed the technical efficiency of milkfish in Taiwan using the SPF approach. In the study, data of 433 aquaculture milkfish farms collected between 1997 and 1999 were used and both the Translog and the Cobb Douglas frontier production models were estimated using the maximum likelihood estimation. The production frontier was based on five inputs (pond area, fry cost, feed cost, water and electricity cost and other costs) and a single output (milkfish production quantity).

Inefficiency factors included the data collecting time (dummy), monoculture farm (dummy), fresh water (dummy), location (dummy), and pond size (dummy), education (dummy), experience, labour. The empirical results examined that the mean technical efficiency was 84 percent in the Translog model and milkfish farming in Taiwan diminished return to scale. The results show a positive relationship among fresh water, location variables, education, experience and labour and technical inefficiency. However, the study of Chiang, Sun et al. (2004) used data from 1998 and proved that the monoculture farm and the reading ability of the farmer had negative effect on the technical inefficiency (Table 3).

Pantzios et al. (2004) implemented the input-oriented Malmquist productivity index to aquaculture farms in Greek using the SFP approach and Translog input distance function. Panel data sets of 14 sea-bass and sea-bream farms from between 1995 and 1999 were used for the analysis. Its Translog input-distance function was based on four inputs (labour, stocking rate, fish feed and cages area) and two outputs (the total annual production of sea-bass and of sea-bream measured in tons) (Table 15). The empirical results show that the mean technical efficiency of sea-bass and sea-bream farms and it is always approximate 7 percent over the time (Table 3).

From Table 3 shows that in 2000, Sharma and Leung measured the technical efficiency of carp production in India using the stochastic frontier analysis (SPF) approach. Since then its levels and determinants in carp pond in this country were examined. Sharma and Leung used cross section data of 906 carp farming in India classified into semi-intensive, intensive and extensive. The analysis was based on the Cobb Douglas production frontier involving one output of aggregated quantity of fish production in kilogram per hectare and six inputs such as seed, labour, chemical fertilizer, organic manure, feed, and other inputs. The technical efficiency model further included primary activity (dummy), farmer's experience, owner operated, pond area, fish management index, water management index, feed management index and location variables (dummy).

The main findings were 65,8 percent and 80,5 percent of technical efficiency score for extensive and semi-intensive/intensive respectively and the former was found technically more efficient than the later. Furthermore, fish, water quality and feed management practices had positive effect on technical efficiency. Meanwhile, there was a negative relationship between technical efficiency of extensive system and aquaculture as primary activity, semi-intensive/intensive farms' technical efficiency and farmers' experience (Sharma and Leung 2000).

In 1999, Iinuma, Sharma and Leung assessed the technical efficiency of carp pond culture on the Peninsula Malaysia by using The SPF approach. The technical efficiency was estimated in order to give some policy recommendations for promoting carp production in the area. A sample of 94 carp pond farms classified into intensive/semi-intensive and extensive cultures was used for analysis. The analysis was based on the production frontier, which was in Cobb Douglas functional form, a single output with the total quantity of fish harvested in the 1994 production year measured in kilograms per hectare and six input variables including seed, seed ratio, feed, feed ratio, labour and other inputs. The technical efficiency model included five farm-specific variables such as culture intensification, ownership, carp farming as a primary activity, pond area and pond age. The main results showed that the mean technical efficiency was 42 percent. The intensive/semi-intensive system was technically more efficient than the extensive with 56,5 percent and 23,6 percent on average respectively. In addition, age and ownership were found to have a positive effects on technical inefficiency (Table 3).

Meanwhile, there was a negative relationship between the technical inefficiency and intensive culture (Iinuma, Sharma et al. 1999). Sharma et al. (1999) also measured the economic efficiency of fish poly-culture in China using the DEA approach. They used cross-section data of 115 fish poly-culture farms from eight provinces in China with four output categories of fish including black carp, grass carp, silver carp and common carp and a combination of inputs such as seed, feed, and labour. The main results reveal that the sample average technical, allocative, and economic efficiencies were 83 percent, 87 percent, and 74 percent, respectively. However, the technical and economic efficiency had a negative relationship with the farm size. The large farms with more than 10 ha and those farms from underdeveloped provinces were technically less efficient than the small ones (less than 0.5 ha) and those from the developed provinces (Sharma, Leung et al. 1999).

In 1997, Jayaraman analyzed the economics analysis of carp culture in Thanjavur district, Tamil Nadu state, India, and identified the reasons for yield variations by using the probabilistic frontier production function model (PFPF). Using cross section data of 40 carp farms were analysed. The analysis was based on the average production function estimated by Ordinary Least Square method and PFPF involving the mean yield of carp and five inputs such as pond size, stocking ration, labour, feed cost, and average price of fish. The results measured that 23 out of 40 farms had technical efficiency of less than 5 percent; only one farm was technical efficient (Jayaraman 1997) (Table 3).

To sum up, data envelopment analysis and stochastic frontier analysis have been used in most of the above studies. With the SPF approach the efficiency was measured by using econometric techniques. Thus, the studies using this method had specific production functional forms such as Cobb Douglas, Translog or a quadratic function. In addition, they imposed specific assumptions on the error term. In contrast, the DEA approach measures the efficiency by using Linear programming techniques. Therefore, it requires specific orientation and returns to scale assumptions instead of assumptions about the functional form and the error terms. On the other hand, regardless of the estimation method used, the mean technical efficiency of aquaculture in the above studies varied from more than 50 percent to 91 percent, except the cases of Malaysia, Malawi, and especially Vietnam. The fish and shrimp farming seemed to be more efficient, except Vietnam. Hence, this is why in this study the technical efficiency of improved extensive shrimp farming in the Southern part of Vietnam is re-estimated in two districts in Ca Mau Province. One most important finding of the studies presented was that human capital such as age, education, experience, and extension contacts affect the technical efficiency and, thus the productivity. Based on these findings, one of the objectives of this thesis is also to test whether some of those characteristics have an effect on the technical efficiency of shrimp poly-culture farms in the study area. Further, some of the presented studies used the stocking density and regional variables as inputs in measuring the efficiency or for forming the production frontier. However, the relationship between stocking density, ecosystem variable and technical efficiency has not been explored in regard to the technical efficiency of aquaculture. Therefore, this study targets to test whether the differences in shrimp and mud crab stocking densities and the production environment in Cai Nuoc or Dam Doi ponds have any effect on the technical efficiency of shrimp poly-culture farms in the study area.

Chapter 4: Research methodology

4.1. Data collection

4.1.1. Primary data

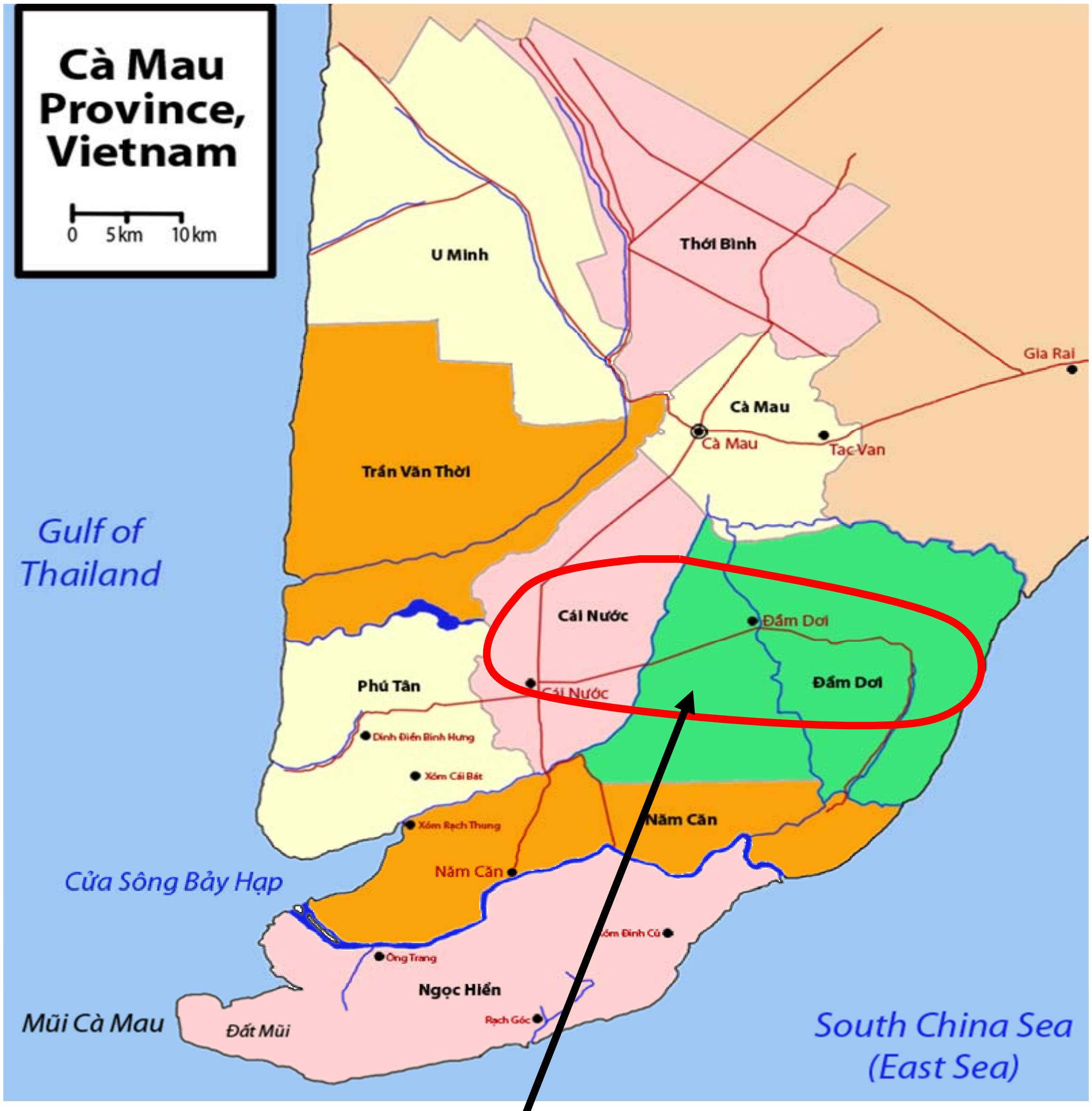


Figure 6: Location of the study area in Ca Mau Province

Source:http://upload.wikimedia.org/wikipedia/commons/f/f1/Ca_mau_province_map.sm.png

The study area Ca Mau Province is situated in the West of Southern of Vietnam. The aquaculture area in two districts Dam Doi and Cai Nuoc of Ca Mau province accounted for 33.2% of total aquaculture. With a questionnaire basic aquaculture information from improved extensive shrimp farming in the area was collected. Shrimp culture combined with mud crab is produced widely in both districts. Though, the aquaculture area in two districts increased slightly from 2002 to 2008, the aquaculture production was unstable. Hence, Dam Doi and Cai Nuoc were chosen as primary sampling areas. Further, factors influencing the technical efficiency were identified and key inputs and outputs variables from this model were determined in this stage of the research.

