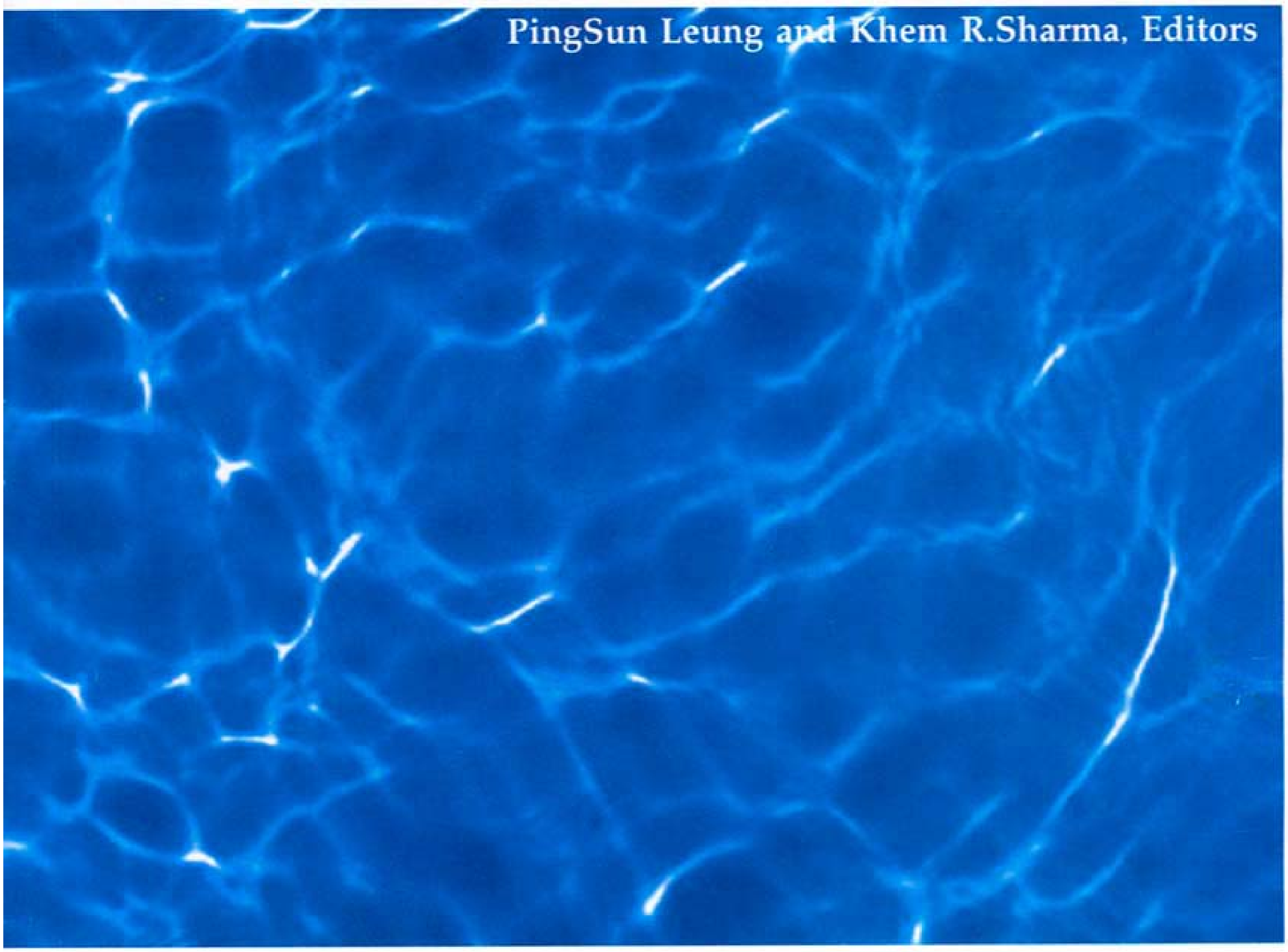
Economics and Management of Shrimp and Carp Farming in Asia:

A Collection of Research Papers based on the ADB/NACA Farm Performance Survey



PingSun Leung and Khem R.Sharma, Editors

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Foreword

The Network of Aquaculture Centres in Asia-Pacific (NACA) and the University of Hawaii at Manoa are pleased to make available this compendium of published research - papers on the economic, environmental and management aspects of shrimp and carp farming in Asia. They are useful for policy, for research, and for management at the farm or enterprise level.

The 16 papers in this volume were largely based on the data from the survey of more than 5000 shrimp and close to 6000 carp farms in 16 countries/territories in Asia-Pacific. This survey was the major exercise conducted under the ADB/NACA regional study and workshop on aquaculture sustainability and the environment (RETA 5534). The data and the information that were processed for and after the workshop, which was held in Beijing in 0ctober 1995, were made available to all interested institutional and individual users. One of the institutions that made extensive use of the data and information is the University of Hawaii at Manoa, College of Tropical Agriculture and Human Resources. The analysis made by the staff and graduate students of the University added immense value to the survey data and workshop results, as explained by the Editors in the Preface.

We should like to extend our appreciation to the Asian Development Bank for having generously allowed, through its agreement with NACA, the further use of the data and information that have been acquired and developed from the project in other analytical purposes.

We hope this presentation of separately published research papers will provide a very handy and useful set of information to policy makers, researchers, project managers and farm managers and advisers.

Hassanai Kongkeo
Coordinator, NACA

Bangkok, January 2001

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Part II - Carp

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Preface

The global aquaculture production has shown tremendous growth in recent years. Aquaculture is now the fastest growing food production sector in many countries. Based on most recent FAO estimates (FISHSTAT), global fish production from aquaculture increased from about 10 million metric tonnes (mt) in 1984 to more than 39 million mt in 1998, with an annual growth rate of about 10%. On the other hand, the production from capture fisheries increased at less than 1% to 87 million mt in 1998. Consequently, aquaculture's contribution to global fish production increased from 11% in 1984 to 31% in 1998. The growing world population has placed a heavy demand on capture fisheries to the extent that many fisheries are overexploited or have collapsed, and are no longer able to satisfy growing demands. It is expected that aquaculture will play an important role in an effort to combat these problems and hence to improve food supply and nutrition in the future.

The majority of global aquaculture production comes from Asia. In 1998, Asia accounted for nearly 36 million mt or more than 90% of global quantity and $US43 billion or more than 80% of value of aquaculture production. China is the dominant producer, accounting for more than 75% of total aquaculture production of Asia, followed by India (5.7%), the Philippines (2.7%), and Indonesia (2.3%).

Carp and other cyprinids are dominant aquaculture species, accounting for more than 14 million mt or 36% of global quantity and $15 billion or 29% of value of production in 1998. Almost all of this (~ 98%) comes from Asia, primarily China (81%) and India (12%). Carp are commonly grown in freshwater environments.

Shrimp have also become increasingly important species in recent times. In 1998, shrimp accounted for about 3% of global production in terms of quantity (~ 1.1 million mt) and 13% in terms of value ($6.9.billion). With respect to both quantity and value, about 80% of this originates in Asia. Thailand is the leading shrimp producing country, contributing to about 28% of total shrimp production in Asia in 1998. Other leading producers of shrimp are Indonesia (19%) and China (16%) and Vietnam (13%). Among other countries, India and Bangladesh have experienced a rapid increase, while Taiwan and the Philippines have experienced a decline in shrimp production in the 1990s. Shrimp are commonly cultivated in brackish water conditions.

The rapid growth in aquaculture in recent years can be attributed to technological breakthroughs (especially advances in hatchery techniques), higher fish prices due to growing demand and increased effort in aquaculture development. In recognition of aquaculture's potential for contributing to food security, enhancing income and employment in rural communities and generating foreign exchange earnings, many developing countries have given high priorities to aquaculture development in their development plans. In the meanwhile, the rapid expansion of the industry often accompanied with intensification of input use and consequent environmental problems has become an increasingly important policy issue. Currently, numerous national, regional and international agencies are engaged in developing appropriate strategies to improve economic viability and environmental sustainability of aquacultural activities. This would require a wide variety of information, including the knowledge of various aquacultural systems and their economic, technological and market characteristics. Papers contained in this edited volume provide some of this information on shrimp and carp farming in Asia and we believe that it will serve as a useful reference for aquaculture research and development.

The volume is an outgrowth of research conducted at the University of Hawaii at Manoa during the latter half of the 1990s. We acknowledge the invaluable role of NACA (Network of Aquaculture Centers in Asia-Pacific) in providing the rich dataset based on a very comprehensive farm performance survey, and which thus allowed researchers and graduate students at the University of Hawaii the opportunity to analyze in details the various economic aspects of shrimp and carp farming. The survey was conducted during 1994 and 1995 on over 10,000 shrimp and carp farms in 17 countries/regions in Asia-Pacific as part of a regional study on aquaculture sustainability and the environment sponsored by the Asian Development Bank. This volume is a collection of research papers mostly stemmed from analyses based on the NACA dataset that have been published in scientific journals and/or presented in major conferences. In addition, two masters theses and two doctoral dissertations have been completed at least partially related to this dataset.

The volume is divided into two sections – shrimp and carp. The general topics covered include individual and intercountry productivity and efficiency analyses, comparative advantage investigation, and identifying risk factors for disease occurrence. The analyses covered are not comprehensive in the sense that not all countries have been analyzed in details. For example, a detailed analysis has been conducted only for the Malaysian shrimp farms and an intercountry analysis has been done only for the South-Asian carp farms. This reflects the interests of the graduate students and researchers as to the various aspects of the analyses as well as geographic coverage. Consequently, this volume is simply a collection of research completed and is not intended to provide a comprehensive economic analysis of every aspect of shrimp and carp farming in the Asia-Pacific region. In addition, some of the data presented may be somewhat outdated depending on when the research was completed.

In the shrimp section, Ling et al. (Chapter 1) review the global shrimp supply and demand, with special attention on the role of shrimp supply, particularly from Asian countries. They also provide information on import tariffs for shrimp products in the three major demand markets – Japan, the U.S.A., and the E.U. The technological advances of Asian shrimp farming systems have not only contributed to a rapid expansion of Asian shrimp culture, but have also created greater opportunities for foreign exchange earnings in the 1980s and 1990s. However, this rapid expansion has led to increased competition among the producers. In Chapter 2, Ling et al. assess the comparative advantage of Asian shrimp producing countries in exporting shrimp to Japan, the US and the EU using the domestic resource cost method. The results show that nearly all Asian shrimp producers have greater comparative advantage in exporting shrimp to Japan than to the US and the EU markets, largely because of the premium shrimp prices received in the Japanese market. Moreover, Thailand, Indonesia and Sri Lanka have stronger comparative advantage relative to the other Asian countries studied. Shang et al. (Chapter 3) review the trends and economics of hatchery and grow-out phases of shrimp farming in Asia. The costs and returns of extensive, semi-intensive and intensive farming systems are compared within the producing country, and the economic efficiency of each system are compared among the major producing countries. Limitations for future development and factors affecting the sustainable growth of the shrimp industry are also discussed.

Leung and Gunaratne (Chapter 4) compare the productivity of the black tiger shrimp culture in the region in an attempt to identify the technological differences across producing countries for systems of various intensities. This comparison provides background information for intercountry transfer of appropriate technology in order to improve the long-term viability of shrimp farming in the region. In extending the productivity analysis, Gunaratne and Leung (Chapter 5) use the stochastic meta-production frontier approach to compare production characteristics and the levels of technical efficiency in black tiger shrimp culture. Regional performances of extensive, semi-intensive and intensive systems are compared, followed by an examination of the influence of farm-specific variables on technical efficiency. In Chapter 6, Gunaratne and Leung provide a comparative analysis of both the parametric stochastic production frontier and the nonparametric data envelopment analysis (DEA) techniques in estimating the farm-level technical, allocative and economic efficiencies for intensive and semi-intensive shrimp farms in Malaysia. The efficiency estimates indicate that there is substantial potential for improving the level of shrimp production using existing inputs and available technology in both systems. None of the efficiency indices (technical, allocative and economic) for the intensive system was significantly higher than those for the semi-intensive system. This raises questions about the present trend of increased intensification. In both systems, on average, optimum levels of feed and seed were lower than their actual levels. These results not only highlight the production structure of the Malaysian shrimp industry but also have implications on sustainability of the industry.

Ling et al. in Chapter 7 use the revealed comparative advantage (RCA) method to evaluate the export performance of nine selected shrimp producers in the Japan and United States markets, separately. Shrimp is marketed in a wide variety of product forms, and prices vary according to various product attributes, including species, size, taste, quality and origin. The results show that vertical product differentiation concerning different varieties of a good in terms of both quality and price plays an important role on the relative export competition of shrimp products among major shrimp exporting countries. As a result of the geographical advantage, Asia-Pacific producers enjoy comparative advantage in the Japanese imported shrimp market. Joint ventures with the United States provide great benefits to Ecuador and Mexico in exporting fresh shrimp into the United States market. Using the bivariate cointegration approach, Ling et al. (Chapter 8) analyze the behavior of the price transmission of black tiger shrimp in both forward and backward directions between Thai and Indonesian shrimp packer markets and the Japan Tokyo wholesale market. The results show that Tokyo wholesale prices have a strong backward impact on the formation of overseas contract prices for Japanese shrimp importers in the Thai and Indonesian shrimp packer markets. Also, there is a tendency for the speed of price transmissions in the long-run to increase with increasing shrimp size, regardless of the direction of price transmissions and origin.

In Chapter 9, Leung et al. test factors such as farm siting and design and farm-management practices for relationships with disease occurrence using logistic regression. Factors affecting disease occurrences were quite different for different farming intensities. Farms that had larger pond production areas, with larger number of farms discharging effluent into their water supply canals, and removed silt had greater disease occurrence. On the other hand, farms that practiced polyculture, and took water from the sea through a canal had lower disease occurrence. In an attempt to look for a model with higher prediction accuracy, Leung and Tran (Chapter 10) develop a probabilistic neural network (PNN) model to predict shrimp disease outbreaks using only the Vietnamese data for comparison with the traditional logistic regression model. Results show that the PNN model has a better predictive power than the logistic regression model. However, the PNN model uses significantly more input (explanatory) variables than the logistic regression. The logistic regression is estimated using a stepwise procedure starting with the same input variables as in PNN model. Adapting the same input variables found in the logistic regression model to the PNN model yields results no better than the logistic regression model. More importantly, the key factors for prediction in the PNN model are difficult to interpret, suggesting besides prediction accuracy, model interpretation is an important issue for further investigation.

In the carp section, to provide a more comprehensive comparison of carp farming in South Asia, Sharma and Leung (Chapter 11) apply the stochastic meta-production frontier model to examine the intercountry differences in levels of technical efficiency of semi-intensive/intensive and extensive systems among the major carp producing countries in South Asia, namely India, Bangladesh, Pakistan and Nepal. The mean technical efficiencies for semi-intensive/intensive farms vary from 0.68 for Nepal to 0.79 for India, with an overall average of 0.75 and those for extensive farms vary from 0.48 for Bangladesh to 0.62 for Pakistan, with an overall mean of 0.57. Differences in efficiency levels are explained in terms of various farm-specific and country-specific factors by estimating a model for technical inefficiency effects. The adoption of recommended fish, water, and feed management practices is found to be critical for improved performance of carp producers. For each country, the study also compares the efficiency scores based on its own production frontier with those obtained from the meta-production frontier.

Sharma and Leung (Chapter 12) examine the technical efficiency and its determinants for a sample of carp farms from the Tarai region in Nepal using a stochastic production frontier involving a model for technical inefficiency effects. The estimated mean technical efficiency is 0.77, with intensive farms being more efficient than extensive farms. The adoption of regular fish, water, and feed management activities has a strong positive effect on technical efficiency. In Chapter 13, Sharma investigates the technical efficiency and its determinants in carp pond culture in Pakistan using a similar approach. The mean technical efficiencies for semi-intensive/intensive and extensive farms are 0.673 and 0.561, respectively. By operating at full technical efficiency the semi-intensive/intensive farms could, on average, increase their production from 3.0 to 4.5 mt/ha and the extensive farms from 2.6 to 4.6 mt/ha. Much of these efficiency gains would come from the improvement in fish, water and feed monitoring and management.

Sharma and Leung in Chapter 14 apply a similar approach to examine the levels and determinants of technical efficiency in carp pond culture in India. The results show significant technical inefficiencies in carp production in India, especially among the extensive farms. The mean technical efficiencies for semi-intensive/intensive and extensive sample farms are estimated to be 0.805 and 0.658, respectively. By operating at full technical efficiency levels, the semi-intensive/intensive farms could, on average, increase their production from about 3.4 mt/ha to 4.1 mt/ha. Similarly, the extensive farms could increase their production from 1.3 mt/ha to 1.9 mt/ha. Much of these efficiency gains would come from the improvement in the adoption of recommended fish, water and feed management and monitoring practices.

In Chapter 15, Iinuma et al. also use the stochastic production frontier approach to examine the productive performance and its determinants in carp pond culture in Peninsular Malaysia. They have found that proper stocking ratio of feed and forage species is important to promote productivity in carp polyculture. The mean technical efficiency for the sample carp farms is estimated to be 0.42 indicating a great potential for increasing carp production in Peninsular Malaysia through improved efficiency. Because the intensive/semi-intensive system is found to be technically more efficient than the extensive system, efforts should be made to promote the intensive/semi-intensive carp culture.

Finally, in Chapter 16 Sharma et al. apply a nonparametric data envelopment analysis (DEA) technique for multiple outputs to measure economic or 'revenue' efficiency and its technical and allocative components for a sample of Chinese polyculture fish farms; and to derive the optimum stocking densities for different fish species. The mean economic efficiency is estimated to be 0.74. Technical inefficiencies accounted for most of the production inefficiencies in Chinese fish farms. On average, farmers should increase grass carp and decrease black carp stocking rates. Smaller farms and those from the developed regions were found to be relatively more technically and economically efficient.

The editors would like to thank several people and organizations who helped make this volume a reality. First and foremost, we would like to thank the staff in NACA for their continuous support not only in providing the dataset but also for their many valuable insights throughout our research. In particular, we would like to thank Mr. Pedro Bueno who has taken the painstaking task of coordinating the publication of this volume. We would also like to thank the College of Tropical Agriculture and Human Resources, University of Hawaii at Manoa, for providing funding support to some of our graduate students and our research infrastructure. Their open mind has allowed us to work on farming issues outside of Hawaii.

We are grateful to the publishers of the following journals who have granted us permissions to reproduce the articles in this volume: *Aquaculture, Aquaculture Asia, Aquaculture Economics and Management, Aquaculture Research, and Diseases in Aquatic Organisms*. We would also like to extend our appreciation for the anonymous journal reviewers who have contributed significantly in improving many of the articles in this volume.

Finally, we are indebted to the many shrimp and carp farmers in the Asia-Pacific region who have participated in the ADB/NACA farm performance survey. We hope the results and insights gained in this volume are helpful for policy makers to improve the long-term sustainability of both shrimp and carp farming which will in turn better the livelihoods of the farmers in this region.

PingSun Leung
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Honolulu, Hawaii

December, 2000

Part One

Shrimp

Chapter 1
Overview of the world shrimp industry

Bith-Hong Ling, PingSun Leung and Yung C. Shang

This study reviews the global shrimp supply patterns with special attention on the role of shrimp supply, particularly from Asian countries, and the current trends of world exports and imports of frozen shrimp. The study provides recent information on import tariffs for shrimp products in the three major demand markets - Japan, the U.S.A., and the E.U.

1.1 Global shrimp supply

World shrimp production includes a wide range of species of shrimp, which come from wild catch landings and shrimp culture. The commercially important shrimp species have been classified into several basic groups. First is the wild coldwater species which inhabit the North and Northeast Atlantic and the North Pacific Ocean mainly dominated by *Pandalus borealis* and *Crangon crangon*. Second is the warmwater species which inhabit tropical coastal areas and are largely cultured in brackish water and fresh water areas along the Indo-Pacific, the Western Indian Ocean, the Western and Eastern Atlantic and Eastern Pacific Ocean. The popular cultured species include *Penaeus monodon*, *P. vannamei*, *P. orientalis*, *P. merguiensis,* and *Macrobrachium rosenbergii.*

1.1.1 Status of world shrimp production

The volume of wild catch and cultured shrimp and their shares in total world shrimp production are given in Table 1.1. The world supply of shrimp increased 60.0% to 3,080 thousand metric tonnes (mt) in 1994 from 1,925 thousand mt in 1984. Traditionally, catch fisheries is the major supply source, however, the supply trend shows that landings of wild catch shrimp have remained relatively stable for the past decade. The main concern has been the maximum capacity of wild stock and its harvest close to full capacity. Approximately 90.8% of global shrimp supply was from catch fisheries in 1984, but the share decreased to 70.1% in 1994.

The majority of the increase in world shrimp production for the past few years was the result of rapid expansion of the world cultured shrimp industry. Cultured shrimp, accounting for only 177 thousand mt or 9.2% of world shrimp production in 1984, had increased tremendously to 921 thousand mt with a share of 29.9% in 1994. There was more than 420% increase between 1984 and 1994. With advances in shrimp farming techniques as well as the growing demand for high value shrimp, the role of aquaculture shrimp in relation to the global supply will become increasingly important.

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1.1.2 Important cultured shrimp species

While there are several different shrimp species cultured in tropical and subtropical farming operations, only a few account for the majority of cultured shrimp production. Over the past decade, the general pattern of cultured shrimp production by species has undergone a significant change in terms of quantity and share, as shown in Table 1.2. Black tiger shrimp had a steady increase in production, with a growth rate of 764% during the period of 1984 - 1994 and was the leading dominant species, except in 1988. As a result of the remarkable expansion of culture shrimp industry in China, production of Chinese white shrimp amounted to 199.5 thousand mt and accounted for the largest share, 35.2% of total aquaculture shrimp in 1988.