A questionnaire was designed and pre-tested with 20 households in both Dam Doi and Cai Nuoc districts in the end of December, 2009 to check how well it suited our purpose. The information sought in questionnaire included:

1) household characteristics such as age, gender, education, and the starting year of shrimp farming;

2) the number of labourers involved in shrimp farming;

3) technical information of ponds such as the area of farming, pond preparation cost, the number of shrimps and mud crabs stocked, pond lease, shrimp and mud crab seed cost;

4) the amount of harvest and prices realized with selling of both mud crabs and shrimps produced;

Table 4: Sample size of improved extensive shrimp farming household survey

Study area	**Communes**	**Samples size**	**Total**
	Tan Dan	7	48
Dam Doi district	Tan Duyet	21	
	Tan Thuan	20	
	Phu Hung	15	44
Cai Nuoc district	Phu My	11	
	Tan Hung	18	
Total	**6**	**92**	**92**

The data collection was carried out from with direct interviews of 92 improved extensive shrimp farmers randomly in six communes via Tan Dan, Tan Duyet and Tan Thuan communes of Dam Doi district and Phu Hung, Phu My, Tan Hung communes in Cai Nuoc district, Ca Mau Province (Table 4). Of which, 48 questionnaires collected in three communes in Dam Doi district and 44 questionnaires from 3 three communes in Cai Nuoc district. For the analysis, the whole samples from the survey was used.

4.1.2. Secondary data

Further information of this study was collected from the Ca Mau Statistic Department, the Research Institute for Aquaculture No. 2, the Southern Economic and Planning Department, the Minh Hai Sub Fisheries Research Institute as well as from scientific journals, research reports and text books relevant to efficiency analysis and production of aquaculture.

4.2. Data analysis

In this thesis, the data collected via the survey were analyzed following three steps:
- First, a statistic description of the observations is presented.
- Secondly, the Data Envelopment Analysis (DEA) approach was used to measure the technical efficiency at farm level.
- Thirdly, the significance of factors affecting the technical efficiency of improved extensive shrimp farming were investigated by using the Ordinary Least Square method.

4.2.1. Descriptive statistic analysis

4.2.1.1 Technical efficiency

Based on the studies of Debreu (1951) and Koopmans (1951), Farrell (1957) was the first person to report the new method to study technical efficiency that eventually led to the development of DEA. He used a simple model with a single output and two inputs under a constant return to scale. Farrell (1957) concluded that locative efficiency and technical efficiency are two main factors of the total efficiency. The technical efficiency refers to the production of a maximum of output from a minimum of inputs with a given technology. Allocative efficiency reflects the ability of a firm to use the inputs or produce the outputs in optimal proportions, given their respective prices and the production technology. Technical efficiency and allocative efficiency is combined to provide a measure of total economic efficiency. Thus, to obtain economic efficiency, one cannot avoid studying technical efficiency and it can be considered as an integral tool. In terms of efficiency there are two approaches: input orientation or output orientation. The result of input-orientated efficiency is that it finds out a projected point and produces a given level of output from an optimal combination of inputs or maximizing the proportion reduction in inputs and output orientated efficiency finds out a projected point that produces the optimal output from a given set of inputs or maximizes the proportional augmentation in outputs.

4.2.1.2 Input-oriented measure

Input-oriented technical efficiency answers the question: "Without changing the output quantities produced, how much can input quantities be proportionally reduced?".

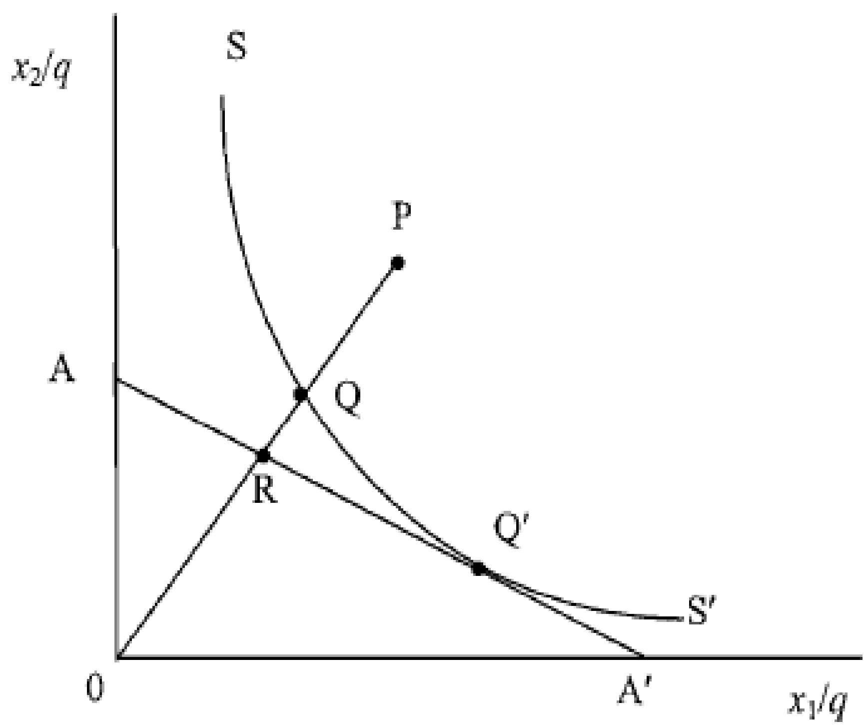


Figure 7: Input orientated measures two inputs x_1, x_2 and a single output q

Sources: Coelli at el, 1998

Figure 7 shows the input-oriented efficiency by using a simple model with two inputs x_1, x_2 and a single output q. The curve SS' represents the technically efficient production of a firm. Thus, two points Q and Q' are technically efficient. Meanwhile, point P is technically inefficient and OQ/OP presented an inefficiency of a firm when OQ/OP < 1. This means that the firm should decrease the use of both inputs from P to Q without the reduction in output. In other words, in order to obtain technical efficient production, the firm needs to reduce all inputs proportionally by QP/OP. The technical efficiency (TE) of a firm is most commonly measured by the ratio:

$$\mathbf{TE_I = OQ/OP}$$

The technical efficiency value will be between zero and one. A firm is fully technically efficient if its technical efficiency score is equal to one, and vice versa. If the unit costs of inputs are available, AA' represents an iso-cost line. Thus, Q' or R have the same total costs. Nevertheless, the output at point R is lower than at point Q', which is the SS' iso-quant (production frontier) and the intersection between AA' iso-cost. Therefore, point Q' the firm is technical efficient as well as allocative efficient. In addition, the cost efficiency can be estimated by the ratio:

$$\mathbf{CE_I = OR/OP}$$

The allocative efficiency and technical efficiency can also be calculated by using the iso-cost line:

$$\mathbf{AE_I = OR/OQ}$$

$$\mathbf{TE_I = OQ/OP}$$

From these equations, the relation between the technical, allocative and cost efficiency can be explored by:

$$\mathbf{TE_I * AE_I = (OR/OQ)*(OQ/OP) = OR/OP = CE}$$

4.2.1.3 Output-oriented measure

Output-oriented technical efficiency refers- in contrast to the input-oriented efficiency to the question: “Without altering the input quantities used, how much can output quantities be proportionally expanded?” The figure 8 below illustrates this concept using two outputs and only one input.

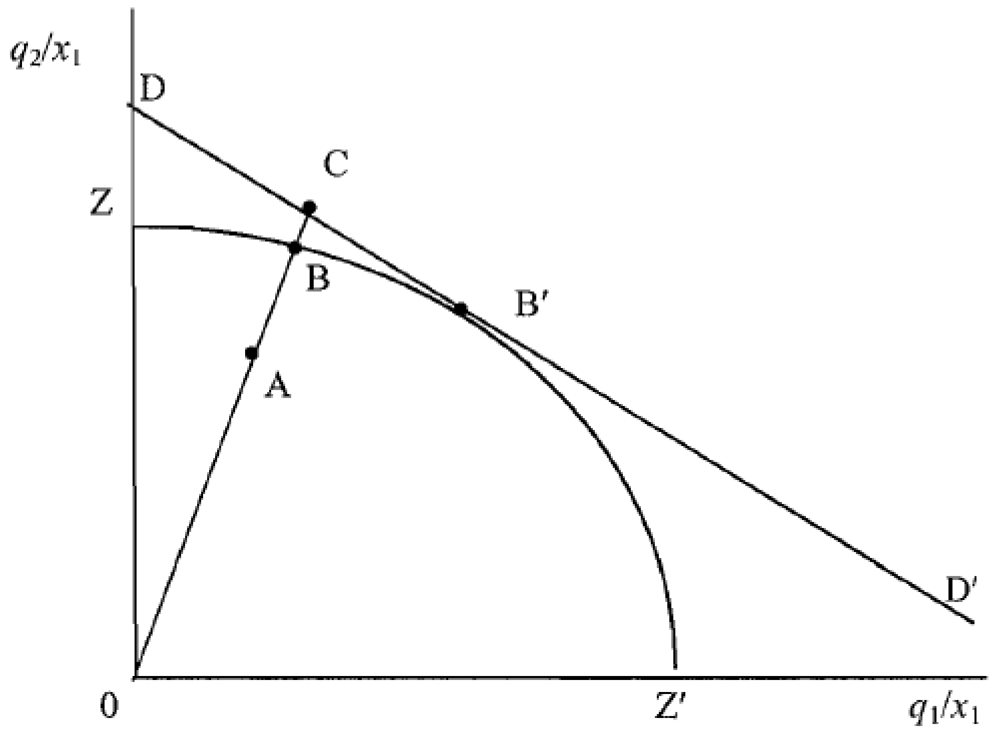


Figure 8: Output-orientated measures

When considering two outputs being produced from a single input, the curve ZZ’ is the unit production possibility curve. Then, the point A corresponds to an efficient production. The distance AB represents technical inefficiency, which is the amount by which the output could be increased without requiring extra input. Hence, a measure of output orientated technical efficiency is the ratio of OA and OB:

$$\mathbf{TE_O = OA/OB}$$

Similar to the input-oriented efficiency, DD' represents the isorevenue line. The intersection between DD' isorevenue line and the ZZ' technical efficient curve B', is said to be revenue efficient. Thus, the revenue efficiency can be determined as the ratio:

$$\mathbf{RE_O = OA/OC}$$

Then allocative efficiency and technical efficiency can also be calculated by the ratio:

$$\mathbf{AE_O = OB/OC}$$

$$\mathbf{TE_O = OA/OB}$$

The relation amongst allocative, technical and cost efficiency can be defined as:

$$\mathbf{TE_O * AE_O = (OA/OB)*(OB/OC) = OA/OC = RE}$$

Generally, the level of technical efficiency of a firm can be defined as the relationship between the observed production and the best practice production. A firm is technical efficient if its production point is on the frontier. On the other hand, it is technical inefficient if the production point of that firm lies below the frontier.

4.2.1.4. Measurements of efficiency

According to Banker (1984), Cooper, Charnes and Rhodes (1978) and the special study of Farrell (1957) research on technical efficiency in production has devolved from a non-frontier approach to a frontier approach. In which, the technical efficiency has measured by non-frontier comparative with the standard frontier and the actual output which is estimated from the experimental data. Thus, although one can be separated and examine, the interaction between non-conventional inputs and conventional by the farmer, often not efficient to conduct experimental studies. In addition, the real production conditions are not easily replicated under experimental conditions. The later approach describes the maximum output that can be produced from any given combination of inputs by an efficient firm. The two most popular approaches are stochastic frontier analysis and Data Envelopment Analysis (DEA) and DEA is more specific in multi output analysis.

4.2.1.5 Stochastic Production Frontier (SPF)

Stochastic production frontier (SPF) analysis is an econometric and parametric approach. It constructs a production function based on "average" values of the observed data. The propitious of this approach takes into account the stochastic variation. which is of importance if outputs are affected by random noise. Nevertheless, this method requires a specific functional form such as a Cobb-Douglas, Translog or quadratic production function. Further, several distributional assumptions need to be made in order to separate the stochastic component from the inefficiency component. It can not be applied to multiple output circumstance. Hence, two outputs production functions can be not applied.

4.2.1.6 Data Envelopment Analysis (DEA)

The descriptive statistic analysis was done in both stages of the thesis and included mean, variance, standard deviation, maximum, minimum and percentages. The main inputs and outputs were used to estimate the technical efficiency and description in the first stage. Further, using the Ordinary least squares the summary of significant characteristics of the shrimp-mud crab culture of farmers were analyzed. The characteristic differences between Dam Doi and Cai Nuoc groups were small. A t-test was done to test whether it is different from zero or not. The t – value to test for significance of difference is estimated by using the formula:

$$t = \frac{(\bar{y}_1 - \bar{y}_2) - (\mu_1 - \mu_2)}{\sqrt{[\frac{(n_1 - 1)s_1^2 + (n_2 - 1)s_2^2}{n_1 + n_2}].(\frac{n_1 + n_2}{n_1.n_2})}}$$

Degree freedom is df = $n_1 + n_2$

Where

$\bar{y}_1$ is the mean value of pond in Dam Doi group

$\bar{y}_2$ is the mean value of pond in Cai Nuoc group

μ_1 is expected value of pond in Dam Doi group

μ_2 is expected value of pond in Cai Nuoc group

s_1^2 is variance of pond in Dam Doi group

s_2^2 is variance of pond in Cai Nuoc group

n_1 observations of pond in Dam Doi group

n_2 observations of pond in Cai Nuoc group

The test statistic includes:

$$\bar{y}_1 - \bar{y}_2 \neq 0$$

$$\min_{\theta,\lambda_j} \theta$$

$$Y\lambda \geq y$$

$$\theta x_i \geq X\lambda$$

1. The null hypothesis is $H0$: $\sum_{i=1}^{N} \lambda_i = 1$ $\quad \bar{y}_1 - \bar{y}_2 = 0$.

$$\lambda_i \geq 0$$

$$\theta$$

$$\leq$$

$$\lambda$$

The alternative hypothesis is $H1$: $\bar{y}_1 - \bar{y}_2 \neq 0$

2. The test statistic $t \sim t\ (n_1 + n_2)$ if the null hypothesis is true

3. The level of significance was chosen as α = 0.05. In a two tails test α/2 = 0.025 of probability is allocated to each tail of the distribution. The critical value is $t_{(0.975,92)} = 1.96$ with $n_1 + n_2 = 92$ degrees of freedom. Therefore, we will reject the null hypothesis in favour of the alternative if $t \geq t_{(0.975,92)}$ or if $t \leq t_{(0.975,92)}$.

In 1978, Charnes et al, constructed the efficient frontier as an envelopment of the data by using Linear programming methods. Farrell (1957) was the first researcher studying to study about the efficiency based on the construction of hypothetical firms as a weighted average of some of observed firms. Then, based on his idea, many researchers analysed the efficiency with the results model called Data Envelopment Analysis (DEA), which is a non-parametric method.

In contrast to the stochastic production approach, Data Envelopment Analysis measures the relative efficiency in the presence of single input-output and multiple inputs and outputs factors at farm level or decision making units (DMUs). When the weights are restricted, efficiency of DMUs could be defined as the ratio of the weighted sum of outputs over the weighted sum of inputs

$$\text{Efficiency} = \frac{\text{Weighted sum ofoutputs}}{\text{Weighted sum of inputs}}$$

Although the basic version of DEA cannot separate the random error due to the deterministic nature from errors due to inefficiency, the huge advantage of DEA approaches is that they can be applied in multi input – multi output situation. Data Envelopment Analysis (DEA) is a non-parametric method. DEA constructs the efficient frontier based on extreme values of the observed data and uses Linear programming techniques to measure the efficiency. Assumption about the distributions of errors or about specific functional forms are not needed to be made. DEA can also identify sources, amounts of inefficiency in each input, output for each farm as well as the benchmark members of the efficient set.

In this thesis the data envelopment analysis method to measure efficiency is chosen over stochastic production frontier approach for three reasons. First of all, data envelopment analysis is able to deal with multi outputs of improved extensive shrimp farming of the sample farms, which can not be dealt with within the stochastic production frontier method. Secondly, it is aimed to avoid assumptions about the functional form or the distribution of errors, which would be necessary in stochastic production frontier. Finally, the Data Envelopment Analysis to measure technical efficiency was used by the researcher before in order to evaluate improved extensive shrimp farming in Ca Mau, Vietnam. Thus, data collection I also used data envelopment analysis two step approach to identify the factors influence technical efficiency results.

4.2.2. Technical efficiency analysis: Data Envelopment Analysis

DEA Method

Charnes, Cooper and Rhodes (CCR) (1978) improved, developed and proposed the Data Envelopment Analysis (DEA) based on the efficiency measurement of the simple model of two inputs and single output under constant return to scale of Farrell's study in 1957.

The DEA method is used to measure the relative efficiency or performance at the farm level and using the Linear programming methods are used to construct a non-parametric piece-wise frontier over the data collection. The comparison between inputs and outputs with the production frontier is calculated. The production point of a Decision Making Unit (DMU) is on the frontier when the efficiency score is equal to one. The production point of a DMU is inside the frontier when the efficiency score is smaller than 1.
Input-orientation or output-orientation can be defined by efficiency. According to Farrell (1957), the technical efficiency based on input-orientation can be addressed with the question: "By how much can inputs be proportionally reduced without changing the output quantities produced?". Meanwhile, output-oriented technical efficiency focuses on maximizing the output quantities and addresses the question: "By how much can outputs be increased proportional without changing the inputs quantities used?".

Charnes et al. (1978) proposed the Charnes, Cooper, and Rhodes (CCR) model to find out radial reduction in input or radial expansion in output based on the restrictions of constant return to scale (CRS), strong disposability[1] of inputs and outputs, and convexity of feasible input-output combinations. Nevertheless, Coelli et al, (1999) mentioned in an introduction to efficiency and productivity analysis, "CRS assumption is only appropriate when all farms are operating at an optimal scale". On the other hand, Banker, in 1984 Charnes and Cooper continued to extend the model by turning to the problem of DEA concepts have developed into four models: CCR (Charnes, Cooper, and Rhodes) returns to scale (Banker, Charnes et al. 1984; Timothy J. Coelli, D.S. Prasada Rao et al. 2005;

[1] Strong disposability of inputs refers to a situation where an increase or un-change in inputs would not lead to a decrease in outputs. On the contrary, weak disposability of inputs is defined if x can produce y, and a proportional increase in inputs which is larger than one, could also produce y (Fare 2000).