Table 1.1 World shrimp production by source, 1984 - 1994

Year	Wild catch		Aquaculture		Total
	(1,000 mt)	Share (%)	(1,000 mt)	Share (%)	(1,000 mt)
1984	1,748	90.8	177	9.2	1,925
1985	1,938	90.1	213	9.9	2,151
1986	1,962	86.5	305	13.5	2,267
1987	1,900	79.5	490	20.5	2,390
1988	1,985	77.8	566	22.2	2,552
1989	1,949	76.1	613	23.9	2,562
1990	1,967	74.8	662	25.2	2,630
1991	2,013	71.0	823	29.0	2,836
1992	2,062	70.1	881	29.9	2,943
1993	2,071	71.3	835	28.7	2,906
1994	2,160	70.1	921	29.9	3,080

Source: Aquaculture Production Statistics, 1984-1994. Fisheries Department, FAO.

In Asia, the major shrimp species are mostly from the *Penaeidae* family, including black tiger shrimp (*Penaeus monodon*), Chinese white or fleshy prawn (*Penaeus orientalis*), banana shrimp (*Penaeus merguiensis*) and Metapenaeu shrimp (*Metapenaeus spp.*). Black tiger shrimp is the most commonly cultured shrimp species of all warmwater shrimp and is commercially cultivated in Southeast Asia and Far East. In 1994, Thailand was the leading producer of black tiger shrimp (accounting for 47.4% of total), followed by Indonesia (23.7%) and Philippines (19.4%). In China, Chinese white shrimp was the primary cultured species. Nearly all of world Chinese white production was provided by China and very slight account was from Republic of Korea. In Indonesia, other important traditional species after black tiger shrimp were banana shrimp and Metapenaeu shrimp. In the Latin America, Western white or whiteleg shrimp (*Penaeus vannamei*) made up the vast majority of aquaculture shrimp dominated by Ecuador in the 1984 - 1993 period.

Table 1.2 Production and share of major cultured shrimp species, 1984 - 1994

	Black tiger shrimp (P. monodon)		Western white shrimp (P. vannamei)		Chinese white shrimp (P. orientalis)		Other species		Grand total
Year	Quantity (mt)	Share (%)	Quantity (mt)	Share (%)	Quantity (mt)	Share (%)	Quantity (mt)	Share (%)	Quantity (mt)
1984	58,532	33.1	36,338	20.5	19,375	10.9	62,773	35.5	177,018
1985	61,726	29.0	33,947	15.9	40,703	19.1	76,641	36.0	213,017
1986	96,884	31.8	36,217	11.9	82,909	27.2	88,983	29.2	304,993
1987	155,356	31.7	73,321	15.0	153,385	31.3	107,921	22.0	489,983
1988	168,758	29.8	78,336	13.8	199,520	35.2	119,506	21.1	566,120
1989	223,056	36.4	75,842	12.4	186,124	30.4	127,697	20.8	612,719
1990	250,777	37.9	82,012	12.4	185,074	27.9	144,490	21.8	662,353
1991	332,729	40.4	111,413	13.5	220,036	26.7	158,522	19.3	822,700
1992	391,462	44.5	120,457	13.7	207,428	23.6	161,272	18.3	880,619
1993	434,887	52.1	94,184	11.3	88,128	10.6	217,961	26.1	835,160
1994	505,658	54.9	109,447	11.9	64,389	7.0	241,123	26.2	920,617

Source: Aquaculture Production Statistics, 1984 - 1994. Fisheries Department, FAO.

The composition of cultured shrimp production by species changed significantly in 1993. With severe disease problems causing a large-scale failure in shrimp farming industry in China and Ecuador in 1992 - 1993, the share of Chinese white shrimp production has dramatically fallen from 26.7% in 1991 to 10.6% in 1993 and 7.0% in 1994, while its production decreased from the peak of 220 thousand mt in 1991 to 88 thousand mt in 1993 and 64 thousand mt in 1994. Similarly, western white shrimp also faced a decrease in production from 120 to 94 thousand mt in the 1992 - 1993 period. Consequently, the continued growth of black tiger shrimp supply led to increase its share, up to 54.9% in 1994. The accompanying increase in production of black tiger shrimp played a significant role in the expansion of world aquaculture shrimp production in the 1990s.

1.1.3 Importance of Asian shrimp farming

Shrimp culture development has expanded to many parts of the world. However, the largest increases in aquaculture shrimp production have been in Asia and Latin America, particularly in Thailand, Indonesia, China, the Philippines and Ecuador. Table 1.3 presents the aquaculture shrimp production by region and country for 1984, 1987, 1990 and 1994. About all of the world cultured shrimp in the period 1984 - 94 came from Asia and Latin America. Asia was the largest cultured shrimp-producing region, accounting for 78.6% and 83.3% of total production in 1984 and 1994, respectively. Its production increased from 139.2 thousand mt in 1984 to 766.7 thousand mt in 1994, a 451% increase; Latin America's increased by 285%.

The growth of the Asian shrimp farming industry is due primarily to the large extent of suitable natural environmental conditions such as land and climate; technological breakthroughs in shrimp feed and hatchery; the efficiency in the management of growout operations; government supporting promotion and planning programs; and the intra-region (particularly in the ASEAN region) transfers of farming technologies and cooperative investment in shrimp farming.

However, viral and other diseases have caused severe reduction in shrimp production in a number of major producing countries, particularly for Taiwan in 1988 and China in 1993 (and Thailand in 1995-1996). Meanwhile, shrimp farming is growing in Southeast Asia, South Asia and Latin America and countries in these regions will likely increase world cultured shrimp production despite the persisting disease problems.

Table 1.3 Cultured shrimp production by region and country, 1984-1994

Region/Country	Quantity (1,000 mt)				Increase (%)	Market share (%)	
	1984	1987	1990	1994	1984-94	1984	1994
Grand total	177.0	490.2	662.4	920.6	420	100.0	100.0
Asia	139.2	404.1	559.4	766.7	451	78.6	83.3
ASEAN	82.5	129.1	304.1	569.7	591	46.6	61.9
Thailand	13.0	23.6	119.5	267.8	1,959	7.3	29.1
Indonesia	32.1	59.0	107.3	167.4	422	18.1	18.2
Philippines	29.3	35.7	54.0	92.6	216	16.6	10.1
Malaysia	0.1	0.8	2.3	5.9	9,572	0.0	0.6
Vietnam	8.0	10.0	21.0	36.0	350	4.5	3.9
South Asia	18.2	30.3	49.3	121.8	568	10.3	13.2
Bangladesh	8.2	14.8	18.6	28.8	250	4.6	3.1
India	10.0	15.0	30.0	92.0	820	5.6	10.0
Sri Lanka	0.0	0.5	0.7	1.0	9,900	0.0	0.1
China	19.3	153.3	184.8	63.9	231	10.9	6.9
Taiwan	12.1	80.3	9.2	8.9	-26	6.8	1.0
Latin America	37.5	83.3	99.2	144.3	285	21.2	15.7
Ecuador	33.6	73.0	76.4	98.7	194	19.0	10.7
Honduras	0.6	1.8	3.3	8.1	1,372	0.3	0.9
Other	0.3	2.6	3.1	9.6	3,222	0.2	1.0

Source: Aquaculture Production Statistics, 1984-1994. Fisheries Department, FAO. Fisheries Yearbook Taiwan Area, 1984-1994. Taiwan Fisheries Bureau.

1.2 Global shrimp trade

Based on the Standard International Trade Code (SITC) system in the FAO publications, there are three categories of shrimp products used in international trade, namely frozen raw shrimp (SITC 0306.11), fresh or chilled shrimp (SITC 0306.2) and preserved and prepared shrimp (SITC 16.05).

Frozen raw shrimp is the most popular and commercial product form in the international market, which accounted for about 95% of world trade in frozen, fresh, or chilled shrimp products in volume for the past decade. Frozen raw shrimp do not require further value-added processing and are normally exported directly to the international market by shrimp producing countries. Although trade statistics of shrimp are not specifically categorized as to whether they are cultured shrimp or wild catch shrimp, knowing the country of origin allows an educated guess to be made about the amount of cultured shrimp that are traded in the international market. Shrimp products under the category SITC 16.05 are in the processed form, such as frozen cooked and peeled shrimp and canned shrimp products. It is difficult to identify the shrimp species and product form at the point of country of origin due to re-processing and re-exporting activities involved in trade statistics. For instance, in the European Union most shrimp from Asian shrimp producing countries is imported raw frozen shell-on and then used by processors in the preparation of cooled and peeled, breaded, canned or ready shrimp meals for re-export to the members of the European Union.

The following reviews the status of global trade flows of frozen shrimp products during the period between 1984 and 1994. Import tariffs for shrimp products in the U.S., Japan and the E.U. markets are then discussed.

1.2.1 World shrimp exports

The global trade for shrimp is a one-way flow, from tropical developing countries to industrial countries. Table 1.4 shows world exports and imports of frozen shrimp in value by country between 1984 and 1993. Frozen shrimp exports have increased from 462.9 thousand mt in 1984 to 972.9 thousand mt in 1993, which generated US$ 6,883 million in export revenues for shrimp exporting countries. The value of Asian shrimp exports has increased steadily from about $1,282 million to $4,259 million between 1984 and 1993, with the Asia's share increasing from 45.7% to 61.9%. For most Asian countries, revenues from shrimp exports became the important source of foreign exchange earnings in the 1980s and 1990s.

Only a few countries export the bulk of world frozen shrimp. In 1993, Thailand and Indonesia, with 21.3% and 11.5%, respectively of world frozen shrimp exports in value were the largest, followed by India (8.4%), Ecuador (6.5%), China (5.4%) and Mexico (4.3%). The structure of export share among major exporting countries has changed during the period between 1984 and 1993. For the past decade, frozen shrimp exports are substantially dominated by cultured shrimp producing countries. According to the region of shrimp farming industry, the ASEAN (the Association of Southeast Asian Nations) was the most important exporter of frozen shrimp and received export revenues of $2,823 million, with the market share of 41.0% in 1993 which increased from 15.4% in 1984. Ecuador was the main frozen shrimp exporter from Latin America.

Within the ASEAN, Thailand was the top world cultured shrimp producer. Thai export revenues from frozen shrimp have significantly increased by 1,135%, from $119 million in 1984 to $1,466 million in 1993. Indonesia was the second largest exporter and its export share increased from 6.8% in 1984 to 11.5% in 1993. In contrast, the slow growth rate of South Asian frozen shrimp exports has led to the decrease in its export share in the international market.

Accompanying the large-scale failure in the Taiwanese shrimp farming industry in the mid-1988 as well as the strong competition from the low production cost of shrimp farming in the ASEAN was a significant fall in the value of frozen shrimp exports from Taiwan. Its export share with respect to world shrimp exports has fallen steadily from 12.0% in 1987 to 0.9% in 1993.

Table 1.4 World exports and imports of frozen shrimp by country, 1984 - 1993

	Value (million US$)				Increase (%)	Market share (%)	
Region/Country	1984	1987	1990	1993	1984 - 1993	1984	1993
A. World exports	2,806	5,092	5,902	6,883	145	100.0	100.0
Cultured country	1,429	3,154	3,973	4,704	229	50.9	68.3
Asia	1,282	2,768	3,600	4,259	232	45.7	61.9
ASEAN	432	889	1,831	2,823	554	15.4	41.0
Thailand	119	223	781	1,466	1,135	4.2	21.3
Indonesia	191	342	644	789	314	6.8	11.5
Philippines	35	155	219	222	537	1.2	3.2
Malaysia	39	57	74	81	108	1.4	1.2
Vietnam	49	112	112	265	447	1.7	3.9
South Asia	424	527	557	783	85	15.1	11.4
India	289	309	346	577	99	10.3	8.4
Bangladesh	69	125	151	144	109	2.5	2.1
Pakistan	65	93	60	62	-5	2.3	0.9
China	96	377	708	370	287	3.4	5.4
Taiwan	191	725	141	61	-68	6.8	0.9
Other Asia	140	249	363	222	58	5.0	3.2
Ecuador	147	386	373	445	203	5.2	6.5
Wild catch country	609	836	652	762	25	21.7	11.1
Mexico	402	435	202	295	-26	14.3	4.3
Argentina	87	19	53	168	93	3.1	2.4
Greenland	49	162	174	140	185	1.7	2
Denmark	71	220	221	159	123	2.5	2.3
Other*	768	1,102	1,277	1,417	84	27.4	20.6
B. World imports	3,111	5,470	6,366	7,393	138	100	100
Japan	1,272	2,325	2,491	2,946	132	40.9	39.9
US	1,119	1,538	1,589	2,080	86	36	28.1
EU	373	989	1,566	1,605	330	12	21.7
Other	347	618	721	762	120	11.2	10.3

Source: Yearbook of Fisheries Statistics, Commodities, 1984-1993. Fisheries Department, FAO. Fisheries Yearbook Taiwan Area, 1984-1993. Taiwan Fisheries Bureau.

* Includes other supplies either from cultured or wild catch shrimp producers.

In 1993, the total volume of cultured shrimp in China was 87.9 thousand mt, a decrease of 52.5% from the record 184.8 thousand mt in 1990. The corresponding value of shrimp exports in 1993 was $370 million which was a 47.7% decline from $708 million in 1990. Consequently, its share of world shrimp exports has fallen steadily from 12.0% in 1990 to 5.4% in 1993. The share of frozen shrimp exports provided by the major wild coldwater suppliers has decreased from 21.7% in 1984 to 11.1% in 1993. This significant change was due to the expanding role of cultured shrimp exporters as well as the dramatic decline in the Mexican shrimp landings from catch fisheries.

1.2.2 World shrimp imports

Around 87 to 89% of world frozen shrimp imports in value take place in the developed world led by Japan, followed by the United States and the European Union, as shown in Table 1.4. In general, the demand for frozen shrimp is principally determined by the changes in the price of frozen shrimp relative to competing products, the price of frozen shrimp in alternative markets, population, real disposable income and consumer preferences in the demand markets. Price appears to be the main determinant of demand in Japan while personal disposable income seems to be more important in the U.S.

Although per capita consumption of shrimp lags behind that of Japan (3.3kg) and the United States (1.3kg), the European Union as a trading block was the world third largest shrimp importer and is the fastest growing market. Over the period 1984-1993, frozen shrimp imports into the European Union increased by 330% in value, from $373 million (12.0% of world imports) to $1,605 million (21.7% of world imports). The most significant change in the import structure of frozen shrimp in the European Union has been the emergence of warmwater cultured shrimp from Asia. In particular, the increase in price of the preferred coldwater shrimp species resulting from the supply shortage has led importers to switch to low-priced Asian cultured shrimp. The market share held by frozen coldwater shrimp has been directly affected by the success of Asian cultured shrimp.

1.2.3 Shrimp import tariffs

While the international trade in shrimp is mainly determined by demand and supply, countries which represent large demand market are precisely those that have the best well designed trade policies to protect their domestic shrimp producers and consumers. In particular, the low proportion of shrimp in the processed forms in developing countries exports is primarily a function of the effect of the high import tariffs imposed by developed countries on processed shrimp imports. Customs tariffs for shrimp products in the United States, Japan, and the European Union are compared and summarized in Table 1.5, which also contains tariff concessions extracted from the schedules established by *the Uruguay Round of Multilateral Trade Negotiation* in Marrakeshthe, Morocco in April, 1994. In general, the national statistics classify imports of shrimp under three headings: 0306.13, which covers frozen shrimp; 0306.23, which cover non-frozen shrimp, such as live, fresh, chilled or cooked by simply steaming or by boiling in water; and 1605.20, which encompasses prepared and preserved shrimp, such as cooked, peeled and canned.

Although there are no quantity restrictions on imports of shrimp products, import tariffs imposed by importing countries differ from one country to another, according to different tariff code item number. Under tariff code 0306.13.00 (frozen), 0306.23.00 (non-frozen) and 1605.20.10 (other prepared or preserved), shrimp imports are tariff-free in the United States market. A duty of 10% *ad valorem* is imposed on imports of prepared or preserved containing fishmeal and prepared meals.

Imports of frozen, live, fresh, or chilled shrimp in Japan are dutiable at 3% *ad valorem*. Prepared or preserved shrimp which is smoked; boiled in water or in brine; or chilled, frozen, salted or dried after simply boiled is imposed an *ad valorem* duty of

15%, which is higher than that in the United States market. A duty of 7.5% *ad valorem* is charged for the rest of non-specified shrimp products.

Table 1.5 Import tariffs for shrimp products in the US, Japan, and the EU

Country / Tariff item number		Base rate of duty (1)	Base rate of duty (2)
United States of America			
0306.13.00	Frozen shrimps	Free	Free
0306.23.00	Non-frozen shrimps	Free	Free
1605.20.05	Prepared or preserved shrimps containing fish meat; prepared meals	10%	5%
1605.20.10	Other prepared or preserved shrimps:		
	Breaded and not in airtight containers	Free	Free
	Other	Free	Free
Japan			
0306.13	Frozen shrimps	3%	1%
0306.23	Non-frozen shrimps		
	Live, fresh or chilled shrimp	3%	1%
	Other	7.5%	5%
1605.20	Prepared or preserved shrimps		
	Smoked; simply boiled in water or in brine; chilled, frozen, salted, in brine or dried, after boiled in water or in brine	15%	4.8%
	Other	7.5%	5.3%
European Union			
0306.13	Frozen shrimps		
0306.13.10	of the family *Pandalidae*	12.0%	12.0%
0306.13.30	of the genus *Crangon*	18.0%	18.0%
0306.13.90	of other	18.0%	12.0%
0306.23	Non-frozen shrimps		
0306.23.10	of the family *Pandalidae*	12.0%	12.0%
0306.23.30	of the genus *Crangon*	18.0%	18.0%
0306.23.90	of other	18.0%	12.0%
1605.20.00	Prepared or preserved shrimps	20.0%	20.0%

Source: Trade Regulations and Trends in the Fish Trade in the USA, the European Union and Japan. GLOBEFISH Research Programme, Vol. 32. Fisheries Department, FAO.

Note: "Base rate of duty (1)" reflects the most recent bound rate for the described good. "Base rate of duty (2)" reflects either a new concession rate established in the Uruguay Round of Multilateral Trade Negotiations or a reaffirmation of the bound status of the prior existing Schedule XX rate in the US; shall become effective on January 1, 1999 in Japan; will be the new schedule to be implemented in 5 equal rate reductions with the first such reduction made on the date of entry into force of the Agreement establishing the WTO and each successive duty reduction will be made on January 1 of each of the following years in the European Union.

The European Union imposes tariffs on shrimp imports in three categories. First, a duty of 12% ad valorem is imposed on the family of Pandalidae shrimp in both of frozen and non-frozen forms, which is mainly the North Atlantic coldwater pink shrimp (Pandalus borealis) and is imported from Nordic countries such as Denmark, Norway, Iceland and Greenland. Secondly, imports of the genus Crangon and other shrimp species either in frozen or non-frozen forms are dutiable at 18% ad valorem. The vast majority of shrimp species under this tariff treatment included coldwater brown shrimp (Crangon crangon) and any tropical warmwater shrimp species. Finally, a higher import tariff, 20%, is charged for prepared or preserved shrimp products in order to protect the domestic shrimp processing industry. In addition, the common external tariffs of the European Union also vary subject to different categories of exporting countries. First, countries without any special tariff agreements with the EU have to pay the full common customs tariff as mentioned in Table 5. Secondly, developing countries which in general receive preferential treatment under the Generalized System of Preference (GSP) will benefit from special tariff rates of 4% for shrimp products under the code of 0306 and 6% for the prepared or preserved shrimp. Thirdly, countries such as the African, Caribbean and Pacific countries (ACP), less developed countries (LDC) and members of the EU will be exempt from import duties and enjoy the tariff-free access to any member of the EU.

Chapter 2

Comparing Asian shrimp farming: the domestic resource cost (DRC) approach

Bith-Hong Ling, PingSun Leung and Yung C. Shang

Abstract

The technological advances of Asian shrimp farming systems have not only contributed to a rapid expansion of Asian shrimp culture, but have also created greater opportunities for foreign exchange earnings in the 1980s and 1990s. Current trends, however, indicate significantly increased competition in world shrimp markets with many Asian countries initiating or expanding shrimp culture. Oversupply of cultured shrimp products in the global market has already occurred in the early 1990s. Consequently, market prices of shrimp have dropped and profit margins have been squeezed by export markets. The purpose of this study is to estimate the degree of comparative advantage of Asian cultured shrimp countries in producing shrimp and exporting it to Japan, the US and the EU (European Union) in 1994. First, cost comparisons of Asian shrimp farming technologies using intensive, semi-intensive and extensive systems among Thailand, Indonesia, Philippines, Malaysia, Vietnam, India, Bangladesh, Sri Lanka, China and Taiwan are discussed. Next is an analysis of comparative advantage using the domestic resource cost (DRC) method, taking into account not only opportunity costs of input factors, but also the foreign exchange rate and the price of shrimp in the foreign market. Results show that nearly all Asian shrimp producers have greater comparative advantage in exporting shrimp to Japan than to the US and the EU markets, largely because of the premium shrimp prices received in the Japanese market. Moreover, Thailand, Indonesia and Sri Lanka have stronger comparative advantage relative to the other Asian countries studied. On the other hand, owing to high input costs, Bangladesh has a comparative disadvantage in exporting shrimp to the EU and US markets.

2.1 Introduction

Methods of hatching, producing, harvesting, transporting, processing, marketing and exporting cultured Asian shrimp have progressively improved during the past decade. By 1994, almost 30% of the global shrimp supply came from aquaculture operations, of which 82% was provided by Asian producers. Moreover, Asia accounted for more than 60% of global shrimp exports since 1985 (FAO, 1996).