Alam and Murshed-e-Jahan 2008; Kiatpathomchai 2008) ratio model, BCC (Banker, Charnes and Cooper) returns to scale model, additive model and multiplicative model (Roland 2003). Whereas other, "a firm to be not operating at optimal scale can be caused by imperfect competition, government regulations, constraints of finance, etc". Improved extensive shrimp farming in Ca Mau Province is characterized by limited resources in regard to infrastructure, canal systems, high quality seeds. Also environmental protection for aquaculture areas, capital, availability of man power for investment limit the production possibilities. The input-oriented DEA approach is suitable to describe the production possibility situation. The input-oriented examination is used to answer the question about the most efficient combinations among the limited inputs that improve the extensive shrimp culture model with unchanged outputs. Thus, to avoid wasting resources several possibilities are available. The inputs can be reduced, the technical efficiency increased, the producing cost reduced or the gross margin from black tiger shrimp mix with mud crab culture at the same pond can be increased. In addition, due to the existence of imperfect competition, limited finance and socioeconomic limitations of household farmers, the majority of shrimp farms in the study area are not operating at optimal scale. Thus, in this study, the VRS, DEA model is a more suitable measure for analyzing the technical efficiency than the CRS.

In the present study, the standard BCC-DEA model (Banker, Charnes and Cooper) under input-oriented approach was used to measure the technical efficiency of improved extensive shrimp culture in this study. A two-stage DEA methodology of efficiency analysis was applied to identify the exogenous factors affecting the farm technical efficiency. First of all, technical efficiency scores were calculated. The results of the first stage were used as dependent variables in the second stage and the technical efficiency scores were regressed against a set of explanatory variables. Tobit is the standard method used in many studies and it was mentioned in literature review above. OLS model has been used in very few studies due to the biased estimates. Therefore, OLS model was chosen instead of Tobit in the present study because the dependent variables are restricted between one and zero, it effects on the regression stage. For this reason, super-efficiency was measured in the first stage and scores were used as dependent variables in OLS regression in the second stage.

Model specification of technical efficiency

Consider n as the improved extensive shrimp farming or decision making units (DMUs), and in the present study n was 92. Every farm uses K inputs to produce M different types of species. The inputs are pond size, labour input, pond preparation cost and total seed cost which vary among each household doing improved extensive shrimp culture in 2009. M outputs are the production of black tiger shrimp and mud crab households harvest in the same year. Inputs and outputs vectors are represented by the vectors x_{it} and y_{it}, respectively, for i-th farm. The data for all firms may be denoted by the KxN input matrix (X) and the MxN output matrix (Y). The envelopment form of the input-oriented VRS DEA model is specified as:

$$\min_{\theta,\lambda_j} \theta$$

Subject to

$$Y\lambda \geq y$$
$$\theta x_i \geq X\lambda$$
$$\sum_{i=1}^{N} \lambda_i = 1$$
$$\lambda_i \geq 0$$

Where θ is the technical efficiency (TE) score having a value ranging from zero to one ($0 \leq \theta \leq 1$), the farm is technically efficient and on the frontier if θ is equal to one. The vector λ is an Nx1 vector of weights (constants) which defines the linear combination of the peers of i-th farm. Y is a vector of output quantities and X is a vector of observed inputs. $-y_i$ is the vector of output of the i-th farm compared to the output vector of the theoretically efficient farm ($Y\lambda$). $X\lambda$ is the minimum input of a theoretically efficient farm, given the actual level of output produced by the i-th farm. x_i is the actual level of inputs of i-th farm. If θ is equal to one, the farm is technically efficient because the level of input of that farm is as small as the quantity of input utilized by the theoretically efficient farm in producing the same level of output. On the contrary, if θ is less than one, the farm is technically inefficient. That farm can still further reduce the level of input used to as low as $X\lambda$ in producing the same level of output.

Super-efficiency

Andersen and Petersen (1993) originally proposed the super-efficiency method and the term of efficiency score larger than one because each firm is not permitted to use itself as a peer. Although one of its drawbacks is unfeasible results of some samples, it is normally used in sensitivity testing, identifying the outliers, Tobit regression (Coelli, et al., 2005) was replaced by OLS regressing in the second stage.

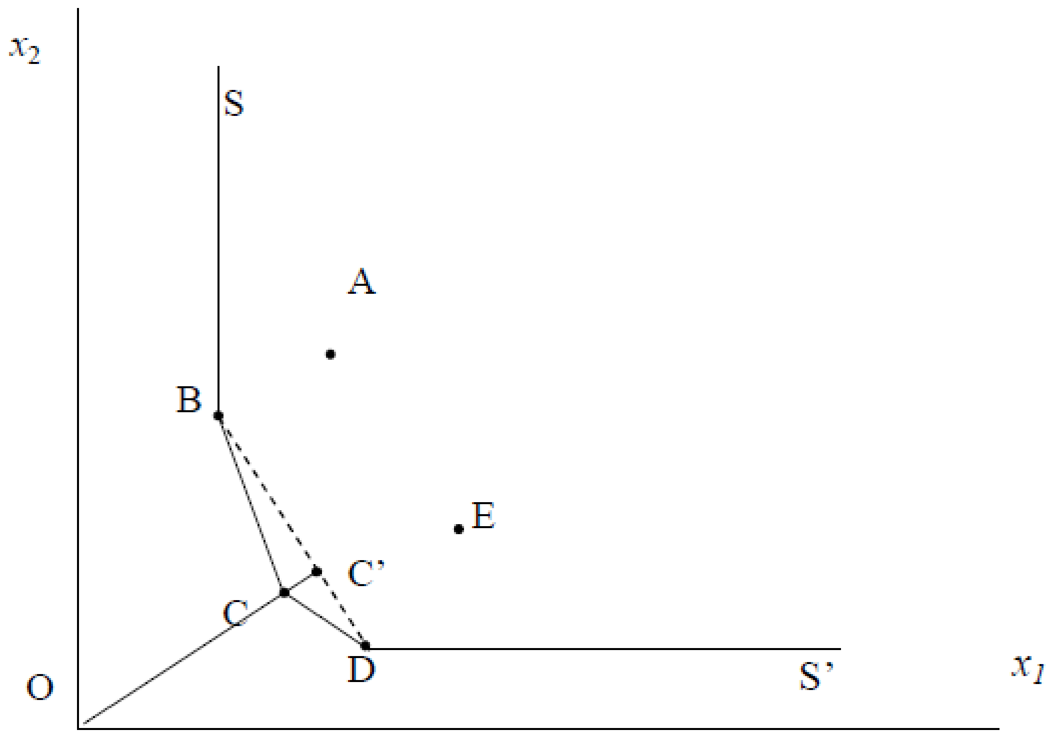


Figure 10: Super-efficiency

Considering the case of using two inputs producing a particular output, if the standard DEA is applied, firms B, C and D are on the frontier and have technical efficiency score equal to one. We also need to take into consideration the case of firm C, if super-efficiency DEA is applied, C itself will no longer form a part of the frontier. Two firms B and D are forming the new frontier. The projected point of C is C'. The super-efficiency score of C is the ratio of OC'/OC. Two firms A and E are inefficient firms and their original technical efficiency scores do not change when the super-efficiency method is used (Coelli et al. 2005).

4.2.3. Ordinary Least Square regression (OLS)

In the first stage technical efficiency scores were measured to identify factors affecting on production of shrimp and mud crab. In the second stage OLS model was used. The first stage index on some discretionary and non-discretionary factors were regressed in this stage. Because the upper limit on the efficiency index from the first stage is 1, OLS regression can produce biased estimates. The solution to this potential problem is to use the Tobit instead of OLS regression or to use super-efficiency scores instead of normal-efficiency for OLS regression in the second stage. The latter method was chosen to solve the above mentioned problem in this thesis. This stage requires an a-priori specification of the functional form. Further a Cobb Douglas model to identify the relationship between super-efficiency and some inputs variables such as education level and age of the operator of improved extensive shrimp farmers was used.

$$\mathbf{SUPEFF = \alpha\ PA^{\beta1}\ EXP^{\beta2}\ SDEN^{\beta3} MDEN^{\beta4}\ EDU^{\beta5}} \qquad (1)$$

Where

SUPEFF: super-efficiency scores were measured in the first stage.

PA: Pond area

EXP: year of operators experience in improved extensive shrimp culture.

SDEN: stocking densities (individual/m^2) of black tiger shrimp culture in 2009

MDEN: stocking densities (individual/m^2) of mud crab culture in 2009

EDU: education level;

From (1) function would be transferred to the following formula:

$$\mathbf{LnSUPEFF = Ln\alpha + \beta_1 LnPA + \beta_2 LnEXP + \beta_3 LnSDEN + \beta_4 LnMDEN + \beta_5 LnEDU}$$

4.2.4. Variables

With the DEA two-stage methodology used in the present study, two groups of inputs and outputs were classified.

a. Used trap net to collect big sized shrimps

b. Pond poly culture (shrimps + mud crabs)

c. Improved extensive shrimp culture in mangroves

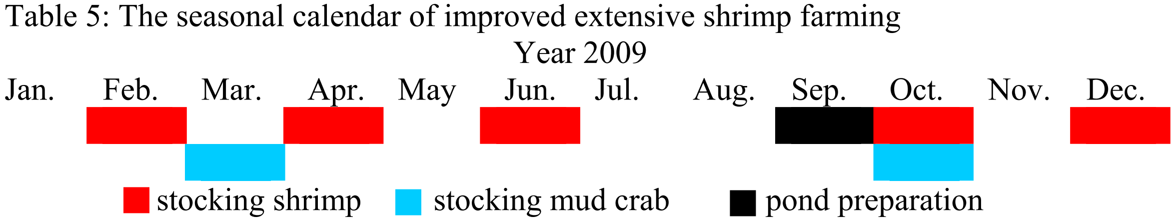
d. Using sluice gate to take out and in water

Mud crab *(Scylla serrata)* species

Black tiger shrimp *(Penaeus monodon)* species

e. Mud crab *(Scylla serrata)* mix with black tiger shrimp *(Penaeus monodon)* culture at the same pond

Table 5: The seasonal calendar of improved extensive shrimp farming



DEA stage

Outputs used in estimating the technical efficiency score were the quantity of two kind of aquatic products including Black tiger shrimp *(Penaeus monodon)* and mud crab *(Scylla serrata)* that were harvested during the 2009 production year and measured in kilogram of each specie.

The results of the interviews show that the giant prawn and mud crab were harvested selectively during the whole year. The harvest of crabs and black tiger shrimps at the same time when owner was done pond preparation.

The inputs used to calculate the technical efficiency score were seeds, labour and pond preparation costs. As seeds, juvenile of *Penaeus monodon* were used. The seeds in the present study were expressed as total juveniles cost of shrimps and mud crabs and it was measured in Vietnamese dongs.

As labourer only household members that were involved working in aquaculture during the whole year were considered. The number of employees was depending on the size of the farm. During the crop time, the family members mainly worked fulltime from the beginning until the end of cropping including maintenance activities and harvesting. The results of the survey indicate that in improved extensive shrimp farming only family members with one to three labourers were engaged- mainly due to the fact that within this culture model no feeding is necessary as only natural feeds are used.

Pond preparation cost is examined one time in year during September when the farmers took mud outside the ditches and clearing trees around the edge of pond. They were following traditional culture and the farmers hired labours from neighbour or used only household labour.

OLS stage

In the first stage the technical super-efficiency scores were estimated, while input variables were not used. We were categorized into three groups such as pond characteristics, farmer characteristics of the shrimp mud crab culture; the juvenile stocking densities;

Pond area characteristics:
+ PA is the pond area of improved extensive shrimp culture.
It was expected to have a positive sign in this study

Farmer characteristics comprising
+ EXP is the number of year farmers had experiences in poly culture.
+ EDU is the education level of farmers.
In this study, the two variables have a positive relationship with super-efficiency.

Stocking density
+ SDEN refers to giant prawn stocking density measured in unit per square meter.
+ MDEN refers to mud crab stocking density measured in unit per square meter.
Those two variables were expected to have no effects on super-efficiency in this study.

Chapter 5: Results and Discussion

5.1. Results

5.1.1. Technical efficiency analysis

5.1.1.1. Data set of technical efficiency analysis

Table 6 shows the efficiency analysis at pond level per hectare on the basis of the variables from Dam Doi and Cai Nuoc district in 2009. In general, improved extensive shrimp farmers in Cai Nuoc district used fewer inputs but produced an output of black tiger shrimp of 131 kg per hectare, whereby the tiger shrimp output in Dam Doi district was 95 kg per hectare. The mud crab output was nearly the same in both districts.

The Table 6 indicates that on average the 2,18 mill.vnd juveniles cost were spent per hectare in improved extensive shrimp culture production. The ranges of this inputs variable were from 55,000 VND to 10,50 mill.vnd. The farmers in Cai Nuoc District spent 2,17 mill.vnd per hectare on black tiger shrimp and mud crab juveniles, while shrimp farmers in Dam Doi district spent 2,2 mill.vnd for seeds. Therefore, total seed cost in Dam Doi District were a little higher than in Cai Nuoc District.

Table 6: Descriptive statistics of the sample variables per hectare

	All improved extensive shrimp farming				**Cai Nuoc**		**Dam Doi**	
	Mean	**S.D**	**Min**	**Max**	**Mean**	**S.D**	**Mean**	**S.D**
Output/ha								
Shrimp (kg/ha)	112.5	115.4	4.7	550	131.1	140.8	95.4	83.8
Mud crab(kg/ha)	42.5	41.5	1.7	271	43.0	38.1	42.1	44.9
Input/ha								
Family labour involved in poly culture (labour/ha)	1.2	0.6	0.5	3.3	1.3	0.7	1.1	0.5
pond preparation costs (mill.vnd/ha)	2,34	1,66	0,23	10,00	1,85	1,35	2,79	1,80
Total seed costs (mill.vnd/ha)	2,18	1,68	0,05	10,50	2,17	1,76	2,20	1,63

The results also proved that the average costs for pond preparation per hectare was 2,3 mill.vnd with a minimum of 230,769 VND and a maximum of 10 mill.vnd. The pond clearing costs in Cai Nuoc were less than in Dam Doi District. Similarly, the average labourer employed were 1.2 in Cai Nuoc District and 1.3 Dam Doi District. The average outputs per hectare of all farms were more than 112 kg/ha of giant prawns and 42 kg/ha of mud crabs. The quantity of black tiger shrimp range from 4.7 kg/ha to 550 kg/ha and of mud crab from 1.7 to 271 kg/ha.

5.1.1.2. Technical efficiency results

Looking at the average technical efficiency of Table 7 below it can be shown that the mean technical efficiency scores of whole shrimp farming sampling and it also was divided into pond groups of Cai Nuoc and Dam Doi districts.

Table 7: Average technical efficiency scores

			Efficiency farms			
		Mean	**No. farms**	**Percentage (percent)**	**Min**	**S.D**
Total	CRSTE	0.36	7	7.61	0.02	0.30
	VRSTE	0.67	16	17.39	0.25	0.24
	SCALE	0.51	7	7.61	0.06	0.32
Cai Nuoc	CRSTE	0.50	8	18.18	0.10	0.31
	VRSTE	0.81	15	34.09	0.37	0.19
	SCALE	0.60	8	18.18	0.15	0.30
Dam Doi	CRSTE	0.40	6	12.50	0.02	0.31
	VRSTE	0.68	12	25.00	0.25	0.25
	SCALE	0.54	6	12.50	0.06	0.30

Table 7 shows that the constant return to scale technical efficiency (CRSTE) was 7 out of 92 samples representing 7.6 percent of the sample. The estimated technical efficiency under constant return to scale (CRS) efficiency ranged from 0.02 to 1, while variable return to scale technical efficiency (VRSTE) ranged from 0.37 to 1. The mean CRS technical efficiency of the total samples was 0.36. 0.5 or about 18 percent in Cai Nuoc District and 0.4 or 12.5 percent in Dam Doi District. Nevertheless, the minimum score of both districts were the same (0.02).

The results indicate that VRS technically efficient were 16 out of 92 shrimp farms, representing 17 percent of the whole sample. The technical efficiency under VRS ranged from 0.25 to 1, with the mean measure of 0.67. The VRS efficient farms in Cai Nuoc were 15 farms (34 percent) and 12 shrimp farms (25 percent) were in Dam Doi district. The range of VRS technical efficiency of pond in Cai Nuoc district ranged from 0.37 to 1 and was also larger than that of pond in Dam Doi district ranged from 0.25 to 1. Similarly, the mean value of technical efficiency score under VRS was higher in Cai Nuoc farms than in Dam Doi farms with 0.81 and 0.68, respectively.

The difference between VRS and CRS technical efficiency indicates the existence of scale inefficiency in the sample farms. The mean scale efficiency score of total farms in both areas was 0.51 or 7.6 percent. There were 85 scale inefficient farms in the whole samples size. Although the number of scale efficient farms in Cai Nuoc district amounted for 0.6 or 18.18 percent which was higher than in Dam Doi district (0.54 or 12.5 percent).

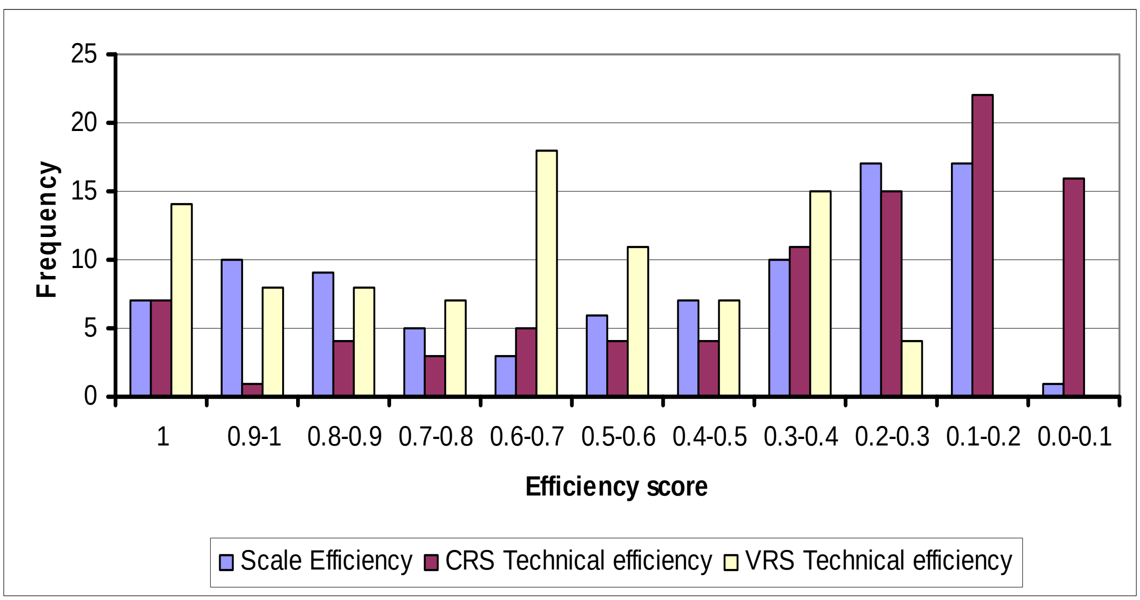


Figure 9: Frequency distribution of technical efficiency

The Figure 9 describes the frequency distribution of estimated technical efficiency scores under scale efficiency (SC), constant return to scale (CRS) and variable return to scale (VRS) scores. 14 percent of the sample shrimp farms had a score of 1 for VRS. The same percentage of farms (6 percent) had the CRS technically efficient and scale efficient score of 1. There was about 5 percent of the samples that had pure technical efficiency score from 0.4 to 0.5. Nevertheless, no farms had VRS technical efficiency scores lower than 0.2. Variable return to scale (VRS) technical efficiency scores were about 18 percent and 5 percent constant return to scale (CRS) technical efficiency. However, there was only 3 percent scale efficiency (SC) technical efficiency.