The technological advances of Asian shrimp farming systems have not only contributed to a rapid expansion of Asian shrimp culture, but have also created greater opportunities for foreign exchange earnings in the 1980s and 1990s. Current trends, however, indicate that competition has significantly increased in world shrimp markets, as many Asian countries initiate or expand shrimp culture. Oversupply of cultured shrimp products in the global market has already occurred in the early 1990s. Consequently, market prices of shrimp have dropped and profit margins have been squeezed (Chong, 1991).

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No study has been conducted to evaluate the social opportunity costs of using natural domestic resources to develop Asian shrimp aquaculture and the consequences to foreign exchange earnings. This study meets this need by using social opportunity costs to develop a comprehensive profile of the comparative advantages of Asian countries in producing and exporting shrimp. Highlighted are some of the economic features of shrimp culture in the Asian producing countries. The analysis provides important insights for understanding the relative production efficiency and export competitiveness of shrimp culture across countries and across different Asian farms.

First, the costs of shrimp production of different culture systems (intensive, semi-intensive and extensive) among Thailand, Indonesia, the Philippines, Malaysia, Vietnam, India, Bangladesh, Sri Lanka, China and Taiwan are compared. Next is an analysis of comparative advantage using the domestic resource cost (DRC) approach, taking into account opportunity costs of input factors, foreign exchange rates and shrimp prices in the foreign market. Estimation results of the resource cost ratio (RCR) indices for Asian shrimp producing countries by different culture systems are summarized and discussed in the final section.

Table 2.1 Intensity (%) of major shrimp species cultured in Asian shrimp farms

	Penaeus monodon	Penaeus indicus	Penaeus orientalis	Penaeus merguiensis	Penaeus japonicus	Metapenaeus species
Intensive system						
Thailand	100	0	0	0	0	0
Indonesia	92	44	1	10	0	0
Philippines	100	0	0	0	0	0
Malaysia	95	5	0	10	0	0
India	67	83	0	0	0	0
Sri Lanka	100	0	0	0	0	0
China	0	0	100	0	0	0
Taiwan	84	0	0	0	33	0
Semi-intensive system						
Indonesia	98	2	0	1	0	0
Philippines	100	0	0	0	0	0
Malaysia	100	5	0	14	0	0
Vietnam	91	0	0	0	0	2
India	87	35	0	0	0	0
Bangladesh	100	0	0	0	0	0
Sri Lanka	100	0	0	0	0	0
China	0	0	100	0	0	0
Extensive system						
Thailand	100	0	0	0	0	0
Indonesia	58	44	1	10	0	0
Philippines	100	0	0	0	0	0
Vietnam	86	20	2	3	0	0
India	82	40	0	0	0	0
Bangladesh	73	9	0	1	0	9
Sri Lanka	100	0	0	0	0	0
China	0	0	100	0	0	0

Source: ADB/NACA (1996).

2.2 Cost comparisons of Asian shrimp farms

Shrimp farms can be broadly classified into three types based on major economic and technological differences: intensive, semi-intensive and extensive systems. Production costs of cultured shrimp in ten Asian producing countries were compared based on a recent (1994/1995) farm performance survey, conduced under Asian Development Bank (ADB) and Network Aquaculture Centers in Asia-Pacific (NACA) sponsored project. The survey covered a total of 870 intensive, 1,022 semi-intensive and 2,898 extensive shrimp farms. Because of differences in resource endowment, shrimp species, culture seasons as well as productivity, the cost structure of shrimp production varied from one country to another. Intersystem and intercountry comparisons are based on the production cost per kilogram (kg) of shrimp. Production costs are grouped into variable costs (seed, feed, power, labor and others) and fixed costs (overhead, depreciation and interest). A comparison of the cost of production and cost components provides a better understanding of cost structure and relative production efficiency.

The dominant shrimp species under the intensive system (Table 2.1) is *Penaeus monodon*, followed by *Penaeus orientalis* (China) and *Penaeus indicus* (India and Indonesia). Monoculture dominates. The dominant species cultured in the semi-intensive system is *Penaeus monodon*, followed by *Penaeus orientalis* (China) and *Penaeus indicus* (India). Polyculture is more common in semi-intensive farms, but monoculture still dominates. There is a higher diversity of shrimp species cultured in the extensive system. The dominant species is *Penaeus monodon*, followed by *Penaeus orientalis* (China) and *Penaeus indicus* (Indonesia, India and Vietnam). Both monoculture and polyculture are prevalent in the extensive culture.

2.2.1 Intensive system

The average farm size of intensive shrimp farms ranged between 2.0 ha in Thailand and 19.8 ha in India (Table 2.2). The stocking density varied from 29.9 Pl/m^2 in India to 115.1 Pl/m^2. Feed conversion ratios ranged between 1.4 in Taiwan and 2.1 in the Philippines and China. Culture period was limited to one crop annually in China, but in remaining countries it ranged from 1.3 crops/year in the Philippines to 1.9 crops/year in Thailand, Indonesia and Malaysia.

The cost of production per kg of shrimp was greatest in Taiwan (US$7.33), followed by the Philippines ($6.81). The relatively high costs of land and facilities in Taiwan and high costs of imported feed in the Philippines were the major factors responsible for the higher production costs. Although the variation in annual productivity per hectare was wide (from 1,229 kg in China to 10,727 kg in Thailand), production cost per kg showed less variation (from $4.26 to $5.01 among Thailand, Indonesia, Malaysia, India, Sri Lanka and China). Partly as a result of having the highest domestic price of marketed shrimp ($12.46/kg), Taiwan had the largest profit per kilogram ($5.13). On the other hand, lowest market price resulted in zero profit in China.

Table 2.2 Cost structure per kg of Asian intensive shrimp farms by country

	Thailand		Indonesia		Philippines		Malaysia		India		Sri Lanka		China		Taiwan	
Total farm population		521		10,000		782		371		68		150		731		521
Usable sample size		358		159		17		41		7		31		32		58
% of total population		68.7		1.6		2.2		11.1		10.3		20.7		4.4		11.1
Average farm size (ha)		2.0		2.0		8.9		3.0		19.8		2.2		6.9		2.6
Stocking density (Pl/m^2))		115.1		67.5		37.8		68.2		29.9		32.0		54.0		71.4
Feed conversion ratio		1.7		1.7		2.1		1.9		1.6		2.0		2.1		1.4
Number of crops/year		1.9		1.9		1.3		1.9		1.6		1.6		1.0		1.7
Production(kg/ha/year)		10,727		4,392		3,057		6,256		5,048		7,178		1,229		2,808
	US$/ kg	%	US$/ kg	%	US$/ kg	%	US$/ kg	%	US$/ kg	%	US$/ kg	%	US$/ kg	%	US$/ kg	%
Fixed costs	0.98	23.1	1.19	25.8	2.13	31.4	0.76	15.7	2.08	41.5	0.76	16.8	1.81	37.0	3.35	45.7
Overhead	0.36	8.5	0.15	3.3	0.00	0.0	0.34	7.1	0.38	7.6	0.32	7.1	0.38	7.7	0.69	9.4
Depreciation	0.51	12.0	0.87	19.0	2.13	31.3	0.41	8.5	1.66	33.2	0.38	8.3	1.39	28.4	2.66	36.3
Interest	0.11	2.6	0.16	3.6	0.00	0.0	0.01	0.2	0.04	0.7	0.06	1.4	0.04	0.8	0.00	0.0
Variable costs	3.27	76.9	3.40	74.2	4.67	68.6	4.07	84.3	2.93	58.5	3.80	83.2	3.09	63.0	3.98	54.3
Feed	1.93	45.3	1.78	38.8	2.61	38.4	2.24	46.4	1.93	38.5	2.47	54.2	1.93	39.3	1.66	22.6
Seed	0.58	13.6	0.69	15.0	1.27	18.7	0.74	15.3	0.48	9.5	0.54	11.9	0.38	7.7	0.88	12.0
Power	0.33	7.7	0.45	9.8	0.28	4.2	0.60	12.4	0.28	5.7	0.37	8.2	0.29	5.8	0.66	9.0
Labor	0.18	4.3	0.25	5.5	0.43	6.3	0.17	3.5	0.10	2.0	0.25	5.5	0.05	1.0	0.20	2.7
Other	0.26	6.1	0.23	5.1	0.08	1.1	0.32	6.7	0.14	2.7	0.16	3.5	0.45	9.2	0.59	8.0
Total cost	4.26		4.59		6.81		4.83		5.01		4.56		4.90		7.33	
Farm-gate price	6.89		6.48		7.10		7.57		6.61		8.65		4.91		12.46	
Profit	2.63		1.89		0.29		2.74		1.60		4.09		0.01		5.13	

Source: ADB/NACA (1996).
Overhead includes the general overhead and costs of vehicle operation, maintenance, farm/pond rent, license, insurance and land and taxes.

Table 2.3 Cost structure per kg of Asian semi-intensive shrimp farms by country

	Indonesia	Philippines	Malaysia	Vietnam	India	Bangladesh	Sri Lanka	China
Total farm population	10,200	2,447	381	6,014	4,193	64	750	1,666
Usable sample size	391	72	42	108	153	23	99	67
% of total population	4	3	11	2	4	36	13	4
Average farm size (ha)	2.0	7.5	2.1	1.4	6.4	12.7	2.5	24.9
Stocking density (PL/m^2)	20.7	15.5	39.0	11.5	24.3	29.5	28.8	19.7
Feed conversion ratio	1.4	1.7	1.9	0.3	2.4	2.7	1.9	2.1
Number of crops/year	2.0	1.4	1.9	1.9	1.5	1.4	1.7	1.0
Production(kg/ha / year)	1,479	2,701	4,693	662	2,374	1,633	5,040	848

	Indonesia		Philippines		Malaysia		Vietnam		India		Bangladesh		Sri Lanka		China	
	US$/ kg	%	US$/ kg	%	US$/ kg	%	US$/ kg	%	US$/ kg	%	US$/ kg	%	US$/ kg	%	US$/ kg	%
Fixed costs	0.82	21.8	0.34	8.4	1.59	29.0	1.11	33.2	1.62	27.1	4.57	38.0	0.96	21.1	0.76	33.5
Overhead	0.19	4.9	0.04	0.9	0.38	7.0	0.32	9.5	0.45	7.6	0.68	5.7	0.33	7.2	0.31	13.5
Depreciation	0.62	16.3	0.30	7.5	1.15	21.0	0.79	23.7	1.06	17.9	3.05	25.4	0.61	13.3	0.41	17.9
Interest	0.02	0.6	0.00	0.0	0.06	1.0	0.00	0.0	0.10	1.7	0.84	7.0	0.02	0.5	0.05	2.1
Variable costs	2.95	78.2	3.67	91.6	3.90	71.0	2.23	66.8	4.34	72.9	7.46	62.0	3.59	78.9	1.51	66.5
Feed	1.48	39.3	2.21	55.2	2.38	43.3	0.77	23.1	2.71	45.5	3.16	26.3	2.31	50.6	1.04	46.0
Seed	0.82	21.6	0.70	17.5	0.59	10.8	1.06	31.7	1.08	18.1	2.69	22.4	0.69	15.1	0.23	10.1
Power	0.09	2.4	0.28	6.9	0.39	7.0	0.02	0.5	0.25	4.2	0.58	4.8	0.26	5.7	0.08	3.5
Labor	0.33	8.6	0.43	10.7	0.26	4.7	0.15	4.6	0.15	2.4	0.57	4.7	0.21	4.6	0.09	3.9
Other	0.24	6.3	0.05	1.2	0.29	5.2	0.23	6.8	0.15	2.6	0.46	3.8	0.13	2.8	0.07	3.0
Total cost	3.78		4.01		5.50		3.34		5.96		12.04		4.56		2.27	
Farm-gate price	6.83		6.55		7.03		5.63		7.27		5.26		7.56		3.21	
Profit	3.05		2.54		1.53		2.29		1.31		-6.78		3.00		0.94	

Source: ADB/NACA (1996).

Overhead includes the general overhead and costs of vehicle operation, maintenance, farm/pond rent, license, insurance and land and taxes.

Table 2.4 Cost structure per kilogram of Asian extensive shrimp farms by country

	Thailand		Indonesia		Philippines		Vietnam		India		Bangladesh		Sri Lanka		China	
Total farm population	2,002		24,000		3,029		22,374		45,040		6,500		80		2,681	
Usable sample size	7		1024		68		296		744		163		17		117	
% of total population	0		4		2		1		2		3		21		4	
Average farm size (ha)	12.2		5.0		10.8		10.3		1.2		16.6		5.0		39.5	
Stocking density (PL/m^2)	0.0		3.1		1.7		0.3		3.7		1.5		14.9		7.9	
Feed conversion ratio	0.0		0.3		0.4		0.1		1.2		0.4		0.3		1.4	
Number of crops/year	2.4		2.0		1.7		1.3		1.3		1.2		1.7		1.0	
Production(kg/ha/year)	394		162		260		79		696		216		2,944		421	
	US$/ kg	%	US$/ kg	%	US$/ kg	%	US$/ kg	%	US$/ kg	%	US$/ kg	%	US$/ kg	%	US$/ kg	%
Fixed costs	0.90	51.8	1.20	31.1	1.01	38.5	2.01	66.0	1.33	30.2	1.34	32.9	1.92	55.8	0.74	45.4
Overhead	0.68	39.2	0.40	10.3	0.18	6.9	1.07	35.1	0.28	6.3	0.99	24.3	1.33	38.6	0.13	7.8
Depreciation	0.22	12.6	0.80	20.7	0.83	31.7	0.93	30.6	0.99	22.4	0.35	8.5	0.59	17.2	0.54	33.7
Interest	0.00	0.0	0.00	0.1	0.00	0.0	0.01	0.2	0.07	1.5	0.00	0.0	0.00	0.0	0.06	3.9
Variable costs	0.84	48.2	2.66	68.9	1.60	61.5	1.04	34.0	3.08	69.8	2.73	67.1	1.52	44.2	0.88	54.6
Feed	0.00	0.0	0.22	5.8	0.49	18.7	0.17	5.6	1.39	31.4	0.13	3.3	0.31	8.9	0.29	17.8
Seed	0.00	0.0	1.26	32.7	0.53	20.2	0.42	13.9	0.99	22.4	1.77	43.5	0.76	22.2	0.13	8.2
Power	0.46	26.3	0.01	0.2	0.03	1.0	0.04	1.3	0.27	6.0	0.04	1.0	0.12	3.5	0.10	6.2
Labor	0.08	4.6	0.65	16.7	0.37	14.4	0.24	8.0	0.26	6.0	0.56	13.8	0.31	9.1	0.13	8.1
Other	0.30	17.3	0.52	13.4	0.19	7.2	0.16	5.2	0.18	4.1	0.23	5.6	0.02	0.5	0.23	14.4
Total cost	1.74		3.86		2.61		3.04		4.42		4.07		3.45		1.62	
Farm-gate price	3.63		6.84		7.28		2.73		7.19		6.90		7.05		3.05	
Profit	1.89		2.98		4.67		-0.31		2.77		2.83		3.60		1.43	

Source: ADB/NACA (1996).
Overhead includes the general overhead and costs of vehicle operation, maintenance, farm/pond rent, license, insurance and land and taxes.

Fixed costs accounted for more than 30% of total production costs in Taiwan, China, India and the Philippines, with depreciation being the dominant component. In all of these countries, feed was the most important variable cost, ranging from 22.3% in Taiwan to 54.2% in Sri Lanka. With an exception for China, seed was the second most significant variable cost (ranging from 9.5% in India to 18.7% in the Philippines). Energy was the third significant variable cost (ranging from 5.7% in India to 12.4% in Malaysia), except for the Philippines (4.2%) and China (5.8%) where it ranked fourth. Labor cost followed energy in Indonesia (5.5%), the Philippines (6.3%) and Sri Lanka (5.5%). In contrast, other cost (including chemicals, contract costs for cleaning and harvesting, fertilizer and water) was higher than labor cost in Taiwan, China, Malaysia and Thailand.

2.2.2 Semi-intensive system

With regard to the semi-intensive system (Table 2.3), Chinese farms averaged about 24.9 ha in area, and were by far the largest of the semi-intensive producers, which were often run by cooperatives. Average farm size of Bangladesh semi-intensive farms was 12.7 ha and that of remaining countries ranged between 1.4 ha in Vietnam and 7.5 ha in the Philippines. The stocking density varied from 39.0 Pl/m^2 in Malaysia to 11.5 Pl/m^2 in Vietnam. The feed conversion ratio was highest (2.7) in Bangladesh and lowest (0.3) in Vietnam. The number of cultured crops was the same as that for the intensive farms.

Bangladesh ranked as the highest in terms of cost of production per kilogram ($12.04), followed by India ($5.96), Malaysia ($5.50), Sri Lanka ($4.56), Vietnam ($3.34) and China ($2.27). In comparison, the extremely high cost of seed ($2.69) and depreciation ($3.05) in Bangladesh led to it having the greatest production cost of shrimp per kilogram and consequently resulted in negative profits of $6.78/kg. It is suspected that cost may have been overestimated for Bangladesh.

Considering all countries producing shrimp using the semi-intensive farming systems, feed was the leading cost input, ranging from 55.2% in the Philippines, 50.6% in Sri Lanka, 45.5% in India to 26.3% in Bangladesh. Seed was the second most significant variable cost in all of these countries, ranging from 10.1% in China to 31.7% in Vietnam. Generally, there was large variability in yields of the semi-intensive system (from 848 kg/ha to China and 5,054 kg/ha in Sri Lanka). Because of the relatively lower productivity per hectare in China (848 kg/ha) and Bangladesh (1,633 kg/ha), fixed cost per kilogram was higher than other countries, accounting for 33.5% and 38.0% of total cost, respectively. For other countries, on the other hand, variable cost and its share in total cost for the semi-intensive system ranged from $2.23/kg to $4.34/kg, or from 66.8% to 91.6%, respectively.

2.2.3 Extensive system

The farm size of extensive shrimp farms averaged 12.6 ha (Table 2.4), varying from 1.2 ha in India to 39.5 ha in China. The stocking density of extensive farms was very low, ranging from 0.0 Pl/m^2 in Thailand to 7.9 Pl/m^2 in China, with the exception of Sri Lanka (14.9 Pl/m^2). Significant reduction in the use of feed was the important feature of the extensive system, as compared to intensive and semi-intensive systems. Consequently, the feed conversion ratio was extremely low, except for the case of China (1.4) and India (1.2).

The share of any one input in total cost varied widely from country to country. For instance, overhead cost accounted for the largest share of total cost in Thailand (39.2%), Vietnam (35.1%) and Sri Lanka (38.6%), while depreciation was dominant in the Philippines (31.7%) and China (33.7%). In contrast, feed was the dominant item in India (31.4%), while seed was dominant in Indonesia (32.7%) and Bangladesh (43.5%). Furthermore, the cost of energy power was highest in Thailand, while labor cost was found to be highest in Indonesia, the Philippines and Bangladesh. Excluding the highest productivity (2,944 kg/ha in Sri Lanka) and the lowest productivity (79 kg/ha in Vietnam), production per hectare of the extensive system ranged from 696 kg to 162 kg. As a result of the lowest production per hectare and the lowest market price of shrimp per kilogram, Vietnam earned negative profits of $0.31/kg.

For intersystem comparison, the cost of production per kilogram of shrimp was the highest for the intensive system (Fig. 2.1), followed by semi-intensive and extensive systems in most of the major shrimp producing countries, except for India where the cost of production per kilogram of shrimp was the highest for the semi-intensive system, followed by intensive and extensive systems. Feed and seed were the two largest cost items for intensive and semi-intensive systems, while seed was the largest cost item for extensive system in Indonesia and the Philippines.

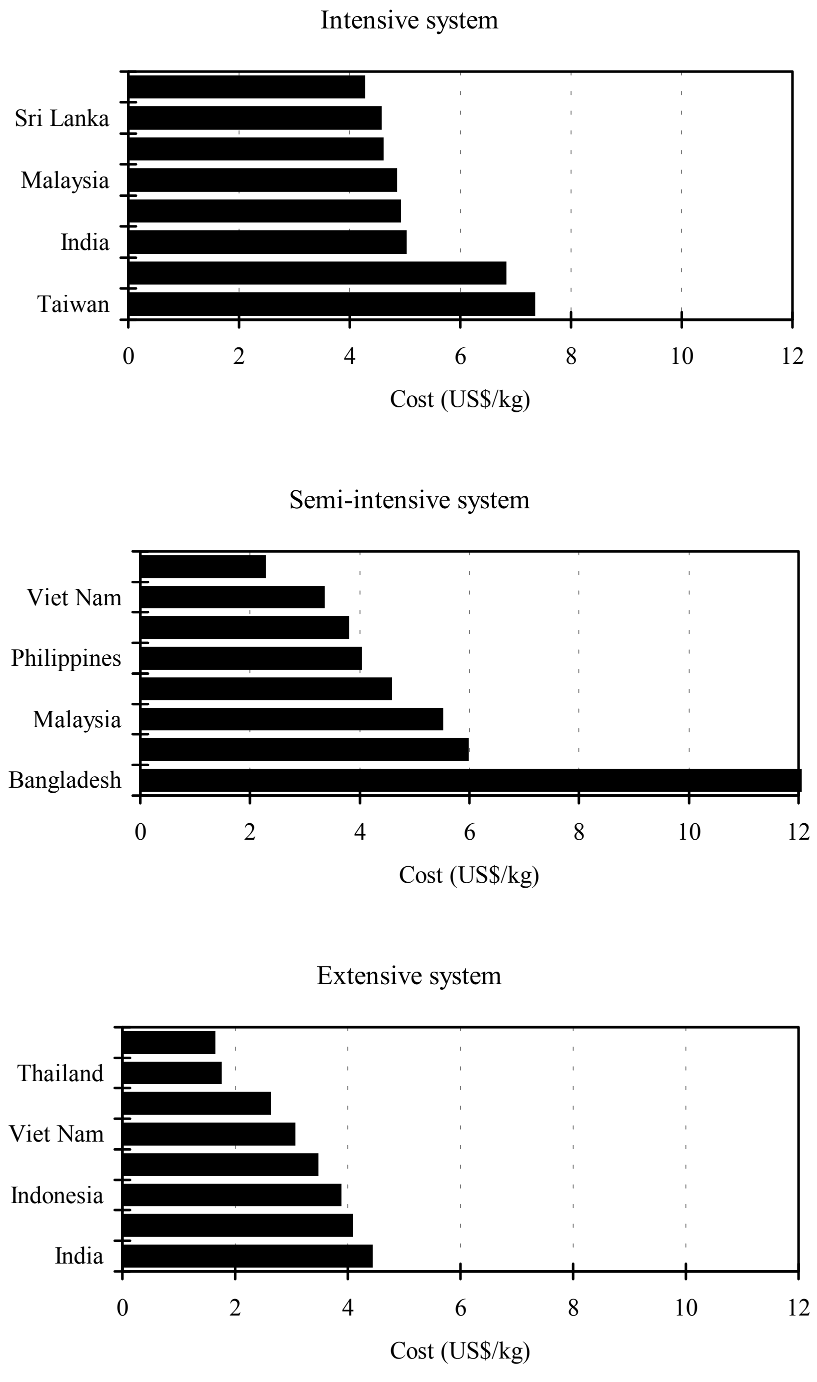

Fig. 2.1 Cost comparisons of shrimp production by farming system, 1994.

2.3 Materials and methods

2.3.1 The DRC approach

The DRC approach focuses on the implication of the comparative advantage for resource allocation which is based on the concept of social opportunity costs. According to Chenery (1961), a country has a comparative advantage in the production of a given commodity if the social opportunity costs of producing, processing, marketing and transporting an incremental unit of the commodity are less than the world prices. The DRC approach permits comparison of the relative degree of efficiency in producing an identical exportable commodity among different countries. Also, differences in production technologies and resource endowments can be identified directly by comparing input-output structures. The technique also allows room for analysis of the interactions between economic efficiency and government polices.

The DRC approach was used by Pearson and Meyer (1974) to identify comparative advantage among major African coffee producers. Later, Pearson et al. (1976) investigated the comparative advantage in rice production among the Philippines, Thailand, Taiwan and the US using this approach. Jitsanguan (1988) applied DRC on policy incentives and comparative advantage in the fisheries industry of Thailand. Gonzales et al. (1993) analyzed the degree of regional comparative advantage in production of food crops (rice, corn, soybean and cassava) in Indonesia.

The indicator of the domestic resource cost (DRC) proposed by Gonzales et al. (1993) is:

$$DRC = \frac{\sum b_{ok} P_k^s}{P_{of}^w - \sum a_{oj} P_{jf}^w} \qquad (2.1)$$

where production inputs are classified as tradable inputs (j) and non-tradable inputs (k). Shadow prices are used in evaluating the social opportunity costs of all inputs (j & k) and outputs (o). World prices are taken as shadow prices of tradable inputs (j) and output (o). The variables are defined as: P_k^s is the shadow price of non-tradable input k; P_{of}^w is the world price equivalent of output o in foreign currency, adjusted for transport, storage, distribution and quality differences; P_{jf}^w is the world price equivalent of tradable input j in foreign currency, adjusted for transport, storage, distribution, and quality differences; a_{oj} is the quantity of the j th tradable input needed to produce a unit of output o; and b_{ok} is the quantity of the k-th non-tradable input needed to produce a unit of output o .

The numerator in Eqn. 2.1 represents the opportunity costs in local currency of non-tradable inputs required to produce one unit of the commodity, while the denominator indicates the net foreign exchange, which is the difference between per unit foreign exchange earnings generated from exporting and the opportunity cost in foreign currency of the tradable inputs required for producing one unit of commodity. By comparing the DRC in Eqn. 2.1 with the equilibrium nominal exchange rate (E), which is taken as the shadow value of the exchange rate, the RCR becomes an index of comparative advantage at a given point in time and can be expressed as:

$$\mathrm{RCR} = \frac{\mathrm{DRC}}{\mathrm{E}} \tag{2.2}$$

If RCR < 1, there is a comparative advantage in producing and exporting the particular commodity. RCR > 1 and RCR = 1 show a comparative disadvantage and comparative neutrality, respectively. Each country's comparative advantage can be found by ranking the computed ratio of DRC per unit of foreign exchange earned or saved. If one country has a lower ratio of RCR than another country, the former has a relatively higher comparative advantage than the latter in exporting the commodity.

2.3.2 Determining comparative advantage of shrimp farming

Returning to the DRC index in Eqn. 2.1, there are two forces to induce the smaller DRC ratio, which indicates a greater degree of comparative advantage. The increase in world prices of exportable commodity, expressed by (P_{of}^{w}) in the numerator term is one force. The reduction in the costs of input uses, either on the costs of domestic inputs, ($\sum b_{ok} P_{k}^{s}$), or the costs of foreign inputs, ($\sum a_{oj} P_{jf}^{w}$) is the other force. By comparing both export prices and input costs for each country, the underlying differences in the degree of DRC ratios can pinpoint its comparative advantage source. This is true either across exporting countries within a given culture system or across different culture systems within a given country. The approach also allows a comparison of the source of the relative comparative advantage of a country's alternative farming technologies. Results of comparisons of comparative advantage at the international level, however, become more complex.

From the concern of DRC, Asian shrimp producing countries rely on factors, such as land, labor and fragile eco-systems (land-water resources such as mangrove coasts). On the other hand, they also heavily rely on the imports of input factors, for instance, shrimp feed ingredients including fish meals, soybeans and other grains, shrimp feed itself, equipment and machines, and/or foreign expertise. In particular, feed costs are high, almost always due to import tariffs and value-added taxes on feed ingredients or the feed itself. The import costs of these inputs used in the cultured shrimp industry increase the foreign content of the shrimp product and raise its production cost (Chong, 1991).

Export competitiveness of cultured shrimp could also be determined by comparative advantage that a country has the integration between the cost structure of shrimp culture, its value-added network and transportation facilities. For example, the physical infrastructures a country has such as communication and transportation are necessary to enhance marketing efficiency of shrimp products. Basic transportation infrastructures necessary for shrimp culture include roads, electrical distribution, export facilities including availability of refrigerated containers, cold-storage facilities, and container-based port facilities, and well-coordinated export marketing and promotion with respect to import regulations, product promotion and market information.

2.3.3 Data sources, assumptions and shrimp prices

The 1994/95 shrimp production cost used was from ADB/NACA (1996). The average 1994 C.I.F. (cost, insurance and freight) prices of shrimp exports were collected for three major markets – Japan, the US, and the European Union from Japan Tariff Association (1995), U.S. Department of Commerce (1995) and ERUOSTAT (1995), respectively. The nominal exchange rate between two trading countries was converted into the US dollars and was from ASIAWEEK (1994).

All input factors, except shrimp feed, are assumed as domestic non-tradable and their shadow prices are equal to their market prices. Feed that is either produced domestically or imported is treated as a tradable foreign cost, primarily because many Asian countries cannot supply required feed ingredients locally. Thus, imported feed enlarges the foreign content of the final output of shrimp. Since a majority share of international trade in shrimp is provided in the frozen form, only frozen shrimp is considered in the analysis. The C.I.F. prices in foreign markets are treated as shadow prices of shrimp exports, taking into account opportunity costs of transport, storage, distribution and quality differences.

Product differentiation concerning a wide variety of product attributes such as shrimp species, size and country of origin becomes an important feature of international trade in frozen shrimp and also leads to price differentials for frozen shrimp exports. In particular, shrimp are usually graded by size and sold by count (the number per pound). The difference in prices received by exporters is a result of the different sizes of shrimp exported. As the size of shrimp increases, the price also increases.

Moreover, shrimp exporters face additional exporting costs and risks. One of the main costs is the import tariff, which varies among different shrimp importing countries. For instance, frozen shrimp exporters enjoy the tariff-free access to the US market. Exporters of frozen shrimp to Japan have to pay a 3% *ad valorem* duty over the C.I.F. price. In the European Unit market, on the other hand, a 12% import tariff is imposed on imports of coldwater shrimp in the family *Pandalidae* and a 18% import tariff is paid by exporters coldwater shrimp in the genus *Crangon* and warmwater shrimp. However, the African, Caribbean and Pacific countries (ACP), less developed countries (LDC) and EU members included in the Generalized System of Preference (GSP) are exempted from import duties. In addition, risks facing shrimp exporters mainly revolve around uncertainties of market prices and exchange rate fluctuations. Consequently, shrimp prices received by exporters in foreign markets vary from one market to another.

Fig. 2.2 compares the 1994 average C.I.F. frozen shrimp prices per kilogram received by the shrimp exporting countries for markets in Japan, the US and the EU. The prices are approximations to national export prices per kilogram. The shrimp prices in the Japanese market are substantially higher than the US and EU, with Japanese preferring larger shrimp and willing to pay the higher price. In contrast, smaller shrimps of both coldwater and warmwater species are more popular in the EU. Therefore, the average price per kilogram of imported shrimp in the EU market is lowest at $5.93, while it is $11.19 in Japan and $9.66 in the US.

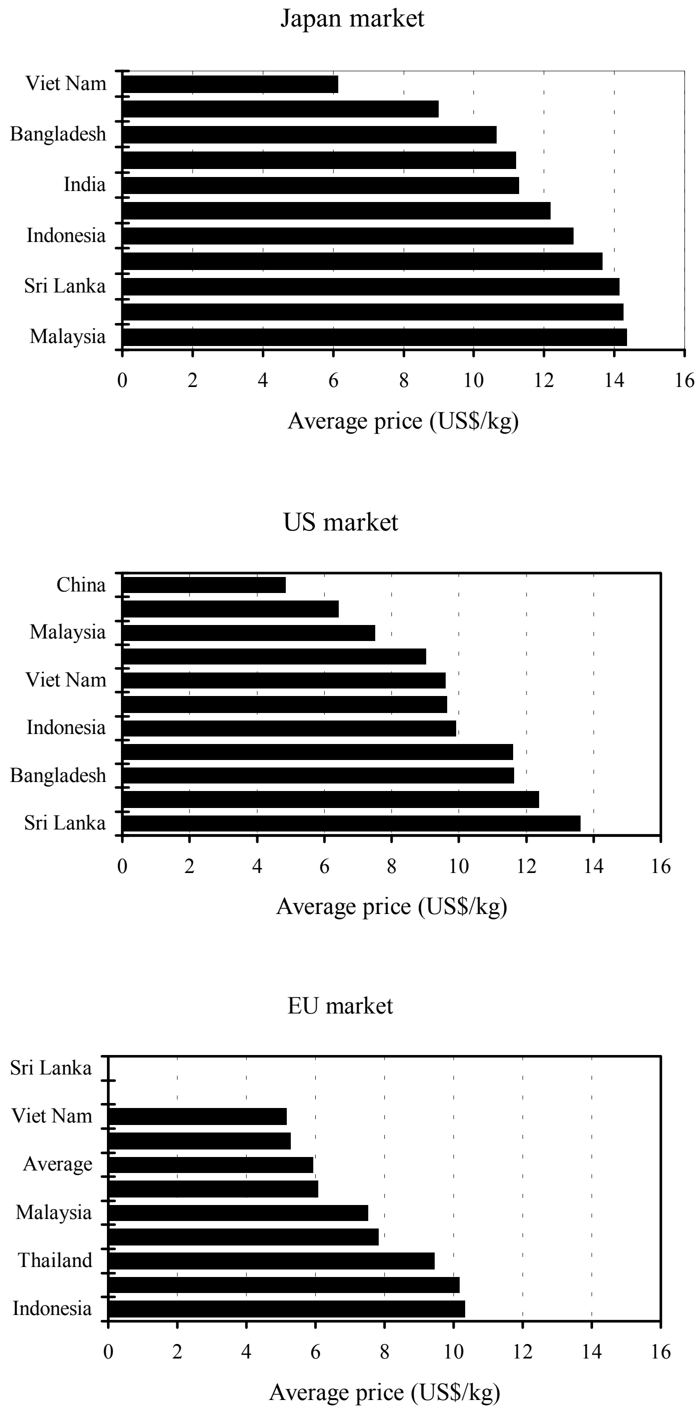

Fig. 2.2 Frozen shrimp prices received by exporters in Japan, the US and the EU, 1994

2.4 Results and discussion

Comparative advantage in the shrimp farming industry encompasses the entire economic process of shrimp production to its export. The degree of comparative advantage in both shrimp production and export influences a country's international competitiveness. The RCR indices of Asian shrimp exporting countries to the Japan, US and EU markets are estimated separately, taking into account the differences in cost per kilogram between shrimp farming systems across Asian countries as well as in C.I.F. prices received by exporters in foreign markets.

Generally, consumer preference and product differentiation that characterize the shrimp import markets lead to price differentials across markets. At any point in time, the relevant price for any country depends on the quality of shrimp produced for export as well as that consumed in demand markets. As a result of the premium price in Japan ($11.19), the RCR index appears to be lowest in the Japanese market and commands a substantial comparative advantage, followed by the US, and then the EU markets, regardless of country of origin and culture system. With the exception of semi-intensive and extensive systems used in Bangladesh and Vietnam, comparative advantage appears to prevail in the US market, mainly due to prices as high as $11.64 and $9.60, respectively.

Aside from intensive farms in China with respect to the US market (1.02) and semi-intensive farms in Bangladesh with respect to market in Japan (1.09) and the EU (1.15), the values of the RCR ratios (Figs. 2.3 - 2.5.) indicate a comparative advantage in producing and exporting shrimp to foreign markets. The RCR index ranges are between 0.14 and 0.97. While nearly all countries demonstrate comparative advantage, Thailand, Indonesia and Sri Lanka with relatively lower RCR ratios have considerably stronger comparative advantage than the remaining countries.

Among Asian intensive shrimp producers (Fig. 2.3.), Thailand, Sri Lanka and Indonesia have relatively stronger comparative advantage in all three markets, with RCR ratios between 0.18 and 0.34. The opportunity cost of imported feed is significantly high in both Thailand and Sri Lanka, and feed input accounts for the greatest share in total cost at 45.3% and 54.2%, respectively (Table 2.2). However, their lower domestic factor costs and higher prices received in export markets enhance significantly the level of comparative advantage, as compared with other Asian competitors.

On the other hand, in the cases of India, Malaysia and China, which have production costs quite close to Thailand, Sri Lanka and Indonesia, the RCR values are relatively higher and present less degree of comparative advantage, due largely to their lower shrimp prices received particularly in the US and EU markets. In addition, the sustainable development of the domestic feed industry in Taiwan brings the substantial feed supply at a cheaper cost. In spite of the consequently lowest share of feed in total cost (22.6%) in Taiwanese intensive system (Table 2.2), its relative advantage is offset by the higher opportunity costs of other domestic input factors such as depreciation and energy power. Therefore, the Taiwanese intensive system appears to have less comparative advantage in exporting shrimp to the US and the EU markets.

Comparisons of the RCR values for Asian semi-intensive shrimp farming systems are given in Fig. 2.4. In the case of Bangladesh, the tremendously high costs of both domestic (depreciation and seed) and foreign (feed) inputs result in a relatively large value of the RCR ratio that is greater than one. It shows that the semi-intensive farms in Bangladesh clearly has a comparative disadvantage in exporting shrimp, particularly to the EU and US markets, with RCR values being 1.15 and 1.09, respectively. The semi-intensive system in India, Malaysia and Vietnam (except in the US market) tends to have less of a comparative advantage in the US and EU markets relative to Indonesia, Philippines, Sri Lanka and China, with RCR values ranging from 0.17 to 0.38 across three markets. While results of the intercountry comparison for intensive and semi-intensive farms show wide differences in the degree of comparative advantage among Asian countries with respect to the three export markets, the variability of comparison regarding the extensive system is smaller. As can be seen in Fig. 2.5., the Asian extensive shrimp farms selected in the study present a comparative advantage, with the value of RCR ratio that is clearly less than one.

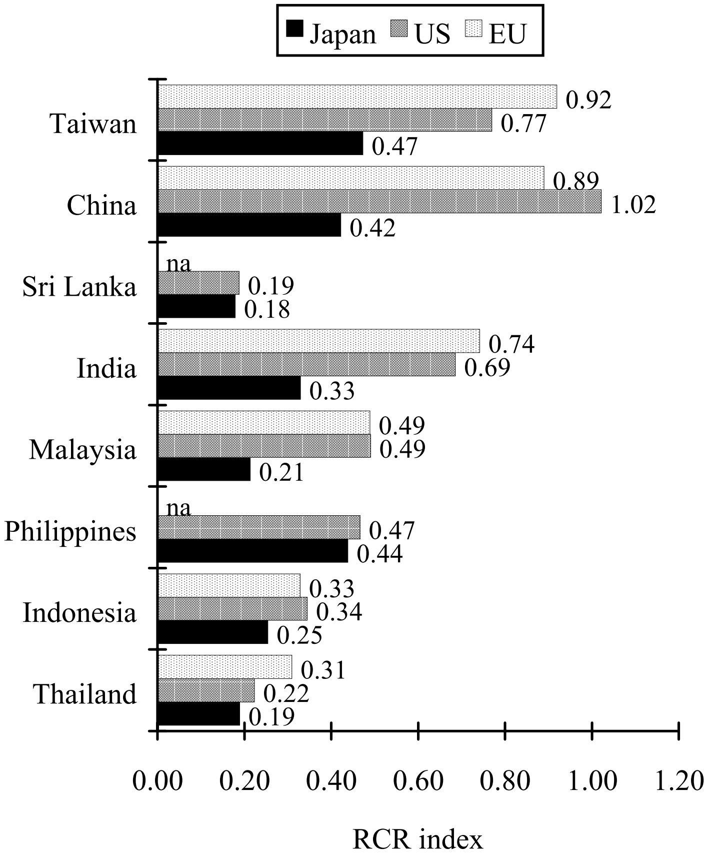

Fig. 2.3 Resource cost ratio (RCR) index of Asian intensive shrimp farms by market

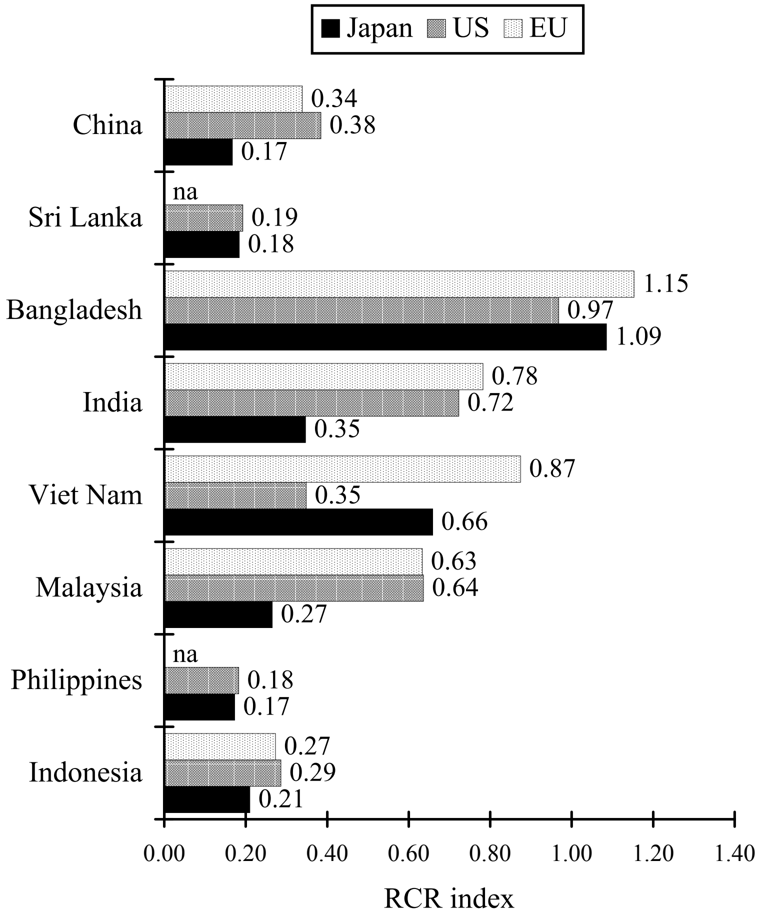

Fig. 2.4 Resource cost ratio (RCR) index of Asian semi-intensive shrimp farms by market

The relatively higher cost resulting mainly from imported feed in India and Vietnam causes the opportunity cost of the extensive farms to be much higher than in Thailand, the Philippines, Sri Lanka, China, Indonesia and Bangladesh. In addition, shrimp prices received by India in the US and EU markets and by Vietnam in the Japan and EU markets, on average, are lower than shrimp prices received by other Asian countries. Hence, a lesser degree of comparative advantage can be found in India and Vietnam using extensive shrimp farming system.

Given a particular Asian shrimp producing country, the degree of comparative advantage across alternative farming systems can be also compared. The difference in the value of RCR ratio associated with different systems is obviously smaller for Sri Lanka, Indonesia and Thailand than for the remaining countries. This indicates the similar variability of advantage among their shrimp farming systems. On the other hand, the RCR value of the intensive system the Philippines is larger than that of semi-intensive and extensive systems. More interestingly, the value of the RCR ratio corresponding to Indian intensive and extensive systems is close to each other in all three markets, but different from the RCR ratio for the semi-intensive system in the US and EU markets.