Table 8: The results of return to scale and mean value of production

Return to scale	Group	Efficient Farms No	percent	Production (kg/ha)
	All	16	17.39	342
	Cai Nuoc	7	15.91	324
CRS	Dam Doi	6	12.50	276
	All	3	3.26	462
	Cai Nuoc	5	11.36	339
DRS	Dam Doi	6	12.50	292
	All	73	79.35	136
	Cai Nuoc	32	72.73	109
IRS	Dam Doi	36	75.00	106

Table 8 revealed that most of the farms had increased returns of scale. 73 farms out of 92 farms produced only 136 kg/ha. Therefore, farmers need to increase the inputs to obtain optimum outputs. In addition, 16 shrimp framings amounted for 17 percent of constant return to scale and produced 342 kg/ha of total outputs. Nevertheless, only three farms or 3 percent had decreasing returns of scale and produced 462 kg per one hectare of pond. In this case, the farms could reduce inputs.

Similarly, at the results examined that constant return to scale of shrimp farming in Cai Nuoc district was higher than for the farms in Dam Doi district. The farming in Cai Nuoc district should decrease return to scale less than in Dam Doi district and increases return to scale of improved extensive shrimp farming also were less than in Dam Doi district (Table 8).

5.1.2. Factors affecting the technical efficiency of improved extensive shrimp farms

5.1.2.1. Descriptive statistic of variables used in OLS stage

OLS regression was applied to identify the relationship between technical super-efficiency and some main factors which were grouped into three categories: Pond area characteristics, farmers' education and experiences (EDU, EXP), black tiger shrimp and mud crab stocking density (SDEN, MDEN). The mean values of independent variables of Cai Nuoc's pond groups were higher than Dam Doi's pond groups (Table 9), except for shrimp stocking density which is similar in both districts, while Super-efficiency (SUPEFF) of improved extensive shrimp farms in Cai Nuoc was larger than that of Dam Doi's pond farms.

Table 9: Mean value and standard deviations of variables used in the OLS regression

Variable	All shrimp farming (n=92)		Cai Nuoc district (n=44)		Dam Doi district (n=48)		P-value
	Mean	S.D	Mean	S.D	Mean	S.D	
DEPENDENT VARIABLE							
SUPEFF	0.41	0.49	0.60	0.53	0.50	0.63	0.0000
INDEPENDENT VARIABLE							
Pond area							
PA	2.4	2.3	2.5	3.0	2.3	1.3	**0.0141****
Farmer's experiences in shrimp culture							
EXP	11	4	9	2	12	5	**0.0000*****
Stocking density							
SDEN	1.3	0.9	1.3	0.9	1.3	0.9	0.4179
MDEN	0.10	0.09	0.1	0.1	0.1	0.1	0.9235
Farmer's education							
EDU	1.5	0.5	1.5	0.5	1.5	0.5	**0.0002*****

Notes: ***Significant at 1 percent ** Significant at 5 percent * Significant at 10 percent

On average, owners were involved in poly culture shrimp farming for 11 years. Shrimp farmers in Cai Nuoc District had nine years of experiences, while farmers in Dam Doi district had 12 years of experience. Average years of education is similar in both districts with 1.5 year. The stocking density of shrimps and mud crabs differs in both districts with 1.3 and 0.1 species/m^2 respectively. The p-value results have tested different mean values from zero among two districts groups. The results also indicate that the value of test statistics of pond area, farmers experiences, and education variable were less than the critical value ($0.05<p<0.1$ significant at 10 percent; $0.01<p<0.05$ significant at 5 percent; $0.00<p<0.001$ significant at 1 percent). The null hypothesis of farmers in Cai Nuoc and Dam Doi districts were rejected because there was no difference in both districts. Shrimp and mud crab stoking density had no significant effect in both districts.

5.1.2.2. OLS results

The Cobb Douglas model in OLS regression was used to estimate every parameter (Table 8). Each individual coefficient of explanatory variables has been different with respect to districts (Cai Nuoc or Dam Doi).

The coefficients show the percentage of change in the independent variables caused by changing percentages of the dependent variables. The positive coefficients mention that an increase of super-efficiency techniques of improved extensive shrimp farming is caused by an increase in such variables. Negative coefficients express that an increase in those variables would lead to a decrease in technical super-efficiency of shrimp farming.

All improved extensive shrimp farming

The results presented in Table 10 show that 51.62 percent of the variation in technical super-efficiency can be explained by the variation in pond area, farmer characteristics, shrimp and mud crab stocking density and the level of farmers' education. In addition, the education and experiences of operators working in improved extensive shrimp farmers were significant factors at the one percent level and affect the technical efficiency. The pond area had a statistically significant positive effect on the technical super-efficiency at the five percent level. However, the stocking density of the black tiger shrimps and mud crabs had not explanatory effect on the technical super-efficiency.

On the other hand, LnPA (Pond area), LnEXP (experience of the farmers), and LnEDU (farmers education) had a positive relationship with technical super-efficiency. In contrast, LnSDEN and LnMDEN (stocking density of black tiger shrimp and mud crab) had a negative relationship with technical super-efficiency.

Table 10: Parameter estimate values of the determinants for samples of shrimp farming

Explanatory variable	**All shrimp farming**			**Cai Nuoc district**			**Dam Doi district**		
	(n=92)			**(n=44)**			**(n=48)**		
	Coeff	Std.	P-value	Coeff	Std.	P-value	Coeff	Std.	P-value
Constant	-5.07	0.60	0.0000	-4.82	0.71	0.0000	-4.89	0.89	0.0000
Pond area									
LnPA	0.31	0.12	0.0141**	0.27	0.13	0.0476**	0.39	0.22	0.0878*
Farmer's experiences in shrimp culture									
LnEXP	1.59	0.28	0.0000***	1.48	0.35	0.0001***	1.39	0.40	0.0013***
Stocking density									
LnSDEN	-0.10	0.13	0.4179	0.01	0.14	0.9690	-0.43	0.23	0.0693*
LnMDEN	-0.01	0.08	0.9235	0.03	0.11	0.8102	0.02	0.13	0.8756
Farmer's education									
LnEDU	0.82	0.21	0.0002***	1.09	0.26	0.0002***	1.09	0.32	0.0014***
R squared	0.5162			0.6666			0.5491		

Notes: ***Significant at 1 percent ** Significant at 5 percent * Significant at 10 percent

Improved extensive shrimp farming in Cai Nuoc district

Based on results presented in Table 10, the pond area variables had a significant effect (5percent) on (P_{PA} = 0,0476>0.01) on technical super-efficiency. Moreover, farmer experiences and education of farmers in Cai Nuoc district had a significant effect on the super-efficiency on a one percent level with P_{EXP} = 0.0001<0.01 and P_{EDU} = 0.0002<0.01 respectively. Further, it is shown that, besides technical considerations, also knowledge and awareness of farmers doing poly culture shrimp farms need to be taken into consideration. However, the stocking density of shrimp and mud crab had no statistically significant effect on the technical super-efficiency for shrimp farming in Cai Nuoc district, which means that there were in total two variables that are not effecting the technical super efficiency.

Improved extensive shrimp farming in Dam Doi district

The pond area and shrimp stocking density variables had on a 10% level, with P_{PA} = 0.0878>0.05 and P_{SDEN} = 0.0693>0.05 respectively and these variables have a significant effect on technical super-efficiency. Like in Cai Nuoc, experiences and education level of farmers had statistical effects at the one percent level (P_{EXP} and P_{EDU} <0.01), while mud crabs stocking density had no effects on technical super-efficiency (Table 10).

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For pond groups in Dam Doi, the experience, education, pond area and the stocking density of shrimps had a statistically positive relationship with the technical super-efficiency. In contrast, stocking density of mud crabs impacted negatively on the technical super-efficiency.

5.2. Discussion

First of all, looking at (Table 7), it must be mentioned that the mean technical efficiency of the total sample under constant return to scale was 36 percent. This means, for obtaining an optimal scale without changing the current level of outputs, those farms had to decrease 64 percent of all inputs. The difference between CRS and VRS technical efficiency scores shows that the CRS technical inefficiency is caused by scale inefficiency as a main factor. In addition, scale inefficiency includes 51 percent of the total sample and indicates that those farms should upgrade the size of shrimp farming to improve their productivity.

Table 7 reveals that the mean technical efficiency of improved extensive shrimp farming under VRS was estimated 67 percent. This means that inputs were used inefficiently by shrimp farm operators in 23 percent of all farms. Thus, to produce the current level of outputs, farmers, in both districts could decrease the current level of inputs by 23 percent. This result is lower if we compare with findings in extensive shrimp farms in Thailand, where the mean technical efficiency reach 72 percent and 91 percent in poly culture (prawn mix with rabbit fish and crab in Tamgiang lagoon reported by Au (2008)). However, this result is higher compared with 42 percent of average technical efficiency estimated by Dey et al. (2005) in extensive freshwater poly-culture pond in Vietnam. It should be noticed that the results of this thesis can be only used particularly to data collected in Cai Nuoc and Dam Doi districts. It may be representative for improved extensive shrimp farming in whole Ca Mau Province of Vietnam.

Second to the comparison of the mean technical efficiency between the two districts (Table 7) shows that the under constant return to scale of pond in Cai Nuoc district was higher in Cai Nuoc (50 percent) than in Dam Doi (40 percent) district. When producing at optimal scale without changing the current level of outputs, the farms in Cai Nuoc have to decrease all inputs by 19 percent, while Dam Doi shrimp farmers have must to reduce their inputs by 32 percent. Moreover, scale efficiency in Dam Doi's farms was lower compare to Cai Nuoc's farms, indicating that the improved extensive shrimp farms in Dam Doi need to expand the size of shrimp farming more than the Cai Nuoc shrimp farming. Because, farmers in Cai Nuoc had experience in improved extensive shrimp culture and pond scale was also larger than farmer and pond scale in Dam Doi district. However, based on coefficient results about scale efficiency of both district which gives indication of farmers that were reliable with shrimp farming, scale in bith the districts need to expand more to improve productivity, not only productivity of black tiger shrimp but also mud crab in poly culture model. The individual analysis reveals that the Cai Nuoc's pond group used the combination of inputs less inefficiently than improved extensive shrimp farming in Dam Doi District because they selected good shrimp seed and good pond condition.

The analysis of each individual improved extensive shrimp farm revealed that CRS shrimp farming were expected to expand 17 percent of optimal scales and IRS farms have to expand about 73 percent of their operating scale to improve shrimp and mud crab productivities. In regard to the IRS farms, farmers were expected to harvest one percent of outputs production if their farms have to increase by one percent of input levels. For 16 CRS of improved extensive shrimp farms, an increase of any k percent in input levels will lead to an increase of outputs by k percent. However, total poly culture farming accounting for 3.26 percent should not need to increase their scale because their outputs were only expanded less than 1 percent (Table 8).

It can be seen, Table 10 proved that a one percent increases in pond area would lead to a significant ($P<0.05$) increased in technical super-efficiency of improved extensive shrimp farming, with a coefficient of 22,6 percent. Similarly, 7 percent in Cai Nuoc and 87 percent in Dam Doi increased in technical super-efficiency, correlates with a one percent increase in pond area of shrimp farming in both districts.

Concerning the variable "Farmers Experience", the coefficient were positive for both districts (73,1 percent in Cai Nuoc and 65 percent in Dam Doi) and for the entire sample (19,5 percent). This means that a one percent increase in technical super-efficiency comes with a one percent increase in experiences of farmers. Nevertheless, the coefficient of the variable "stocking density" of improved extensive shrimp farming in Dam Doi district is negative. Thus, stocking density of black tiger shrimp is a main factor influencing the technical efficiency. It reveal that a one percent increase in shrimp stocking density would lead to a reduction of 58,5 percent in technical efficiency. This means to get a high efficiency a lower stoking density of giant shrimp is necessary, because limited food from natural and farmer no feeding for shrimp, mud crab culture and this variable had a specially effect on the technical efficiency score of ponds in Dam Doi district. Because, improved extensive shrimp farming were not feed for shrimp and mud crab. Feed came from nature when they exchange water. Further, a one percent increase in shrimp density would lead to a 59 percent increase in technical super-efficiency.

Finally, it must be noticed that farmers' education had a positive effect on the giant shrimp mix with mud crab culture production with a higher level of technical efficiency. The results show that a 76,1 percent increase in technical super-efficiency is associated with a one percent increase in farmers' education. These scores of coefficients in Cai Nuoc and Dam Doi districts were also giving a positive effect on the in technical super-efficiency 93,5 percent and 74,1 percent respectively. These results imply that most of the farms should increase the pond area, their experiences and education to improve their technical efficiency. The slack of inputs will be an interested topic for further studies.

Chapter 6: Conclusion and recommendations

6.1 Conclusion

This thesis specified a two-stage data envelopment analysis to estimate the technical efficiency of Black tiger shrimp (*Penaeus monodon*) mixed culture with mud crab *(Scylla serrata)* in Cai Nuoc and Dam Doi districts Ca Mau province, Vietnam. In this study the technical super-efficiency scores of character of pond area, farmer's experiences and education, black tiger shrimp and mud crab stocking density was estimated.

A comparison of the technical efficiency of improved extensive shrimp farming between three communes in Cai Nuoc and three communes in Dam Doi districts was presented. The results of first stage examined that scale inefficiency led to the technical inefficiency of shrimp mix with mud crab culture in both districts.

Farmers in Dam Doi District that would like to improve technical efficiency of improved extensive shrimp farming should expand the ponds' scale and decrease the stocking density of shrimps. In addition, a mean technical efficiency of improved extensive shrimp farming in Cai Nuoc were 81 percent more efficient than a mean of 68 percent of Dam Doi's farming

The results of the analysis using Cobb-Douglas function in OLS regression showed that about 52 percent of the variance in technical super-efficiency was explained by the variance in pond area character, farmers experience, stocking density and operator education. The variance in technical super-efficiency including pond area, experience and education of farmers had positive sign. An exception was the stocking density of Black tiger shrimp in Dam Doi's shrimp farming which had a negative impact on technical efficiency.

The elasticity of technical super-efficiency with respect to all variables were statistical significant for both districts. The results also indicate a statistical significant positive relationship between technical super-efficiency and pond area characteristics, farmers' experiences and education of improved extensive shrimp farming in Cai Nuoc and Dam Doi District. Meanwhile, only giant prawn stocking density was found to have a statistically significant negative effect on the technical super-efficiency of Dam Doi farms and a positive one in Cai Nuoc farms. Because shrimp farmer in Dam Doi district lacked experiences and knowledge in improved extensive shrimp culture. In addition, this area were just diversified from rice cultivation to shrimp culture.

6.2 Recommendations

Based on the results presented in this thesis a contribution to evaluation of improved extensive shrimp farming of Cai Nuoc and Dam Doi districts in Ca Mau Province was made. The outcome of analyses of shrimp poly culture showed that there was a higher level of mean technical efficiency in Cai Nuoc district than in Dam Doi district. In addition, the results suggest that improved extensive shrimp farming should be applied not just in these districts but throughout Ca Mau province to improve technical efficiency. However, shrimp stocking densities should be reduced in shrimp poly culture in Dam Doi district. Local government offices should run training courses on the technical aspects of shrimp poly culture to improve the efficiency of poly culture production. In addition, the determinant analysis has shown that experience, education and pond area have a particularly significant positive impact on technical efficiency. It is thus suggested that local government organize training courses for shrimp poly culture techniques and support the extension officers in frequently visiting and supporting farmers to improve their awareness and solving their technical problems. Moreover, the government should give projects to Non Government Organization (NGOs) that provide funding to these areas and that establish farmers' organizations within the whole province. The purpose of this strategy is to help shrimp poly culture farmers engaging in co-management activities with support from local officers that conduct aquaculture training courses in order to increases the overall productivity.

Appendix

Appendix 1: Frequency distribution of technical efficiency

Year	Aquaculture area (ha)	Aquaculture Households (household)	Aquaculture production (tonnes)	Shrimp production (tonnes)	Other production (tonnes)	Total value mill.dongs
2000	204381	221961	63917	35377	28540	3071724
2001	254191	226401	84279	55330	28949	4537024
2002	270851	230841	82546	60619	21927	5189436
2003	277688	236289	85722	62241	23481	5304652
2004	277705	245068	96445	72936	23509	6708591
2005	278241	255479	112630	81100	31530	7383644
2006	275195	257882	128973	88443	40530	8342623
2007	290749	261499	140267	89737	50530	9227459
2008	293223	264376	164866	94291	70575	9795435

Appendix 2: Descriptive statistics of the sample variables per hectare

	All improved extensive shrimp farming				**Cai Nuoc**		**Dam Doi**	
	Mean	**S.D**	**Min**	**Max**	**Mean**	**S.D**	**Mean**	**S.D**
Output/ha								
Shrimp (kg/ha)	112.5	115.4	4.7	550	131.1	140.8	95.4	83.8
Mud crab(kg/ha)	42.5	41.5	1.7	271	43.0	38.1	42.1	44.9
Input/ha								
Family member involved in poly culture (labour/ha)	1.2	0.6	0.5	3.3	1.3	0.7	1.1	0.5
pond preparation costs (mill.vnd/ha)	2,34	1,66	0,23	10,00	1,85	1,35	2,79	1,80
Total seed costs (mill.vnd/ha)	2,18	1,68	0,05	10,50	2,17	1,76	2,20	1,63

Appendix 3: Frequency distribution of technical efficiency

Score	Scale Efficiency	CRS Technical efficiency	VRS Technical efficiency
1	7	7	14
0.9-1	10	1	8
0.8-0.9	9	4	8
0.7-0.8	5	3	7
0.6-0.7	3	5	18
0.5-0.6	6	4	11
0.4-0.5	7	4	7
0.3-0.4	10	11	15
0.2-0.3	17	15	4
0.1-0.2	17	22	
0.0-0.1	1	16	

Appendix 4: Results from the Super Efficiency DEA models

Inputs	**Outputs**
Family involed poly culture (labour/ha)	Shrimp (kg/ha)
pond preparation cost (vnd/ha)	Mud crab (kg/ha)
Total seed cost (vnd/ha)	