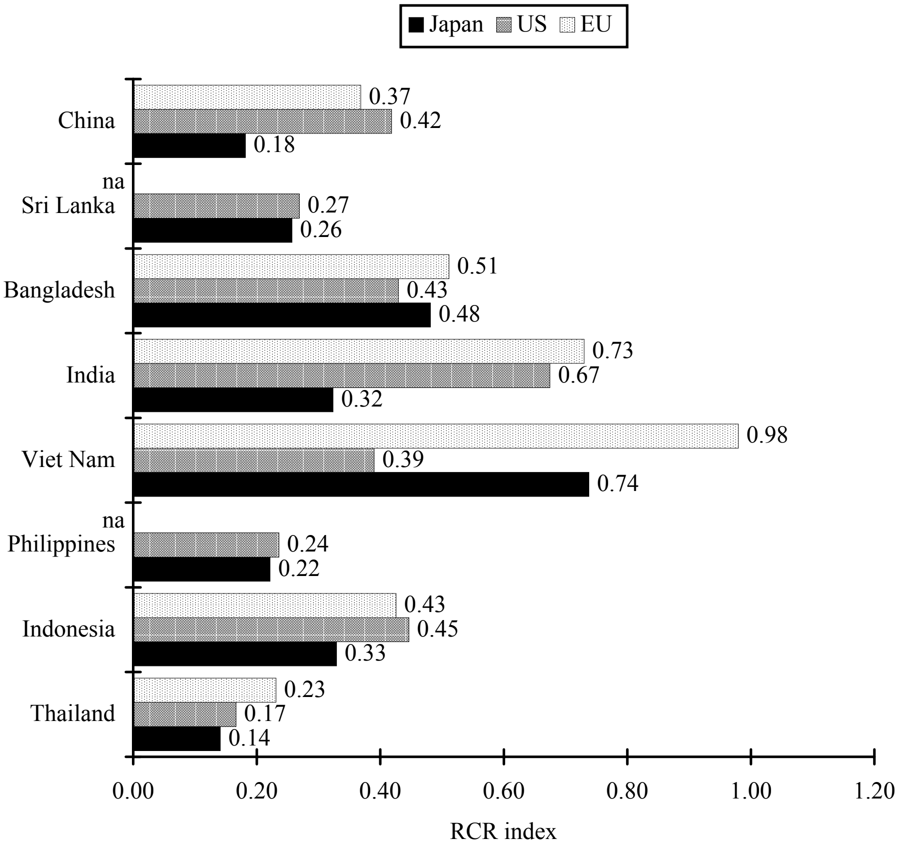

Fig. 2.5 Resource cost ratio (RCR) index of Asian extensive shrimp farms by market

2.5 Conclusions

Nearly all the Asian shrimp producers have a larger comparative advantage in exporting shrimp to Japan than to the US and the EU markets, largely because of the premium price received in the Japanese market. Moreover, Thailand, Indonesia and Sri Lanka for all culture systems have a stronger comparative advantage than other Asian countries in three foreign markets studied. On the other hand, due to the high cost of input use in the semi-intensive system Bangladesh has a RCR ratio greater than one and indicates comparative disadvantage in exporting shrimp, particularly to the EU and US markets. As a result of relatively high production costs and the lowest shrimp price, the Chinese intensive system is comparatively neutral in the US market (an RCR value about one).

Given significant differences in the cost structures and export performances among Asian cultured shrimp producers, the inter-country comparisons provide insights into the competitiveness of the Asian cultured shrimp industry. This information can be particularly useful in forming domestic shrimp policies. For example, one policy implication is that competitive countries may seek to increase acreage under shrimp culture, develop export market, or both.

The main factors affecting net foreign exchange earnings and the degree of comparative advantage of Asian shrimp farming are opportunity costs of shrimp operations and export prices received in the international market. The sensitivity of the DRC index to the costs of non-tradable inputs (such as capital and labor) and tradable inputs (such as imported shrimp feed and feed ingredients) used in shrimp farms have several policy implications. For instance, financial supports provided by national governments through tax relief and investment tax credits to shrimp producers, loans at low interest rates, and reductions in import tariffs on shrimp feed and feed ingredients may be alternative incentives to enhance the levels of comparative advantage in shrimp culture.

Moreover, because of the sensitivity of the DRCs to changes in and volatility of world shrimp prices, knowledge of the price trends of world shrimp products tends to be very important information for the sustainable growth of comparative advantage in the shrimp farming industry. Shrimp prices in the international market are often subject to fluctuations of world shrimp supply and demand. In addition, well-coordinated export marketing and promotion with respect to import regulations, product development and market information also play an important role in improving the efficiency of international shrimp marketing and in influencing shrimp export price and competitiveness. With growing concern of increased inter-country competition in Asian shrimp farming industry, the competitive export price becomes the crucial determinant of comparative advantage in the culture shrimp development in Asia.

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Chapter 3

Comparative economics of shrimp farming in Asia

Yung C. Shang, PingSun Leung and Bith-Hong Ling

Abstract

This paper reviews the trends and economics of hatchery and grow-out phases of shrimp farming in Asia. The economics of small, medium and large-scale hatcheries are evaluated based on a recent Philippine study. Costs and returns of shrimp grow-outs in major Asian producing countries are analyzed based on a recent farm performance survey conducted by the Asian Development Bank (ADB) and Network of Aquaculture Centers in Asia-Pacific (NACA). The costs and returns of extensive, semi-intensive and intensive farming systems are compared within the producing country, and the economic efficiency of each system is compared among the major producing countries. Comparative advantage of producing and marketing of shrimp among major producing countries in Asia is also evaluated. Limitations for future development and factors affecting the sustainable growth of the shrimp industry are also discussed.

3.1 Introduction

The global shrimp farming industry had a rapid growth in the 1980s mainly due to technological breakthroughs (such as hatchery and feed), high demand for shrimp resulting in high price and high profit of shrimp farming, and public support. However, its growth has slowed down since 1991. Serious outbreaks of shrimp diseases have been reported in most of the major producing countries. Viral diseases have reduced shrimp production.

Farmed shrimp amounted to about 712,000 metric tonnes (mt) in 1995, which accounted for about 27% of total shrimp production from both wild-caught and farm-raised sources. Asia produced about 78% of farmed shrimp and Western countries 22%. Thailand was the leading producer, followed by Ecuador, Indonesia, China, India, Vietnam, Bangladesh and the Philippines in 1995. Black tiger shrimp (*Penaeus monodon)* was the most important species farmed, accounting for 57% of cultured shrimp production, followed by western white shrimp *(Penaeus vannamei)* at 20% (Rosenbery, 1995).

This paper reviews and compares the relative economics of hatchery and grow-out phases of shrimp farming among different culture systems and among the major producing countries in Asia.

3.2 Hatchery

Seed supply of the shrimp industry originally relied on captured wild seed. However, wild seed stocks have proven limited and unreliable in supporting a rapidly

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expanding industry. Shrimp hatcheries have been gradually established in major producing countries. Pioneering hatcheries had a painful struggle because hatchery-reared seed was unable to compete with wild-caught seed which was cheaper and considered superior by many shrimp farmers (Csavas, 1995). Improvements in hatchery operations have reduced the price of hatchery-produced seed to competitive levels and made the rapid expansion of the industry possible in the 1980s. The rapid expansion of shrimp production in Taiwan and Thailand started after the price of hatchery-reared seed dropped below US$10 per one thousand postlarvae in the mid-80s.

Shrimp hatcheries can be classified into three sizes: small-scale, medium-scale and large-scale (Rosenbery, 1995). Small-scale hatcheries, sometimes referred to as "backyard hatcheries", have the advantages of low construction and operating costs, low-technical input, and flexible operation depending on season and supply of wild seed. They use small tanks, low stocking densities, untreated water and usually concentrate on just one phase of production, e.g. nauplii or postlarvae. Diseases and water quality problems often knock them out of production, but they can quickly disinfect and restart operation without serious financial losses.

Medium-scale hatcheries use large tanks, low stocking densities, low water exchange and encourage an ecosystem to bloom within the tank as feed. In Asia, most of the medium-scale hatcheries are based on a design developed in Japan and improved in Taiwan, thus they are referred to as "eastern hatcheries".

Large-scale hatcheries require high-technology and high-cost facilities that produce large quantities of seed in a controlled environment. They use big tanks and filtered water, high water exchange and grow algae and brine shrimp in separate tanks for feeding the larvae. They have the advantage of scale economies by producing seedstocks throughout the year, and most of them maintain broodstock. Referred to as "western hatcheries", large-scale hatcheries often have problems with disease and water quality, and take a long time to recover from production failures.

Worldwide, the distinction between eastern-style and western-style hatcheries is increasingly blurred as a large number of hybrid operations are adapted to local conditions. Many hatcheries built in the 1980s failed because technology from aquaculturally advanced countries was directly transferred to developing countries without modifications according to local conditions.

Shrimp hatcheries worldwide have grown from 3,439 in 1990 to 5,003 in 1995. About 93% of the hatcheries are located in the eastern hemisphere and 7% in western hemisphere. On the average, each hatchery covers about 210 ha of shrimp ponds in the eastern hemisphere and about 447 ha in the western hemisphere, more than double that in Asia. The area of shrimp ponds served by one hatchery is declining in both hemispheres. In 1995, most shrimp hatcheries were small and medium-scale categories (80-100%) in the major producing countries except China where 40% of shrimp hatcheries were large-scale (Rosenbery, 1995).

Juveniles are sometime cultured at high densities in small earthen ponds or tanks for a short period between the hatchery and grow-out phases referred to as "nursery phase". Some farmers revealed that the nursery phase contributes to better survival during grow-out. The economic benefit of the nursery operation needs to be studied.

3.2.1 Hatchery economics

Very limited economic information is available for hatchery operation in the major shrimp producing countries. Table 3.1 summarizes results of a 1992 field survey of hatcheries in the Philippines (Auburn University, 1993; Agbayani et al., 1996).

Table 3.1 Costs (%) and economic indicators of shrimp hatchery operations by scale in the Philippines

	Small-scale	Medium-scale	Large-scale
(A) Costs			
Variable cost			
Spawners/broodstock/nauplii	26.29	22.88	22.04
Starters/fertilizer	0.73	0.92	0.79
Supplemental feeds	7.49	7.67	6.99
Artemia	13.29	15.54	14.38
Chemicals/medicines	4.38	2.51	2.29
Power	2.75	4.66	5.27
Gasoline/oil	1.49	0.55	1.13
Salaries/allowances	7.95	7.99	5.34
Repairs/maintenance	2.63	0.77	1.29
Sales commissions	4.02	6.26	6.95
Miscellaneous	3.37	1.79	3.24
Incentives: Technicians	14.44	16.26	17.23
Sub-total	88.84	87.80	88.67
Fixed cost			
Interest	3.33	1.26	1.20
Depreciation	6.23	9.52	9.06
Rental	1.60	1.42	1.07
Sub-total	11.16	12.20	11.33
Grand total	100.00	100.00	100.00
(B) Economic indicators			
Variable unit cost (Philippine pesos)[a]	0.07	0.05	0.08
Total unit cost (Philippine pesos)[a]	0.10	0.07	0.13
Return on working capital	71.95	159.19	90.46
Return on investment/year	40.81	45.34	14.85
Benefit/cost ratio	1.38	1.87	1.57
Internal rate of return	48.73	656.29	875.03

Source: Auburn University, 1993.

[a] US$1 = 25 Philippine pesos in 1992.

The survey revealed that the distributions of variable and fixed costs are similar for all scales of operation. Variable costs account for 87.80 - 88.84% of total costs while fixed costs contribute 11.16 - 12.20%. Among variable costs, the costs of spawners and feeds (Artemia and supplemental feeds) are the most important items comprising about 47%, 46% and 43% of total cost, respectively, for small, medium and large-scale hatcheries. Economic indicators revealed that medium-scale hatcheries had the lowest variable and total costs per fry at 0.05 Philippine Pesos (PhP) and PhP 0.07, respectively, followed by small-scale hatcheries at PhP 0.07 and PhP 0.10. Large hatcheries on the other hand had the highest variable and total costs per fry at PhP 0.08 and PhP 0.13, respectively.

Returns on working capital and on initial investment are all positive from medium-scale hatcheries with the highest rates at 159% and 45%, respectively. The difference between these two indicators can be explained by the amount of initial investment for construction and equipment.

The five-year cash flow analysis revealed that medium-scale hatcheries had the highest benefit-cost ratio of 1.87, followed by 1.57 for large-scale and 1.38 for small-scale. Large-scale hatcheries on the other hand had the highest internal rate of return of 875%, followed by 656% for medium-scale and 49% for small-scale.

Risk assessment using sensitivity analysis by changing output and input prices and by decreasing production showed that small- and large-scale hatcheries suffer losses when combinations of the above changes occur. Only medium-scale hatcheries can survive when output price decreases by 20%, input prices increase by 20% and production falls by 30% simultaneously (Auburn University, 1993). Potential investors in shrimp hatcheries in the Philippines are better off investing in medium or small-scale hatcheries. Large hatcheries need high technical inputs and high costs, and have relatively high risks.

3.3 Grow-out

This section compares the (1) costs of shrimp production of different farming systems (extensive, semi-intensive and intensive) within and among the major producing countries in Asia, (2) production efficiency of different farming systems across countries, and (3) comparative advantage of producing and marketing of shrimp among major producing countries in Asia.

3.3.1 Culture systems

Shrimp culture systems can be broadly classified into three types based on major economic and technological differences: extensive, semi-intensive and intensive. Different types of culture system have different effects on their socio-economic and environmental viability.

Extensive production systems typically use slightly modified versions of traditional methods and are called low-density and low-input systems. They normally produce insignificant loading of nutrients or organic matter to the ecosystem. System relies mainly on natural productivity of the pond, but organic and inorganic fertilizers are occasionally used to promote the growth of natural foods. Most of farm labor comes from the household of the owner-operator or tenant-operator (Muluk and Baily, 1996).

Intensive production systems are characterized by relatively high densities and high inputs (such as pelletized feed and chemicals/drugs), which normally increase the nutrients and organic matter load to the ecosystem. The cost of pollution abatement often limits the enterprise’s commercial viability. Most investors in intensive operations are urban entrepreneurs or members of the local elite with business interests in other sectors of the economy, or large corporations. Employees hired by intensive operators tend to be recruited from distant communities rather than from the immediate surroundings (Muluk and Baily, 1996). Similarly, workers hired for pond management are often outsiders organized as specialized teams. Farm owners often do not play an active management role themselves, instead they hire managers and technical staff.

Semi-intensive operations practice intermediate levels of stocking and other inputs. Investors in semi-intensive shrimp farms generally are local residents who recognize the profit potential of shrimp production. Farm labor is recruited from members of the family or from the immediate community. The owner often plays an active management role in production (Muluk and Baily, 1996).

Over 90% of shrimp farms in major Asian producing countries are classified as extensive and semi-intensive types of operation, except for Thailand where only 15% of shrimp farms are in these two categories in 1995 (Table 3.2). The extensive system is the most important type of operation in Bangladesh accounting for 90% of shrimp farms, followed by Vietnam (80%), India (70%) and Indonesia (45%). Semi-intensive systems are most popular in China (85%), followed by the Philippines (50%), and Indonesia (45%) while intensive systems are important only in Thailand (85%).

Table 3.2 Level of intensity of shrimp farms, 1995

Country	Extensive (%)	Semi-intensive (%)	Intensive (%)
China	10	85	5
Bangladesh	90	10	0
India	70	25	5
Indonesia	45	45	10
Philippines[a]	35	50	15
Thailand	5	10	85
Vietnam	80	15	5

Source: Rosenbery (1995).
[a] Data for 1994.

3.3.2 Cost of production

A 1994/1995 farm performance survey conducted by the Asian Development Bank (ADB)/Network of Aquaculture Centers in Asia-Pacific (NACA) covered a total of 2,898 extensive, 1,022 semi-intensive and 870 intensive shrimp farms in 13 major Asian producing countries (ADB/NACA, 1996). Production costs of cultured shrimp were analyzed. Due to differences in resource endowment, shrimp species, crop seasons as well as productivity, the cost structure of cultured shrimp production varies from one country to another. For consistency in intersystem and intercountry comparison, the production cost per kg of shrimp is used as a criterion. Production costs are grouped into variable cost (seed, feed, power, labor and others) and fixed cost (overhead, depreciation and interest). A comparison of the cost of production and cost components provides a better understanding of cost structure and relative production efficiency.

For intersystem comparison, the cost of production per kg is highest for the intensive system followed by semi-intensive and extensive system in all of the major producing countries, except for India where the cost of production per kg was highest for the semi-intensive system, followed by intensive and extensive systems (see Tables 2.2-2.4 in this volume). Feed and seed are the two most important cost items for the intensive and semi-intensive systems while seed is the most important cost item for the extensive system in Indonesia and the Philippines.

For intercountry comparison (Table 2.2), the cost of production per kg for the intensive system was highest in Taiwan (US$7.33), followed by the Philippines ($6.81), India ($5.01), China ($4.90), Malaysia ($4.83), Indonesia ($4.59), Sri Lanka ($4.56) and Thailand ($4.26). The relatively high costs of land and facilities in Taiwan and high costs of imported feed in the Philippines are the major factors responsible for the higher production cost. Fixed costs account for more than 30% of total production costs in China, India, the Philippines and Taiwan. In these countries, feed is the most important variable cost, ranging from 23% in Taiwan to 46% in Malaysia, followed by seed, power and labor.

For the semi-intensive system (Table 2.3), China had the lowest production cost per kg ($2.27), followed by Vietnam ($3.34), Indonesia ($3.78), Philippines ($4.01), Sri Lanka ($4.56), Malaysia ($5.50), India ($5.96) and Bangladesh ($12.04). Among all semi-intensive farming countries, feed is the leading input cost, ranging from 23% in Vietnam to over 55% in the Philippines. Seed is the second most significant variable cost in all of these countries, ranging from 10% in China to 32% in Vietnam.

For the extensive system (Table 2.4), again China had the lowest production cost per kg ($1.62), followed by Thailand ($1.74), the Philippines ($2.61), Vietnam ($3.04), Sri Lanka ($3.45), Indonesia ($3.86), Bangladesh ($4.07) and India ($4.42). Significantly lower use of feed is the important feature of extensive system as compared with intensive and extensive systems. The share of feed in total cost ranged from 0% in Thailand to 31% in India. Seed was the most important variable cost for the extensive system in Indonesia, Vietnam, Bangladesh, Sri Lanka and the Philippines.

Tables 2.2-2.4 in the preceding paper also show the profitability of each culture system by country. For the intensive system, Taiwan had the highest profit per kg ($5.13) while China and the Philippines could barely cover their production costs. For the semi-intensive system, Bangladesh recorded a net loss of $6.78 per kg, while all other countries showed a profit ranging from $0.94 in China to $3.05 in Indonesia. For extensive shrimp culture, Vietnam exhibited a loss of $0.31 per kg, while profit from all other countries ranged from a high of $4.67 in the Philippines to a low of $1.43 in China.

3.3.4 Factors affecting performance and sustainability

Based on the NACA/ADB farm survey, many bio-technical factors identified as affect the economic performance and sustainability of the industry with the important ones summarized below.

1. Farm performance is generally improved (higher profit and lower losses due to diseases) when farms employ separate intake and drainage canals, and where the number of farms discharging shrimp pond effluent into supply canals is small.
2. Profit decreases when production pond area increases due to difficulties in farm management and disease control.
3. Farms with storage ponds for water conditioning, pre-filling and sedimentation ponds prior to effluent discharge reported fewer diseases and environmental problems.

4. Fallowing the ponds after each harvest usually reduces the cost of drugs (chemicals and antibiotics) and environmental stress.
5. Limiting water exchange to the level needed to maintain the pond environment results in savings in natural pond productivity and chemical/pumping costs.
6. Shrimp and milkfish rotation in the Philippines maximized utilization of natural productivity and minimized organic matter accumulation.
7. Utilization of biological treatment (e.g., use of filter-feeding organisms such as bivalves and seaweed) in storage and effluent treatment ponds or in the outfall channel can minimize aquaculture pollution.
8. Silt removal usually minimizes financial loss due to diseases.
9. Indices of correlation between shrimp farm and soil type show a lower profitability and higher incidence of diseases for acid-sulphate and sandy types of soil.
10. Improving seed quality from hatcheries increases survival and hence profit rates.
11. Improving feed formulation and feeding practices reduces feed costs and water pollution.

3.3.5 Intercountry efficiency analysis

This section is based largely on results from ADB/NACA (1996). Two complementary approaches used to analyze the production efficiency differences across countries and across different production systems are: interspatial total factor productivity (TFP) index and data envelopment analysis (DEA). Due to the lack of time series data in the NACA/ADB survey, the dynamic process of technological change and sustainability cannot readily be analyzed.

The interspatial TFP index uses the growth accounting (index number) approach and compares the efficiency of a particular production system in each country with respect to a reference country. On the other hand, DEA compares the system in question for each country in reference to all other countries. In other words, DEA implicitly calculates an efficient production frontier with which every country will be compared against and provides a breakdown of the efficiency of utilization of different production inputs. Technical descriptions of these two approaches can be found in Fried et al. (1993).

To correct for different products/species (say *P. monodon* vs. *P. japonicus*) from each country, we used production value as a measure of output in the calculation of the interspatial TFP index and the DEA. Table 3.3 summarizes the efficiency indices calculated using the two approaches for intensive, semi-intensive and extensive shrimp culture. The interspatial TFP index is a relative cost index showing how much more or less costly a country is compared to the reference country (Philippines). For example, Table 3.3 shows that Bangladesh has a relative cost index of 1.12 for extensive shrimp culture meaning that it would cost Bangladesh about 12% more to produce the same value of production as the Philippines given the same input prices. For extensive culture, Sri Lanka, Thailand and India were found to be more efficient than the Philippines, while Bangladesh, Indonesia and China were less efficient and Cambodia, Myanmar and Vietnam significantly less efficient. For semi-intensive culture, Indonesia and the Philippines appeared to be operating at the same efficiency level. Malaysia, Sri Lanka and India were more efficient than the Philippines, while Bangladesh, Vietnam and China were less efficient. With respect to intensive culture, China was the only country found to be less efficient than the Philippines. Most of the countries showed a TFP index of about 0.5 meaning they can produce the same value of production at about half the cost of the Philippines.

Table 3.3 Intercountry comparisons of efficiency of shrimp farming systems

	Extensive		Semi-intensive		Intensive	
Country	TFP	DEA	TFP	DEA	TFP	DEA
Bangladesh	1.12	0.11	1.43	0.48		
Cambodia	5.69	0.08			0.59	0.43
China	2.25	0.20	3.18	0.30	3.63	0.33
India	0.91	0.16	0.89	0.92	0.69	0.69
Indonesia	1.83	0.09	1.03	1.00	0.81	0.52
Korea					0.68	1.00
Malaysia			0.61	1.00	0.56	0.75
Myanmar	3.90	0.02				
Philippines	1.00	0.41	1.00	0.96	1.00	0.53
Sri Lanka	0.31	0.40	0.64	1.00	0.48	0.74
Taiwan					0.50	1.00
Thailand	0.62	1.00			0.53	0.59
Vietnam	3.61	0.11	2.15	0.69		

TFP = Interspatial total factor productivity index. DEA = Data envelopment analysis index.

It should be noted that the above index may be biased if the quality of inputs are not reflected in the reported prices and if the true shadow prices of the inputs deviate significantly from the reported prices. Nevertheless, this simple index number approach provides a comprehensive comparison of differences in intercountry efficiency.

Efficiency index estimated by DEA measures the technical efficiency of the uses of three major inputs in shrimp production, namely, labor, feed and seed. A value of one indicates the country is on the efficient production frontier and hence it is technically efficient. A country is technically inefficient if inputs can be reduced without reducing output, or output can be increased without increasing the amount of inputs. More efficient countries will have an efficiency index close to one. It differs from the TPF index in that prices of inputs are not taken into account and thus allocative efficiency is ignored. Only the physical quantity of inputs is considered in DEA. However, as mentioned earlier, DEA compares the efficiency of a particular system in each country with reference to all other countries with respect to input usage. For example, the efficiency index shows a value of 0.11 for extensive shrimp culture in Bangladesh indicating that relative to the most efficient operations in the region, Bangladesh can reduce inputs proportionally by about 89% to produce the same value of output.

For extensive culture, Vietnam, Cambodia, Bangladesh and Myanmar were found to be highly inefficient while Thailand was the most efficient. For semi-intensive culture, Malaysia, Indonesia and Sri Lanka were the most efficient while China and Bangladesh were found to be very inefficient. For intensive culture, Korea and Taiwan were the most efficient while China was the least efficient. Malaysia and Sri Lanka were quite close to the efficient frontier and thus were fairly efficient in input usage.

It should be noted that the two indices are in general agreement with each other but they may sometimes differ with respect to their rankings because they measure different aspects of production efficiency. However, this analysis is preliminary in nature and results should be interpreted with care.

3.3.6 Comparative advantage

There are a number of measures of comparative advantage but the two widely used are the domestic resource cost (DRC) analysis and the index of 'revealed' comparative advantage (RCA) (Ling et al., 1996). The DRC approach focuses on the implication of the comparative advantage for resource allocation which is based on the concept of social opportunity costs. A country has a comparative advantage in the production of a given commodity if the social opportunity costs of producing, processing, marketing and transporting an incremental unit of the commodity are less than the world prices. The DRC can be expressed as follows (see Ling et al., 1996 for a more detailed mathematical expression of DRC):

$$\boxed{\text{DRC} =} \quad \frac{\begin{array}{c}\text{The opportunity costs in local currency of non-tradable inputs}\\ \text{required in producing a unit of a commodity}\end{array}}{\begin{array}{c}\text{Net foreign exchange (foreign exchange earnings from exporting}\\ \text{-opportunity costs in foreign currency of tradable inputs required in}\\ \text{a unit of a commodity)}\end{array}} \qquad (3.1)$$

By comparing the DRC with the equilibrium nominal exchange rate (E) which is taken as the shadow value of the exchange rate, the resource cost ratio (RCR) becomes a measure index of comparative advantage at a given point in time, as expressed below:

$$\text{RCR} = \text{DRC/E} \qquad (3.2)$$

If RCR < 1, there is a comparative advantage in producing and exporting the particular commodity. RCR > 1 and RCR = 1 indicate a comparative disadvantage and comparative neutrality, respectively. For intercountry comparison, if one country has a lower ratio of RCR than another country, it indicates that the country has a relatively higher comparative advantage than the latter in exporting the commodity in question.

To apply the RCR approach to the Asian shrimp farming industry, the costs of production information in major shrimp farming countries are again extracted from the NACAP/ADB survey data. To calculate the DRC ratio, all inputs except feed item are treated as domestic non-tradable costs. Feed that is either produced domestically or imported is treated as tradable foreign cost item. Since a majority of international trade in shrimp is provided in the frozen form, only frozen shrimp is considered in the analysis. The C.I.F. (cost, insurance and freight) prices in foreign markets are treated as shadow prices of shrimp exports, taking into account opportunity costs of transport, storage, distribution and quality differences. The average 1994 C.I.F. prices of frozen shrimp are used as a base and collected for three major markets: Japan, the United States and Europe. Shrimp prices received by exporters in foreign markets would vary due to shrimp size differences, exchange fluctuations, quality differences and consumer preferences.

Comparisons of RCR index distribution within three shrimp farming systems are illustrated in Table 3.4. Aside from China (intensive) with respect to markets in US (1.02) and Bangladesh (semi-intensive) with respect to the European market (1.15), the values of RCR ratio are less than one in all countries for each individual system and indicate the comparative advantage in producing and exporting shrimp to those markets. The range of the RCR ratio is between 0.14 and 0.98. While nearly all countries demonstrate comparative advantage, Thailand and Indonesia have the relatively lower RCR ratio and appear to have stronger comparative advantage over the remaining countries. As a result of the premium price in Japan, the RCR ratio appears to be lowest in the Japanese market and commands a substantial comparative advantage, followed by the US and then the EU markets, regardless of farming system.

Table 3.4 RCR (resource cost ratio) indices of shrimp farming systems in Asia, by market

Country	Extensive			Semi-intensive			Intensive		
	Japan	US	EU	Japan	US	EU	Japan	US	EU
Bangladesh	0.48	0.43	0.51	1.09	0.97	1.15			
China	0.18	0.42	0.37	0.17	0.38	0.34	0.42	1.02	0.89
India	0.32	0.67	0.73	0.35	0.72	0.78	0.33	0.69	0.74
Indonesia	0.33	0.45	0.43	0.21	0.29	0.27	0.25	0.34	0.33
Malaysia				0.27	0.64	0.63	0.21	0.49	0.49
Philippines	0.22	0.24		0.17	0.18		0.44	0.47	
Sri Lanka	0.26	0.27		0.18	0.19		0.18	0.19	
Taiwan							0.47	0.77	0.92
Thailand	0.14	0.17	0.23				0.19	0.22	0.31
Vietnam	0.74	0.39	0.98	0.66	0.35	0.87			

Among Asian intensive shrimp farming systems, Thailand and Indonesia have the relatively stronger comparative advantage in all three markets. For semi-intensive system, China, Indonesia and the Philippines have the relatively stronger comparative advantage in the Japanese and/or US markets. The variation of RCR ratio for the extensive system is smaller than that of the other two systems. All RCR ratios for the selected countries are much less than one but India and Vietnam appear to have less comparative advantage in the extensive system.

Returning to the DRC equation, the DRC ratio can be improved by increase in export price and reduction in input costs, either in costs of domestic or foreign inputs. The DRC approach allows decision-makers to identify the areas that need to be improved in order to strengthen their comparative advantages.

3.4 Limitations for development

High demand and high price of shrimp in the 1980s generated high profit in shrimp farming. This lured increasing number of investors into shrimp farming in many countries. The whole process resembled a gold rush. However, the rapidly expanding shrimp industry started to face problems since 1988 (Csavas, 1995).

First to appear were the ecological limits. High profits in shrimp farming and increasing coastal land prices pushed shrimp farmers towards more intensive operation, first in Taiwan followed by Thailand and other countries. Without effective control, intensive operations usually increase the nutrient and organic matter load to the ecosystem well beyond the carrying capacity of the environment. This often results in self-pollution which leads to more frequent disease outbreaks followed by crop failure. The collapse of the shrimp culture industry in Taiwan in 1988 and China in 1993 are good examples. Simultaneously, intensive shrimp culture creates many externalities. For example, discharging pond effluents from intensive operations often causes water pollution in farms downstream, which may result in serious losses; conversion of mangrove to shrimp ponds usually results in reduction of mangrove products, loss of nursery ground for fisheries and coastal erosion; use of ground water for shrimp ponds may result in other crop reduction, land subsidence, salt water intrusion in ground water and agricultural field as in Taiwan. These externalities usually create significant social costs to society which may limit shrimp industry development.

Socio-economic limitations started to emerge at about the same time. As mentioned earlier, investors in intensive shrimp culture are mostly entrepreneurs rather than farmers, outsiders rather than local residents. There is only a marginal trickle-down of benefits of intensive shrimp farming to local communities. In addition, conversion of mangrove and other cropland to shrimp ponds often creates unemployment for unskilled local labor. As for economic limitation, production grew faster than demand in the late 1980s, the world market was saturated around 1989, prices slumped, profitability of shrimp farming eroded, and marginal producers were forced out of business. Hardest hit were the high-cost producers operating under intensive culture systems. The prices of shrimp have recovered the past few ears but the competition among major shrimp producers has become tough. Only efficient producers will survive

3.5 Toward sustainable growth

After an impressive growth phase, shrimp farming has created various socio-economic and environmental problems in many countries, thus sustainable development has become a major concern of the industry. Many shrimp farmers often seek to maximize their short-term gain at the expense of the environment. The 'rape and run' practice in shrimp farming, where ponds in mangrove areas are farmed intensively and quickly abandoned as observed in Thailand and the Philippines, is a good example. This type of farming violates the criterion of sustainability and therefore, is unsustainable. Shrimp farming is sustainable if it is in harmony with other economic activities in using natural resources. It should produce a reasonable and relatively stable net income/benefit to producers/society on a long-term basis without degrading the environment. Its development has to be balanced among production, marketing and other supporting services (such as hatchery, feed mill, legal measures, etc.). Therefore, a sustainable shrimp farming system has to be bio-technically feasible, environmentally sound and socio-economically viable. These three aspects are interrelated (Shang and Tisdell, 1996).

At the farm level, net farm income is affected by the level of production, farm price and operating cost. Increase in farm productivity, reduction in production costs and increase in average farm price received are major measures to improve economic viability. Farm productivity depends mainly on (1) stocking rate, survival rate and growth rate of the stock, which are in turn affected by bio-technical factors such as rate of feeding/fertilization, mono or polyculture, stocking and harvesting strategies, etc., and (2) environmental factors such as water quality (water temperature, dissolved oxygen, pH levels, etc.), chemical inputs to treat diseases and predators, etc. Farm shrimp price is mainly affected by size, form and quality of the product in a competitive seasonal market (see later discussion). The best combination of inputs and the most suitable culture intensity/system are mainly determined by available resources and cost, and the farmer's management ability. Improvement in farmer's management ability is a key factor for sustainable operation, which can be improved by providing adequate extension and/or short training.

The costs of production, on the other hand, relate to the level and prices of inputs, culture system, size of operation, waste treatment as well as institutional factors such as costs of credit, marketing, land lease and the like. The costs of waste treatment or pollution prevention, or the taxes on discharging effluents are not usually included in conventional financial analysis, but they are important cost items for a sustainable operation.

Feed is the most important cost item for a relatively intensive operation. Cost of feed per unit shrimp produced depends primarily on the conversion ratio of feed to shrimp and unit price of feed. Therefore, the cost of feed can be reduced by improving the conversion ratio or by lowering the unit price of feed, or by a combination/substitution of these two factors. The conversion ratio in turn can be improved by reducing waste and improving feed formula. Waste can be reduced by feeding the right amount of feed. The economic principle of feeding is that the amount of feed should be at a level where the additional cost of feed equals its additional benefit generated in revenue. Overfeeding results in higher cost of feed per unit shrimp produced and in water pollution. The unit cost of feed can also be lowered by utilizing locally available materials for feed instead of imported ones.

Seed is another major cost item in several countries. Recent prices of postlarvae have been substantially reduced due to stiff competition of small/medium hatcheries in most of the Asian shrimp producing countries. Further cost reduction is possible only in those newly started countries by improving the hatchery management. But there is an urgent need to develop a sustainable broodstock supply in order to reduce dependence on wild-caught breeders.

Diseases have emerged as a major constraint to the sustainable growth of shrimp aquaculture. Many diseases are linked to environmental deterioration and stress associated with farm intensification. Disease prevention is more important than treatment. The solution to the problem must deal with site selection, design and sustainable farm management. The economics of alternative ways of disease control (e.g. applying drugs and vaccines, fallowing the ponds after each harvest, etc.) need to be assessed and compared for sustainable development. In the long run, genetic improvement of the cultured species is likely to result in disease-resistant strain, greater tolerance to environmental variation and faster growth. The improved virus free fry may also reduce the disease problems in the grow-out stage.

Water is usually not included as a cost item in aquaculture production except the pumping cost. However, as the quantity and quality of water diminishes and deteriorates in the future, the cost of suitable water could become an important cost item for a sustainable operation. Deteriorated water quality causes diseases and low survival rate for intensively managed farms. Better pond management is essential to improve water quality. Cleaning up incoming water in settling ponds, using closed culture systems, sediment management and polyculture are some of the alternatives to improve water quality if they are economically feasible.

As mentioned earlier, shrimp farming creates externalities or spillovers which are important factors influencing the sustainable development. When externality exists, this implies that the private costs of a commercial shrimp farm are less than the social costs of this farming activity. Consequently, if the farm aims to maximize its private profit, it dose not take account of its adverse spillovers. Economic intervention in this case is often needed to bring the private costs of the farm into line with its social costs thereby internalizing the externality (Shang and Tisdell, 1996).

The most popular policy forms recommended to reduce externalities are taxes, subsidies, standards and regulations/permits. Tax is a fee collected by the public agency imposed on each unit of pollutant discharged into public waters. Subsidy is often used in the form of lower input cost for waste treatment/pollution reduction or tariff exemption on imported pollution control equipment. Standards establish maximum acceptable levels of waste discharged. These measures tend to induce shrimp farmers to find cost-effective methods to meet environmental constraints for sustainable development (Shang and Tisdell, 1996).

Regulations/permits are often required to use land and water for aquaculture, to use of particular chemicals on the farm, to discharge effluents into public waters, to import exotic species and to convert mangroves for fish ponds in the developed world. But the shrimp farming industry in many Asian countries is almost unregulated. It is most interesting to review some recently enacted rules and regulations by the Thai government to mitigate the negative environmental impacts of shrimp farming (Lin, 1995; Csavas, 1995).

It is important to mention that most of these measures involve monetary and enforcement costs and may also be difficult to apply. The benefits generated by these measures may not always be justified by their costs. These have to be considered in economic decision making.

3.6 Concluding remarks

Reduction in production costs and negative environmental impacts through bio-technical improvement and efficient management are all important for sustainable development, but the existence of a potential market and an efficient marketing system, together with other adequate supporting services such as hatcheries, feed mills, credit, research, training and extension are necessary. Therefore, in addition to improving production efficiency and minimizing negative environmental impacts, the shrimp farming industry needs to coordinate its production and marketing, diversify markets and products and improve product quality in order to sustain growth. When externalities exist, public intervention is often needed to reduce the externalities if such action is socio-economically justifiable. It is also important to remember that natural resources will have to be shared with all potential users in a way that will benefit society and not harm the ecosystem.

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Chapter 4

Intercountry productivity comparisons of black tiger shrimp culture in Asia

PingSun Leung and Lokugam H.P. Gunaratne

Abstract

This study examines intercountry productivity differences of extensive, semi-intensive and intensive black tiger shrimp production systems in Asia. For each system of culture intensities, countries are compared in terms of both partial productivity indexes for major shrimp inputs (i.e. labor, feed and seed) and total factor productivity measures. This information can be useful for intercountry transfer of appropriate technologies in order to improve the long-term sustainability of shrimp farming in the region.

4.1 Introduction

The global shrimp farming industry expanded rapidly in the 1980s mainly due to technological breakthroughs in hatchery techniques, high demand for shrimp resulting in high price and high profit of shrimp farming and increased public support. Farmed shrimp amounted to about 712,000 metric tonnes (mt) in 1995, which accounted for about 27% of the total shrimp production from both wild-caught and farm-raised. Asia produced about 78% of farmed shrimp and western countries 22%. Thailand was the leading producer, followed by Ecuador, Indonesia, China, India, Vietnam, Bangladesh and the Philippines. Black tiger shrimp (*Penaeus monodon)* was the most important species farmed, accounting for 57% of cultured shrimp production, followed by western white shrimp *(Penaeus vannamei)* at 20%.

However, the growth of shrimp industry has slowed down since 1991 due to serious disease outbreak linked to environmental deterioration. This serious aquatic disease situation has led to huge economic losses in almost all of the shrimp producing countries of the Asia-Pacific region. As a result, Asian Development Bank (ADB) and the Network of Aquaculture Centers in Asia-Pacific (NACA) conducted a regional study aiming at developing broad-based action plan to assist governments and farmers in formulating effective strategies for, among others, sustainable shrimp development. Through a farm level survey, this regional study attempted to provide an understanding of the environmental problems and their subsequent economic impact. Using the data from the farm survey, this article compares the productivity of the black tiger shrimp culture in the region so as to identify static technological differences across producing countries for systems of various intensities. (The survey yielded data on a season's, or, at best, a year's crop so that comparison over time could not be made – hence, “static”.) This comparison should provide background

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information for intercountry transfer of appropriate technology in order to improve the long-term viability of shrimp farming in the region.

4.2 Index of productivity

Economists commonly use partial productivity ratios, such as output per worker and output per hectare to compare productivity of various agricultural production systems. The observed static differences in the partial productivity ratios are generally associated with differences in the use of modern industrial inputs as substitutes for land and labor. The dynamic or time differences of these ratios, on the other hand, provide a good indication of technological changes. But recognizing the inadequacy of these partial productivity ratios, economists have developed a more comprehensive concept which compares output with the combined use of all inputs. Total factor productivity or TFP index, which is the ratio of an index of total output to an index of all factor inputs, is adopted widely as the standard approach to the measurement of total factor productivity. We have compared both the partial and total productivity indexes of black tiger shrimp culture across the Asia-Pacific countries of various production intensities.

Since the NACA/ADB farm survey provides only a snapshot in time, the dynamics of technological changes cannot be discerned.

4.3 Comparisons of production value and major input use

Table 4.1 provides the annual average production value (in US$), labor use (in persondays), feed use (in kg), and amount of seed stocked (in 1,000 Pls) per hectare of production by country and by intensity.

Production value is used instead of production quantity to account for market size and form differences. Production value and quantity are highly correlated for all cases except for Taiwan, where production value is proportionally higher as it produces for the live market. As the table shows, production value has less variation with higher intensity. This may imply that technologies used by intensive and semi-intensive systems are more homogeneous across countries. This is also confirmed by the observed labor, feed and seed inputs. For extensive systems, production value ranges from a low of $409 (Myanmar) to a high of $13,807 (Sri Lanka), while the ranges for semi-intensive and intensive systems are respectively, $7,222 (Vietnam) to $36,485 (Malaysia), and $19,286 (the Philippines) to $71,707 (Sri Lanka).

Labor use ranges from a low of 90 (the Philippines) to a high of 789 persondays (Sri Lanka) for extensive systems. For semi-intensive systems, besides Sri Lanka which recorded 1,467 persondays, labor use is quite similar for the rest of the countries with a range from 472 to 771 persondays. For intensive systems, Sri Lanka again has the highest labor use of 1,334 persondays while Taiwan has the lowest use of 221 persondays. The rest of the countries do not show significant differences in labor use with a range of 425 to 946 persondays.

Table 4.1 Annual average production value, labor use, feed application, and seed stocked by intensity and country

System/ Country	Production value(US$/ha)	Labor use (persondays/ha)	Feed application (kg/ha)	Seed stocked (1,000Pls/ha)
Extensive				
Bangladesh	1,393 d	166 c	162 d	17 e
India	6,039 b	642 a	1,027 b	47 c
Indonesia	3,930 c	175 c	397 c	57 b
Myanmar	409 e	147 c	98 d	29 d
Philippines	1,901 d	90 d	107 d	14 e
Sri Lanka	13,807 a	789 a	2,745 a	160 a
Vietnam	1,989 d	492 b	367 c	26 d
Average	4,210	357	700	50
Semi-intensive				
Bangladesh	12,527 b	661 b	4,503 b	317 b
India	19,609 b	472 b	3,994 b	172 d
Indonesia	12,155 b	478 b	2,483 c	196 c
Malaysia	36,485 a	534 b	9,687 a	446 a
Philippines	17,576 b	531 b	6,456 b	197 c
Sri Lanka	29,492 a	1,467 a	8,567 a	250 b
Vietnam	7,222 c	771 b	984 d	124 e
Average	19,295	702	5,239	243
Intensive				
Cambodia	31,246 b	425 b	9,879 c	587 b
Indonesia	34,914 b	809 b	8,269 c	799 b
Malaysia	62,229 a	428 b	14,122 b	766 b
Philippines	19,286 c	631 b	7,578 c	252 c
Sri Lanka	71,708 a	1,334 a	13,747 b	502 b
Taiwan	38,430 b	221 c	4,807 c	693 b
Thailand	75,350 a	946 b	20,975 a	1,240 a
Average	47,595	685	11,340	691

Means denoted by same letter are not statistically different at the 0.05 level.