DMU No.	***DMU Name***	***Input-Oriented CRS Super Efficiency***	Optimal Lambdas with Benchmarks							
1	Ut	0.57849	0.312	Quy	0.001	Mui	0.023	Tung	0.363	Quan
2	Tuyet	0.15385	0.142	Quan						
3	Muoi	0.08373	0.015	Quy	0.007	Tung	0.046	Quan		
4	Nhon	0.29332	0.652	Dung	0.005	Mui	0.413	Quan		
5	Danh	0.21129	0.169	Dung	0.074	Quan				
6	Nghiem	0.30389	0.083	Sau	0.001	Dung	0.127	Quan		
7	Phuong	0.39179	0.805	Dung	0.250	Quan				
8	Mau	0.09379	0.016	Sau	0.013	Dung	0.018	Quan		
9	Tot	0.21257	0.052	Sau	0.083	Dung	0.018	Mui	0.001	Quan
10	Hoi	0.19681	0.052	Sau	0.024	Quy				
11	Mui	0.16841	0.148	Dung	0.008	Quan				
12	Han	0.63576	0.060	Sau	0.974	Dung				
13	Khanh	0.66958	0.224	Sau	0.157	Quy	0.550	Ly		
14	Sau	1.20162	0.123	Quy	0.223	Dung	2.764	Ly		
15	Dieu	0.10823	0.004	Sau	0.016	Dung	0.049	Quan		
16	Tuoi	0.15532	0.090	Dung	0.063	Quan				
17	May	0.13007	0.047	Dung	0.050	Quan				
18	Go	0.24478	0.090	Dung	0.129	Quan				
19	Kiet	0.11983	0.045	Dung	0.051	Quan				
20	Cot	0.80194	0.300	Dung	0.430	Quan				
21	Loc	0.22794	0.028	Quy	0.009	Mui	0.012	Tung	0.255	Ly
22	Hoa	0.09893	0.025	Sau	0.022	Dung	0.037	Quan		
23	lap	0.09968	0.043	Sau	0.019	Dung	0.070	Quan		
24	Ty	0.13520	0.044	Dung	0.046	Quan				
25	Son	0.09242	0.024	Sau	0.037	Dung	0.024	Mui	0.005	Quan
26	Son	0.49531	0.094	Sau	0.136	Quy				
27	Quy	1.37963	0.274	Sau	0.317	Ly				
28	Dung	2.11063	0.711	Sau	0.322	Tuan				
29	Cot	0.22221	0.052	Quy	0.080	Mui	0.005	Tung	0.019	Quan
30	Muoi	0.15199	0.019	Sau	0.108	Dung	0.160	Mui		

31	Sang	0.51392	0.285	Sau	0.054	Dung				
32	Tu	0.26182	0.197	Dung	0.260	Quan				
33	Tuyet	0.24262	0.019	Dung	0.366	Quan				
34	Mui	1.19289	0.350	Sau	0.117	Dung	0.501	Quan		
35	Ha	0.61859	0.001	Sau	0.354	Dung	0.027	Mui	0.195	Quan
36	Tung	1.10201	0.171	Quy	0.237	Quan				
37	Tung	0.10139	0.045	Dung	0.156	Quan				
38	Nhan	0.22946	0.261	Quy	0.012	Tung	0.122	Quan		
39	Oanh	0.12137	0.147	Dung	0.117	Quan				
40	Mien	0.13633	0.041	Sau	0.014	Dung	0.005	Mui	0.094	Quan
41	Luong	0.64728	0.577	Sau	0.262	Quy				
42	De	0.84124	0.779	Dung	0.094	Quan				
43	Bang	0.66014	0.432	Sau	0.144	Dung	0.003	Mui		
44	Nhuom	0.54543	0.304	Dung	0.113	Quan				
45	Dia	0.09293	0.017	Dung	0.145	Quan				
46	Dung	0.08922	0.010	Sau	0.041	Dung	0.018	Mui		
47	Nghia	0.18702	0.003	Dung	0.177	Quan				
48	Thanh	0.07603	0.015	Sau	0.157	Dung	0.017	Mui		
49	Phuc	0.01534	0.021	Dung	0.019	Quan				
50	Trang	0.03284	0.059	Dung	0.028	Quan				
51	Tan	0.73500	0.022	Dung	0.026	Quan				
52	Luu	0.60489	0.131	Dung	0.280	Quan				
53	Phil	0.31782	0.117	Sau	0.240	Dung	0.213	Quan		
54	Ha	0.34437	0.013	Sau	0.211	Dung				
55	Diep	0.28282	0.007	Dung	0.250	Quan				
56	Viet	0.24708	0.021	Dung	0.200	Quan				
57	Lanh	0.11324	0.018	Sau	0.066	Dung	0.061	Mui	0.023	Quan
58	Noi	0.14297	0.025	Sau	0.021	Quy	0.225	Quan		
59	Phung	0.13366	0.035	Dung	0.050	Quan				
60	Loc	0.12463	0.029	Sau	0.041	Dung	0.110	Quan		
61	Chanh	0.50000	0.700	Dung						
62	Dinh	0.83958	0.448	Quy	0.027	Tung	0.485	Quan		
63	Hanh	0.81438	0.698	Dung	0.012	Quan				
64	Den	0.07179	0.081	Quan						
65	Chen	0.40529	0.042	Sau	0.115	Dung	0.066	Mui	0.048	Quan
66	Nho	0.09213	0.004	Sau	0.095	Dung	0.046	Quan		
67	Dep	0.18050	0.025	Dung	0.099	Quan				
68	Nho	0.36171	0.058	Sau	0.200	Dung	0.202	Mui	0.034	Quan
69	Tuan	0.88566	0.250	Dung	0.148	Quan				
70	Bich	0.07836	0.067	Dung	0.021	Quan				
71	Mai	0.14430	0.020	Dung	0.116	Quan				
72	Uc	0.24869	0.165	Dung	0.030	Quan				
73	Khoa	0.07399	0.012	Dung	0.078	Quan				
74	Ly	1.05958	0.235	Sau	0.045	Quy	0.053	Mui	0.041	Quan
75	Âu	0.92183	0.519	Dung	0.293	Quan				
76	Sang	0.13610	0.109	Dung	0.044	Mui	0.022	Quan		
77	Quan	3.51651	0.283	Mui	1.497	Ha	0.802	Dinh		
78	Dieu	0.30806	0.521	Dung	0.122	Quan				
79	Tham	0.29424	0.273	Dung	0.048	Quan				
80	Dong	0.39179	0.366	Dung	0.114	Quan				
81	Cong	0.32783	0.058	Sau	0.457	Dung	0.017	Mui	0.130	Quan
82	Thao	0.39022	0.287	Dung	0.305	Quan				
83	Hoa	0.41866	0.193	Dung	0.139	Quan				
84	Chien	0.21848	0.230	Dung	0.065	Quan				
85	Nam	0.27117	0.075	Sau	0.351	Dung	0.175	Mui	0.008	Quan
86	Thanh	0.33918	0.143	Dung	0.073	Mui	0.226	Quan		
87	Dau	0.15000	0.140	Dung						
88	Man	0.12667	0.222	Dung						
89	Ha	0.13333	0.133	Dung						
90	Tam	0.96850	0.107	Sau	0.466	Dung	0.029	Mui		
91	Hong	0.06462	0.042	Dung	0.061	Quan				
92	Giau	0.32510	0.042	Sau	0.215	Dung	0.081	Quan		

Appendix 5: Result of parameter estimate values of the determinants for 92 observations in both districts

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	-5.072059	0.606013	-8.369553	0.0000
LOG(PA)	0.317981	0.126927	2.505234	0.0141
LOG(SER01)	1.595537	0.285049	5.597412	0.0000
LOG(SDEN)	-0.108503	0.133308	-0.813927	0.4179
LOG(MDEN)	-0.008123	0.08433	-0.096321	0.9235
LOG(EDU)	0.81898	0.209829	3.90308	0.0002
R-squared	0.516262	Mean dependent var		-1.34749
Adjusted R-squared	0.488137	S.D. dependent var		0.945635
S.E. of regression	0.67655	Akaike info criterion		2.119374
Sum squared resid	39.36395	Schwarz criterion		2.283838
Log likelihood	-91.49119	Hannan-Quinn criter.		2.185753
F-statistic	18.35641	Durbin-Watson stat		1.979605
Prob(F-statistic)	0			

Appendix 6: Result of parameter estimate values of the determinants for 44 observations in Cai Nuoc district

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	-4.82317	0.710326	-6.79008	0
LOG(PA)	0.266009	0.129909	2.047658	0.0476
LOG(SER01)	1.478798	0.350304	4.221475	0.0001
LOG(SDEN)	0.005563	0.142215	0.039117	0.969
LOG(MDEN)	0.025614	0.105902	0.241861	0.8102
LOG(EDU)	1.094601	0.263301	4.157222	0.0002
R-squared	0.666626	Mean dependent var		-1.23406
Adjusted R-squared	0.622761	S.D. dependent var		0.877058
S.E. of regression	0.538687	Akaike info criterion		1.726759
Sum squared resid	11.02698	Schwarz criterion		1.970058
Log likelihood	-31.9887	Hannan-Quinn criter.		1.816986
F-statistic	15.19722	Durbin-Watson stat		1.602808
Prob(F-statistic)	0			

Appendix 7: Result of parameter estimate values of the determinants for 48 observations in Dam Doi district

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	-4.892688	0.886023	-5.522076	0
LOG(PA)	0.390602	0.22346	1.747972	0.0878
LOG(SER01)	1.392491	0.404373	3.443577	0.0013
LOG(SDEN)	-0.433907	0.232772	-1.864084	0.0693
LOG(MDEN)	0.019851	0.126065	0.157464	0.8756
LOG(EDU)	1.087733	0.31792	3.421405	0.0014
R-squared	0.549131	Mean dependent var		-1.451458
Adjusted R-squared	0.495456	S.D. dependent var		1.002259
S.E. of regression	0.711918	Akaike info criterion		2.274759
Sum squared resid	21.28672	Schwarz criterion		2.508659
Log likelihood	-48.59422	Hannan-Quinn criter.		2.36315
F-statistic	10.23068	Durbin-Watson stat		2.264643
Prob(F-statistic)	0.000002			

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