Feed application ranges from 98 kg (Myanmar) to 2,745 kg (Sri Lanka) for extensive systems, 984 kg (Vietnam) to 9,687 kg (Malaysia) for semi-intensive systems, and 4,807 kg (Taiwan) to 20,975 kg (Thailand) for intensive systems. Stocking rate ranges from 17,196 Pls (Bangladesh) to 160,156 Pls (Sri Lanka) for extensive systems, 123,781 Pls (Vietnam) to 445,520 Pls (Malaysia) for semi-intensive systems, and 251, 692 Pls (the Philippines) to 1,239,797 Pls (Thailand) for intensive systems. Amount of feed applied and stocking density generally increase with increased intensity. However, labor usage is not very much different for intensive and semi-intensive systems.

4.4 Comparisons of partial productivity ratios

Table 4.2 shows the partial productivity ratios for labor, feed and seed inputs expressed as production value per hectare per unit of input. For extensive systems, Indonesia, the Philippines and Sri Lanka have very high labor productivity while that for Myanmar and Vietnam is extremely low. This may reflect the lower cost of labor in Myanmar and Vietnam and the differential labor quality.

Feed productivity (or feed conversion) is highest for the Philippines while the other countries do not show much difference. Seed productivity (or survival rate) is highest for the Philippines and India while Myanmar is lowest. It is interesting to see that while the Philippines has the second lowest production value per hectare, it has the highest productivity for all three factor inputs. This may be so because of relatively higher cost of the three factor inputs as compared to land for the extensive system in the Philippines.

Labor productivity is generally higher with increased intensity probably because of higher level of mechanization. Feed efficiency for semi-intensive and intensive systems is quite similar but lower than extensive systems. Seed efficiency does not show a particular trend with respect to intensity levels.

Table 4.2 Partial productivity ratios by intensity and country

System/ Country	Labor ($/ha/day)	Feed ($/ha/kg)	Seed ($/ha/1,000 Pls)
Extensive			
Bangladesh	8.4	8.6	81.0
India	9.4	5.9	128.3
Indonesia	22.4	9.9	69.0
Myanmar	2.8	4.2	14.0
Philippines	21.1	17.8	131.8
Sri Lanka	17.5	5.0	86.2
Vietnam	4.0	5.4	76.5
Semi-intensive			
Bangladesh	19.0	2.8	39.5
India	41.6	4.9	113.7
Indonesia	25.5	4.9	62.2
Malaysia	68.4	3.8	81.9
Philippines	33.1	2.7	89.1
Sri Lanka	20.1	3.4	118.1
Vietnam	9.4	7.3	58.3
Intensive			
Cambodia	73.5	3.2	53.2
Indonesia	43.1	4.2	43.7
Malaysia	145.3	4.4	81.3
Philippines	30.6	2.5	76.6
Sri Lanka	53.8	5.2	142.8
Taiwan	173.5	8.0	55.4
Thailand	79.6	3.6	60.8

4.5 Comparisons of total factor productivity (TFP)

A more complete assessment of productivity can only be made with the total factor productivity (TFP) index which takes into account all factor inputs. Figs. 4.1-4.3 show the TFP for each system in each country as compared to the average system in the region. It is expressed as a relative cost index indicating how much more or less a particular country is as compared to the average in the region. For example, Bangladesh shows an index of 1.37 for the extensive system (Fig. 4.1) meaning that it would cost Bangladesh about 37% more to produce the same value of output than the average in the region.

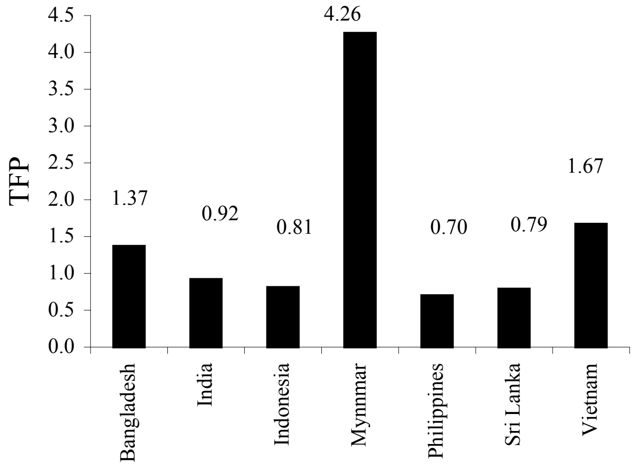

Fig. 4.1 Total factor productivity of extensive systems

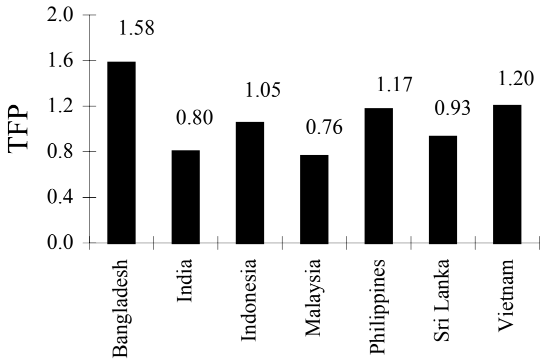

Fig. 4.2 ***Total factor productivity of semi-intensive systems***

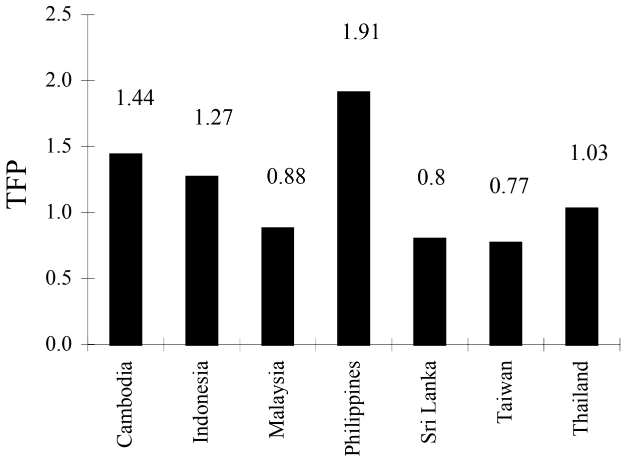

Fig. 4.3 Total factor productivity of intensive systems

Taking into account the differential input prices faced by each country, the TFP index provides a comprehensive comparison of the productivity levels in each producing country. The Philippines is the most productive country for the extensive system in the region, followed by Sri Lanka, Indonesia and India. Myanmar is the least productive, followed by Vietnam and Bangladesh; all three countries are found to be more costly than the average in the region to produce the same value of output.

With respect to the semi-intensive system (Fig. 4.2), Malaysia, India and Sri Lanka are found to be more productive while Bangladesh, Vietnam and the Philippines are less productive than the average in the region. Indonesia's productivity is very close to the regional average. As shown in Fig. 4.3, Taiwan, Sri Lanka and Malaysia are the most productive countries for the intensive system while Cambodia, the Philippines and Indonesia are less productive. Thailand has a productivity level very close to the regional average.

4.6 Productivity of various systems

It is interesting to note that Sri Lanka has a consistently high productivity in the region for all three intensities. Malaysia also demonstrates a high productivity level for its intensive and extensive systems, and India has a consistently high level of productivity for its extensive and semi-intensive systems.

On the other hand, although the Philippines has the most productive extensive systems in the region, its semi-intensive and intensive systems are not as productive as compared to the regional averages. In fact, the Philippine intensive systems are the least productive in the region. This may indicate the relative resource endowments and hence its comparative advantage or disadvantage in adopting production systems of various intensities.

Indonesia shows a similar pattern as the Philippines: its extensive systems are more productive while the higher intensity systems are less productive. With the relatively recent introduction of shrimp culture in Vietnam, it is understandable that its productivity is less than the regional average. However, the Vietnamese semi-intensive systems are more productive than the extensive systems. Similarly, the newly entering countries such as Myanmar and Cambodia are less productive. The extensive and semi-intensive systems of Bangladesh are also less productive. As expected, the more experienced countries such as Taiwan and Thailand are more productive.

Chapter 5

Asian black tiger shrimp industry: a meta-production frontier analysis

Lokugam H.P. Gunaratne and PingSun Leung

In this paper, the analytical framework for the stochastic meta-production frontier model is reviewed. Next, the estimated meta-production and country-specific production frontiers and technical efficiencies are presented for extensive, semi-intensive and intensive black tiger shrimp *(Penaeus monodon)* production systems in Asia. Then, the regional performances of the three production systems are compared. This is followed by an examination of the influence of farm-specific variables on technical efficiency. Finally some concluding remarks are presented.

5.1 Introduction

The farmed shrimp industry in Asia experienced rapid growth during the past two decades, mainly because of sustained high shrimp prices, technological breakthroughs, large investments and expansion of US and Japanese markets for shrimp. Currently, Asia dominates the cultured shrimp production, accounting for more than 80% of global shrimp production. The rapid expansion of the industry together with overuse use of inputs has led to various production and environmental problems, including destruction of mangrove forests, groundwater depletion, soil salinization, estuarine eutrophication and serious disease outbreaks in many parts of Asia. Inability to sustain productivity is the major concern of this rapid growth of the industry and adoption of resource-intensive production practices. For instance, leading shrimp producing countries, especially China, Taiwan and Indonesia have faced production collapses during the past decade. Similarly, competition among shrimp producing countries in Asia has heightened. With the decline of real prices, the competition will become even more intense.

Therefore, policies that help sustain long-term productivity of the industry are imperative. To be sustainable, production should be within the carrying capacity of the supporting ecosystems. Hence, understanding production structure and productive efficiency of shrimp production in Asia as a whole as well as in individual countries is very useful in developing appropriate strategies for the development of sustainable shrimp industry in the region.

In light of this, the objective of this paper is to compare production characteristics and the levels of technical efficiency in black tiger shrimp *(Penaeus monodon)* production in Asian countries using the stochastic meta-production frontier. A second concern is to investigate the factors affecting technical efficiency.

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5.2 Analytical framework

5.2.1 The concept of meta-production frontier

Since only farms that produce black tiger shrimp are included in this study and different culture intensities/systems are being handled separately, a meta-production frontier is deemed appropriate to represent the production structure of shrimp culture in Asia. The meta-production function, which was first introduced by Hayami (1969) and Hayami and Ruttan (1971), is defined as the common underlying production function for a given industry among several countries. The concept of meta-production function does not, however, imply that all the producers operate on a universal production function. Rather, it is an envelope of all neoclassical production functions where producers are on different micro-production functions due to the differences in adoption and diffusion of technology.

The meta-production function was developed based on the assumption that all countries under consideration have a similar access to the technology, but each may choose to operate on a different portion of the envelope depending on resource endowments, relative factor prices and basic economic environments. After the seminal work of Hayami and Ruttan (1971) most of the studies (Mundalk and Hellinghausen, 1982; Kawagoe and Hayami, 1985; Binswanger et al*,* 1987; Lau and Yotopolous, 1989) that compared international agricultural productivity used this concept mainly due to its empirical attractiveness as mentioned by Lau and Yotopolous (1989). An increase in the domain of applicability, a reduction of multicollinearity and an improvement in the reliability of prediction are some of the advantages of using the meta-production function (Lau and Yotopolous, 1989). In this study, the meta-production function concept is extended to the stochastic meta-production frontier to examine the production technology and technical efficiency of the black tiger shrimp industry in nine shrimp producing countries in Asia.

The concept of the stochastic meta-production frontier is similar to that of standard meta-production function approach proposed by Hayami (1969) and Hayami and Ruttan (1971) except that the error term in the former is comprised of two components, namely a symmetric random error and a non-negative technical inefficiency term similar to that in the stochastic production frontier model originally proposed by Aigner et al. (1977) and Meeusen and van den Broeck (1977).

One of the major limitations of using meta-production function is non-comparability of the data across countries. We are fortunate to use highly comparable data gathered under the Aquaculture Sustainability and Environment Survey during the same period (1994/95) using the same questionnaire throughout all the countries involved in the analysis. Also, only the data on black tiger shrimp are being used, and estimations are carried out by system/intensity. The second limitation as indicated by Lau and Yotopolous (1989) is corrected by introducing dummy variables into meta-production frontier models to account for country-specific differences. Furthermore, besides the regional or meta-frontier, own or country-specific frontiers are also estimated for each production system. The results obtained from the two models were compared.

5.2.2 Model specification

The Cobb-Douglas functional form was chosen to characterize back tiger shrimp production technology for several reasons. First, the Cobb-Douglas functional form has been shown to be theoretically sound and attractive due to its computational feasibility and availability of adequate degrees of freedom for statistical testing (Heady and Dillon, 1969). For this reason, the Cobb-Douglas form has been most widely used functional form in farm-level efficiency studies for both developing and developed countries (Bravo-Ureta and Pinheiro, 1993). Secondly, the Cobb-Douglas function was chosen because of high degree of multicollinearity in some country-specific models when using a more flexible translog form. Also in several countries there was a lack of enough observations to estimate the translog form. Choosing the Cobb-Douglas technology for individual country-specific and regional models maintains the consistency for intercountry efficiency comparisons. Kawagoe et al. (1985) stated that the unitary elasticity of substitution implicit in the Cobb-Douglas function was tested elsewhere (Arrow et al., 1961; Griliches and Ringstad, 1971) but no evidence was found against its appropriateness for the intercountry comparisons. Following Aigner et al. (1977) and Meeusen and van den Broeck (1977), the Cobb-Douglas stochastic frontier in this study is specified as:

$$\mathrm{Ln}Y_i = \beta_0 + \beta_1 \mathrm{Ln}(X_{1i}) + \beta_2 \mathrm{Ln}(X_{2i}) + \beta_3 \mathrm{Ln}(X_{1i}) + V_i - U_i \qquad (5.1)$$

where Y_i is the value of shrimp production for the i-th farm in the sample (in US$/ha); X_1 is labor used (in persondays/ha); X_2 is the amount of feed applied (in kg/ha); X_3 is seed stocked in terms of number of post larvae (Pl) (in 1,000 Pl/ha); β_1, β_2, and β_3 are output elasticities of labor, feed and seed, respectively; V_i is the symmetric random error term distributed independently and identically ($N(0, \sigma_v^2)$) to capture errors outside the farmer's control; U_i is the one-sided error term used to denote technical efficiency in production, distributed independently and identically with non-negative truncation of the normal distribution $|(N(0, \sigma_u^2)|$. Then technical efficiency (TE) of the i-th farm is derived as:

$$\mathrm{TE}_i = \exp(-U_i) \qquad (5.2)$$

Eqn. 5.1 gives the stochastic production frontier model for each country for each production system. Following Hayami and Ruttan (1971) the regional or meta-production frontier is obtained by pooling all the observations across the region for each system. Moreover, country dummies are added to account country-specific characteristics as suggested by Lau and Yotopolous (1989).

The average levels of value of production and labor, feed and seed used by the sample shrimp farms by culture intensity and country are presented in Table 5.1.

Table 5.1 Average annual production value, labor used, feed applied and seed stocked by intensity and by country

System/ Country	No. of farms analyzed	Production value (US$/ha)	Labor (days/ha)	Feed (kg/ha)	Seed (1,000 Pl/ha)
Extensive					
Bangladesh	64	1,393	166	162	17
India	343	6,039	642	1,027	47
Indonesia	159	3,930	175	397	57
Philippines	49	1,901	90	107	14
Vietnam	140	1,989	492	367	26
Semi-intensive					
Bangladesh	22	12,527	661	4,503	317
India	120	19,609	472	3,994	172
Indonesia	322	12,155	478	2,483	196
Malaysia	36	36,485	534	9,687	446
Philippines	56	17,576	531	6,456	197
Sri Lanka	77	29,492	1,467	8,567	250
Vietnam	38	7,222	771	984	124
Intensive					
Indonesia	119	34,914	809	8,269	799
Malaysia	36	62,229	428	14,122	766
Philippines	14	19,286	631	7,578	252
Sri Lanka	25	71,708	1,334	13,747	502
Taiwan	17	38,430	221	4,807	693
Thailand	258	75,350	946	20,976	1,240

5.2.3 Factors affecting technical efficiency levels

Three farm characteristics (farm size, experience and land ownership) and three management variables (fish, water and feed) are analyzed to determine their effect on technical efficiency of shrimp framing. Means of these variables are presented in Table 5.2.

In general, larger farms are alleged to be more efficient than smaller ones due to better organization and access to technical knowledge and higher growth resulting from past efficiency in the former (Pitts and Lee, 1981). On the other hand, smaller farms have the advantage of being able to regulate inputs and hence to improve technical efficiency. Lau and Yotopolous (1971) and Sidhu (1974) drew different conclusions on impact of farm size on productive efficiency. It is expected that older farmers have higher technical efficiency presumably because of greater experience and technical knowledge (Battese and Coelli, 1996). The newly entering farmers are generally less concerned with the sustainability of the industry relative to the experienced farmers. When pond farms are operated by the owner, he/she has more concerns over long-term productivity and hence attempts to increase the technical efficiency by carefully managing inputs.

Management activities such as monitoring of stock survival or checking of feed trays obviously have a positive impact on shrimp production. Therefore, a number of management activities carried out on pond farms as listed in the NACA questionnaire under regular fish management and monitoring activities, pond water quality monitoring and feed management activities are assumed to increase technical efficiency in carp production.

Table 5.2 Means of farm-specific and management variables

System/ Country	Farm size (ha)	Experience (years)	Shrimp management[a]	Water management[b]	Feed management[c]
Extensive					
Bangladesh	5.09	2.89	0.67	0.79	0.04
India	1.90	2.97	1.91	2.77	1.39
Indonesia	3.12	8.32	1.85	2.66	0.68
Philippines	13.80	9.48	2.11	2.11	1.16
Vietnam	3.54	4.36	2.25	1.74	1.02
Semi-intensive					
Bangladesh	5.87	5.74	2.18	3.68	2.46
India	4.49	1.63	2.47	3.99	2.20
Indonesia	7.83	9.02	2.41	4.44	1.95
Malaysia	2.01	4.61	2.03	4.08	2.31
Philippines	5.34	6.45	3.06	6.82	2.75
Sri Lanka	1.70	2.99	1.91	2.91	2.09
Vietnam	1.82	2.77	2.56	2.11	1.37
Intensive					
Indonesia	4.57	5.35	2.79	4.92	2.87
Malaysia	3.37	4.67	2.08	6.93	2.61
Philippines	3.30	6.29	3.19	3.74	2.74
Sri Lanka	2.38	3.00	2.06	3.33	2.35
Taiwan	2.13	4.40	2.53	4.54	0.92
Thailand	1.52	3.76	2.69	4.82	1.99

[a] Shrimp management:
Regular monitoring of stock survival
Daily monitoring of shrimp behavior
On-farm shrimp health laboratory/check
Off-farm shrimp health laboratory/check

[b] Pond water quality monitoring:
pH/alkalinity
Salinity
Dissolved oxygen
Nutrients (N and/or P)
Water color and turbidity
Assess sediment condition
Measure of quality of effluent water
Measure quality of inflow water

[c] Feed management:
Feeding tray/checking of left over feed
Regular FCR calculation during production
Regular production/operating cost analysis

5.3 Results and discussion

The parameters for country-specific frontier and meta-frontier models were estimated using the maximum-likelihood (ML) estimation program, FRONTIER 4.1 (Coelli, 1994), which estimates the variance parameters of the likelihood function in terms of $\sigma^2 = \sigma_v^2 + \sigma_u^2$ and $\gamma = \sigma_u^2 / \sigma^2$. The results for the country-specific frontiers are presented in Table 5.3 and for the meta-frontiers in Table 5.4.

5.3.1 Country-specific production frontiers

As shown in Table 5.3, the null hypothesis, $\gamma = 0$ was rejected for all the individual country-specific models for the extensive system, suggesting that one-sided inefficiency error term dominates the variability in shrimp production under the extensive system and that the OLS or average production function is not appropriate. The null hypothesis of constant returns to scale was not rejected for Bangladesh, India and the Philippines. However, the rest of the countries showed decreasing returns to scale. The coefficient estimates or output elasticities of inputs varied widely across countries. The estimated coefficients had appropriate signs but no all coefficients were significantly different from zero. The output elasticity of labor was generally low in all countries except for the Philippines. Feed elasticity ranged from 0.04 in the Philippines to 0.67 in India. Seed elasticity was significant for all countries and ranged from a low of 0.22 in India to a high of 0.65 in Bangladesh.

The technical inefficiency effects were also significant in explaining the variability in shrimp production under the semi-intensive system. The only exception was Bangladesh where the γ parameter was not statistically different from zero. However, both the intercept and the log likelihood values were greater for the ML estimates than the OLS estimates, which indicate that stochastic production frontier is superior to the average production function in that country. The models for Bangladesh, the Philippines and Vietnam rejected the null hypothesis of constant returns to scale in favor of decreasing returns to scale. The output elasticity of labor was fairly low in all countries except for Bangladesh where it was as high as 0.46. The feed elasticity varied from 0.29 in the Philippines to 0.79 in Malaysia. The semi-intensive farms in Vietnam were also quite responsive to feed application, with the feed elasticity of 0.59. Similarly, the output elasticity for seed ranged from a low of 0.11 in Bangladesh to a high of 0.49 in Indonesia.

The null hypothesis, H_o: $\gamma = 0$, which implies that the conventional average or OLS production function is adequate, was rejected for intensive shrimp production for all countries, except for Sri Lanka. Although the γ parameter for Sri Lanka was not significantly different from zero, improvement of intercept and log-likelihood values in ML estimation over the OLS method suggest that the stochastic production frontier is a better representation of intensive shrimp culture in Sri Lanka. The null hypothesis of constant returns to scale was not rejected for Malaysia and Taiwan. The intensive farms in Indonesia, the Philippines, Sri Lanka and Thailand exhibited decreasing returns to scale. Although all the coefficients had expected signs, some parameter estimates in several countries were not significantly different from zero. Output elasticity of labor ranged from 0.06 for Thailand to 0.42 for Taiwan. The output elasticity for feed also depicted a wide variability across countries, ranging from 0.09

for Indonesia to 0.56 for Malaysia. The results suggest that intensive shrimp farms are more responsive to feed in Malaysia and the Philippines but less responsive in Indonesia and Sri Lanka. In general, seed elasticities were significant in most countries but generally less responsive as compared with other inputs.

Table 5.3 Maximum likelihood estimates of the parameters for the country-specific production frontiers

System/ Country	Labor	Feed	Seed	σ^2	γ	Log (likelihood)
Extensive						
Bangladesh	0.092	0.305**	0.651***	3.011**	0.725***	-105.72
	(0.183)	(0.147)	(0.224)			
India	0.018	0.673***	0.220***	0.669***	0.826***	-285.35
	(0.039)	(0.040)	(0.062)			
Indonesia	0.133**	0.113***	0.336***	1.494***	0.968***	-167.71
	(0.065)	(0.037)	(0.069)			
Philippines	0.290***	0.039	0.489***	2.767***	0.999***	-54.74
	(0.096)	(0.061)	(0.071)			
Vietnam	0.017	0.359***	0.248***	4.831***	0.976***	-226.89
	(0.090)	(0.068)	(0.085)			
Semi-intensive						
Bangladesh	0.458**	0.149	0.107	1.097	0.748	-24.90
	(0.165)	(0.104)	(0.689)			
India	0.027	0.356***	0.405***	0.625***	0.953***	-76.61
	(0.060)	(0.099)	(0.124)			
Indonesia	0.096*	0.366***	0.485***	0.486***	0.669***	-249.10
	(0.051)	(0.038)	(0.081)			
Malaysia	0.054**	0.794***	0.161*	0.113	0.954***	7.01
	(0.028)	(0.172)	(0.103)			
Philippines	0.094**	0.292***	0.220***	1.283***	0.999***	-47.99
	(0.023)	(0.036)	(0.024)			
Sri Lanka	0.041	0.352***	0.433***	0.325***	0.806***	-36.86
	(0.037)	(0.068)	(0.105)			
Vietnam	0.193	0.594***	0.189	0.399	0.936***	-60.56
	(0.148)	(0.109)	(0.189)			
Intensive						
Indonesia	0.188**	0.087*	0.159	1.375***	0.931***	-127.46
	(0.086)	(0.049)	(0.121)			
Malaysia	0.173***	0.559***	0.258**	0.157***	0.951***	1.54
	(0.055)	(0.081)	(0.124)			
Philippines	0.242	0.495***	0.190***	0.234**	0.999***	-0.37
	(0.179)	(0.042)	(0.048)			
Sri Lanka	0.270***	0.117	0.283***	0.111	0.892	2.27
	(0.071)	(0.190)	(0.116)			
Taiwan	0.424***	0.305*	0.277***	1.730	0.999***	-17.56
	(0.029)	(0.154)	(0.085)			
Thailand	0.060	0.222	0.216	0.802	0.971	187.96
	(0.030)	(0.036)	(0.046)			

*** Significant at the 0.01 level, ** significant at the 0.05 level, and * significant at the 0.10 level.
Figures in parentheses are asymptotic standard errors. Intercept values are not provided due to space limitations.

5.3.2 Regional or meta-production frontiers

The ML estimates for the parameters of meta-production frontiers for each of the three culture systems in the region are given in Table 5.4. The γ parameter was significant and higher than 0.80 in all three systems. Similar to the country-specific models, technical inefficiency effects were significant in explaining the variations in the level of shrimp production in Asia. This suggests that the conventional average production functions are inadequate to represent the production structure of three shrimp culture systems in Asia. All the regional or meta-stochastic frontier models rejected the null hypothesis of constant returns to scale, suggesting that the shrimp industry in Asia as a whole is operating at decreasing returns to scale. Among the inputs, labor had a negligible contribution to output compared with other two inputs, particularly in the extensive system. These results indicate that labor is less responsive in the extensive system and more responsive in the intensive system. On the other hand, feed and seed seem to be more responsive under the extensive production system.

Table 5.4 Maximum likelihood estimates of the parameters of meta-production frontiers

	Extensive	Semi-intensive	Intensive
Constant	37.257***	18.335**	865.026**
	(0.368)	(0.380)	(0.561)
Labor	0.028	0.062**	0.127***
	(0.036)	(0.027)	(0.026)
Feed	0.319***	0.399***	0.167***
	(0.029)	(0.024)	(0.025)
Seed	0.305***	0.266***	0.205***
	(0.041)	(0.034)	(0.045)
D_1 (Bangladesh)	0.888***	0.082	-
	(0.139)	(0.166)	
D_2 (India)	-0.041	0.667***	-
	(0.098)	(0.122)	
D_3 (Indonesia)	0.364***	0.389***	0.722***
	(0.106)	(0.114)	(0.125)
D_4 (Malaysia)	-	0.639***	-0.367**
		(0.157)	(0.149)
D_5 (Philippines)	0.580***	0.505***	-0.965***
	(0.153)	(0.134)	(0.164)
D_6 (Sri Lanka)	-	0.608***	-0.443**
		(0.134)	(0.163)
D_7 (Taiwan)	-	-	-0.319**
			(0.137)
σ^2	2.143***	0.774***	0.942***
	(0.142)	(0.065)	(0.079)
γ	0.926***	0.793***	0.942***
	(0.015)	(0.038)	(0.016)
Log (likelihood)	-980.641	-616.440	-404.633

*** Significant at the 0.01 level, ** significant at the 0.05 level, and * significant at the 0.10 level.
Numbers in the parentheses are asymptotic standard errors.

As mentioned earlier, inter-country differences were accounted for by including the country-specific dummy variables in each meta-production frontier model. The effects due to differences in resource endowments, relative factor prices and other economic environments are captured by these dummies. Thus, the coefficients associated with these dummy variables indicate differences in performance relative to the reference country. In other words, best-practice frontier for a country lies above or below that of the reference country within the meta-production frontier framework. Vietnam was treated as the reference country in extensive and semi-intensive systems, while Thailand was the reference country for the intensive system. The results revealed some countries outperforming others within the regional stochastic frontier framework. For the extensive system, Bangladesh, the Philippines and Indonesia outperformed Vietnam and India. Bangladesh and Vietnam appeared to be below the rest of the countries for the semi-intensive system. For the intensive system, Thailand was found to be superior to rest of countries in the region.

5.3.3 Technical efficiencies

The mean technical efficiencies for the three shrimp production systems given by country-specific and meta-production frontier models are presented in Table 5.5. Also presented in Table 5.5 are potential earnings increases by operating at full technical efficiency levels.

The mean technical efficiencies for the extensive system varied from a low of 0.353 in Vietnam to a high of 0.61 in India with respect to country-specific or own frontier models. However, in terms of the meta-frontier model the technical efficiency estimates for the extensive system were more or less similar across the countries, ranging from 0.472 for India to 0.526 for Vietnam. It is interesting to note that India showed the highest performance with respect to the country-specific or own frontier but showed the poorest performance in terms of the regional frontier. This indicates that India has more potential for improving production by adopting best-practice technology available in the region.

As shown in Table 5.5, for the semi-intensive system all countries except the Philippines and Vietnam had a mean technical efficiency of more than 0.50 with respect to their own production frontiers. The mean technical efficiencies ranged from 0.37 in Vietnam to 0.783 in Malaysia. When comparisons were made with respect to the regional or meta-frontier, the mean technical efficiencies varied very little across countries, with an overall regional average of 0.60. Similar to the extensive system, countries that performed better with respect to their own frontiers such as India, Indonesia and Malaysia did not perform better in terms of the regional frontier. This suggests that these countries have most potential for increasing production by adopting best-practice technology in the region. On the other hand, the performance of the Philippines and Vietnam improved when these countries were compared relative to the regional frontier. Meanwhile, countries such as India appeared to be invariant to the reference level implying that they are already adopting best-practice technology found in the region.

With respect to country-specific or own frontiers, intensive farms in Sri Lanka had the highest mean technical efficiency of 0.789 while those in Taiwan had the lowest score of 0.467. It is noteworthy that Sri Lanka's technical efficiency dropped by 0.22 when farmers were compared against the regional frontier, indicating that the country has most potential to increase efficiency by using the best technology in the region. The technical efficiencies for intensive farms in Taiwan and Thailand were similar between the country-specific and meta-frontiers.

Several points are worth mentioning. Some countries were more efficient in terms of their own frontier but this was not true in terms of the regional frontier when adjusted for country-specific differences. For example, India for the extensive system, Malaysia and Sri Lanka for the semi-intensive system, and Malaysia, the Philippines and Sri Lanka in the intensive system showed higher performance with respect to their own frontiers compared to the regional frontiers. This implies these countries have more scope to improve production by adopting regional technology. However, Vietnam and the Philippines in extensive and semi- intensive systems, and Indonesia and Taiwan in the intensive system showed higher technical efficiencies with respect to the meta-frontier and relatively lower technical efficiencies in terms of their own frontiers.

Table 5.5 Mean technical efficiencies and potential earnings increases based on country-specific models and the regional or meta-production frontier models

System/ Country	Technical efficiency		Potential earnings increase (US$/ha)	
	Country-specific	Meta-frontier	Country-specific	Meta-frontier
Extensive				
Bangladesh	0.417	0.476	7,409	6,532
India	0.610	0.481	2,714	4,595
Indonesia	0.478	0.472	4,090	6,711
Philippines	0.474	0.491	1,381	1,574
Vietnam	0.353	0.526	3,783	1,852
Region		0.488	3,876	4,253
Semi-intensive				
Bangladesh	0.550	0.576	8,961	7,051
India	0.624	0.621	10,631	9,960
Indonesia	0.673	0.603	5,157	6,801
Malaysia	0.783	0.625	9,241	20,800
Philippines	0.465	0.590	20,331	11,315
Sri Lanka	0.694	0.613	12,348	17,701
Vietnam	0.370	0.580	7,231	2,175
Region		0.600	10,558	10,830
Intensive				
Indonesia	0.506	0.549	30,549	27,561
Malaysia	0.763	0.608	19,442	30,659
Philippines	0.700	0.569	10,007	15,996
Sri Lanka	0.789	0.564	19,148	55,319
Taiwan	0.467	0.500	38,851	25,898
Thailand	0.592	0.595	49,402	48,565
Region		0.566	27,900	34,000

The results showed substantial inefficiencies in shrimp production in the region, improving efficiency seems to be a key to increase production, given current resources and the technology. The mean potential increments in production values at full technical efficiency levels are presented in Table 5.5. Accordingly, if farmers operate on the best-practice frontier of their country, on average, annual per hectare earnings for extensive, semi-intensive and intensive systems could increase by $3,876, $10,558 and $27,900, respectively. The corresponding figures for the regional or meta-frontier were $ 4,253, $10,830 and $34,000, respectively.

5.3.4 Factors affecting technical efficiencies

The above results show substantial technical inefficiencies within and among shrimp producing countries in Asia. In order to identify the sources of inefficiencies, the technical efficiency scores generated by country-specific and meta-production frontiers were regressed against a set of farm-specific variables. Such variables included farm size (in ha), farmer experience (in years), whether the farm is managed by owner or not (i.e. 1 if farm is owner-operated or 0 otherwise) and the number of shrimp, pond and feed management activities. Since the results for country-specific and meta-frontier modes were very similar, only the results obtained from the latter are discussed here. These results are presented in Table 5.6.

Overall, the impact farm-specific variables on technical efficiency was rather ambiguous. However, in some instances a clear relationship was found between the efficiency and farm-specific variables. In case of the extensive farm, farm size had no influence on technical efficiency except for Bangladesh, where small farms were more efficient. The fact that large farms are not technically efficient in extensive systems is important since extensive farms are predominantly large in size. Operator's experience had no significant impact on technical efficiency in the extensive farm. Owner-operation had a negative impact on technical efficiency of extensive farms in India. Among the three management variables, shrimp management, pond management and feed management had a positive impact on technical efficiency in the extensive system in Vietnam, Indonesia and India, respectively.

The regression results for the semi-intensive system revealed a positive relationship between farm size and technical efficiency in Sri Lanka and a negative relationship in India and Indonesia. As in the extensive system, farmer's experience did not have a significant influence on technical efficiency in the semi-intensive system. Owner-managed farms tended to be less efficient in Sri Lanka. Regular/shrimp management in the Philippines, pond management in Indonesia and Vietnam and feed management in India and Malaysia showed positive relationships with technical efficiency.

In the case of intensive system, large farms were found to be more efficient in Thailand. This fact is important given the presence of a large number of small farms (< 1.0 ha) in Thailand and ifs dominant position in global shrimp production. Contrary to expectations, experienced farmers in Malaysia and Thailand appeared to be less efficient. Experience, however, was positively associated with technical efficiency of intensive shrimp production in the Philippines. Owner-operation had a positive effect in Indonesia and Malaysia and negative effect in Sri Lanka. Interestingly, the analysis further revealed that regular/shrimp management activities did not contribute to improvement of technical efficiency in intensive shrimp production. However, pond management improved technical efficiency in Indonesia and Taiwan and feed management had a positive relationship with technical efficiency in Thailand and Sri Lanka.

Table 5.6 Impact of farm-specific variables on technical efficiency obtained from the meta-frontiers

System/ Country	Farm size	Experience	Owner-operated	Shrimp management	Pond management	Feed management
Extensive						
Bangladesh	-0.012***	0.016	-0.007	-0.026	-0.010	0.068
	(0.004)	(0.014)	(0.079)	(0.039)	(0.026)	(0.045)
India	0.003	-0.002	-0.081*	0.005	0.003	0.074***
	(0.003)	(0.003)	(0.042)	(0.016)	(0.009)	(0.012)
Indonesia	0.005	-0.002	-0.063	-0.017	0.022**	-0.029
	(0.007)	(0.002)	(0.062)	(0.024)	(0.011)	(0.021)
Philippines	0.001	-0.006	0.075	-0.040	-0.027	-0.005
	(0.002)	(0.006)	(0.070)	(0.078)	(0.024)	(0.046)
Vietnam	-0.001	0.005	-0.088	0.042**	-0.029	0.026
	(0.003)	(0.006)	(0.080)	(0.021)	(0.019)	(0.022)
Semi-intensive						
Bangladesh	-0.003	-0.020	0.014	0.105	-0.011	0.118
	(0.010)	(0.014)	(0.129)	(0.169)	(0.067)	(0.107)
India	-0.006**	-0.013	0.022	0.015	0.002	0.033*
	(0.003)	(0.012)	(0.027)	(0.018)	(0.008)	(0.020)
Indonesia	-0.014**	-0.001	-0.029	0.001	0.031***	0.019
	(0.006)	(0.001)	(0.019)	(0.012)	(0.006)	(0.018)
Malaysia	-0.010	0.010	0.005	-0.003	0.059	0.028**
	(0.008)	(0.050)	(0.072)	(0.051)	(0.038)	(0.010)
Philippines	-0.003	-0.002	-0.082	0.173**	-0.006	-0.026
	(0.004)	(0.002)	(0.061)	(0.094)	(0.018)	(0.033)
Sri Lanka	0.009*	-0.002	-0.055*	-0.004	-0.013	-0.015
	(0.005)	(0.006)	(0.035)	(0.028)	(0.010)	(0.017)
Vietnam	-0.010	0.009		0.019	0.045**	0.030
	(0.011)	(0.023)		(0.045)	(0.017)	(0.033)
Intensive						
Indonesia	0.002	0.008	0.069*	-0.025	0.039***	0.051
	(0.003)	(0.006)	(0.040)	(0.025)	(0.014)	(0.044)
Malaysia	-0.005	-0.023*	0.152**	0.049	0.022	-0.032
	(0.010)	(0.014)	(0.071)	(0.037)	(0.016)	(0.039)
Philippines	-0.034	0.047**	0.015	-0.107	-0.012	0.356
	(0.026)	(0.024)	(0.109)	(0.185)	(0.049)	(0.263)
Sri Lanka	-0.012	-0.008	-0.193**	-0.035	0.016	0.080**
	(0.010)	(0.016)	(0.064)	(0.071)	(0.021)	(0.037)
Taiwan	0.040	0.308	0.029	-0.306	0.159*	0.095
	(0.032)	(0.228)	(0.163)	(0.270)	(0.095)	(0.091)
Thailand	0.013***	-0.001*	-0.020	-0.013	-0.008	0.023**
	(0.005)	(0.0004)	(0.024)	(0.020)	(0.007)	(0.013)

*** Significant at the 0.01 level, ** significant at the 0.05 level, and * significant at the 0.10 level.
Numbers in parentheses are standard errors.

5.4 Conclusions

The main objective of this study was to examine the levels and sources of technical efficiency in farmed shrimp production among Asian countries. The farm-level data of extensive, semi-intensive and intensive production systems were analyzed using the stochastic production frontiers. Besides country-specific or own frontiers for individual countries, regional or meta-production frontiers were also estimated for the region as a whole for each production systems. The meta-production frontier approach is particularly useful for inter-country comparison of efficiency levels. The shrimp production was explained in terms of three major inputs, namely labor, feed and seed. In order to identify factors influencing technical efficiency in shrimp production, the efficiency scores were regressed against a set of farm-specific variables, including farm size, experience, ownership, and adoption of recommended shrimp, pond and feed management activities.

All inputs had positive impact on shrimp production based on both country-specific and regional models. However, their effects were not always statistically significant. Of the three inputs considered, feed seemed to be most crucial factor. Shrimp production exhibited both constant and decreasing returns to scale based on country-specific and decreasing returns to scale in terms of meta-frontiers. Controlling for country-specific differences, shrimp farms in Bangladesh, the Philippines and Indonesia were found to be more efficient than those from Vietnam and India for the extensive system. Similarly, in the case of semi-intensive system Bangladesh and Vietnam appeared to be less productive than other countries. Thailand was superior to the rest of the countries involved in intensive shrimp production.

The technical inefficiency effects were significant in almost all cases, which suggests that irrespective of culture systems and choice of models, shrimp farmers in the region operated below their best-practice production frontier. More specifically, the extensive, semi-intensive and intensive farms were operating 54%, 40% and 43% below the frontier production level, respectively. On average, by operating at full technical efficiency the extensive, semi-intensive and intensive shrimp producers could increase their per-hectare annual earnings by \$4,253, \$10,830 and \$34,000, respectively.

Although though there was a wide variability in technical efficiency across countries, the results did not reveal a consistent set of determinants to explain inter-country differences technical efficiencies in shrimp production. However, in most cases, the farm-specific variables considered were significantly associated with technical efficiency. Where the effects were significant, farm size had a negative effect on efficiency of extensive and semi-intensive farms and positive effect on intensive farms. In general, owner-operation was negatively associated and experience was positively associated with technical efficiency. The adoption of shrimp, pond and feed management improved technical efficiency in shrimp production under all three systems.

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Chapter 6
Productivity analysis of Malaysian cultured shrimp industry

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Abstract

Black tiger shrimp (*Penaeus monodon*) culture accounts for 85% aquaculture production in Malaysia and it is the fastest growing aquaculture sector. The recent changes in shrimp farming in Malaysia, such as increased stocking density, indicate a trend towards intensification that can be detrimental to the sustainability of the industry. Against this background, the production characteristics and efficiency of resource use in the Malaysian black tiger shrimp industry were examined. The data for this study came from a national survey of Malaysian shrimp farms, undertaken by the Network of Aquaculture Centers in Asia-Pacific (NACA) during 1993/1994. The survey covered a sample of 83 farms, which accounted for 11% of the total shrimp farms in intensive and semi-intensive production systems. Excluding potential outliers, 36 intensive and 36 semi-intensive farms were used in the analysis. Three major inputs, namely labor, feed and seed were considered. Both parametric stochastic production frontier and nonparametric data envelopment analysis (DEA) techniques were employed to estimate the farm-level technical, allocative and economic efficiencies for intensive and semi-intensive shrimp farms. The results obtained from the two approaches were compared. The efficiency estimates indicate that there is substantial potential for improving the level of shrimp production using existing inputs and available technology in both systems. None of the efficiency indices (technical, allocative and economic) for the intensive system was significantly higher than those for the semi-intensive system were. This raises questions about the present trend of increased intensification. In both systems, on average, optimum levels of feed and seed were lower than their actual levels. These results not only highlight the production structure of the Malaysian shrimp industry but also have implications on sustainability of the industry.

6.1 Introduction

Although the value of aquaculture production was only 0.2% of GDP (gross domestic product) in Malaysia in 1993, this sector has shown a promising trend during the recent years. Aquaculture production nearly doubled from 53,100 metric tonnes (mt) in 1989 to 105,200 mt in 1993. Brackish water culture of black tiger shrimp (*Penaeus monodon*) is the fastest growing aquaculture activity. According to the reports of Network of Aquaculture Centers in Asia-Pacific (NACA), in 1993, the industry produced 4,600 mt of shrimp per year from 1,880 ha and provided direct employment of about 17,000, in addition to the people engaged in various related activities, such as harvesting, processing and marketing of shrimp.

However, the level of shrimp production in Malaysia is very low compared to its Southeast Asian neighbors, such as Thailand, Indonesia and the Philippines. FAO sources indicate that the Asia-Pacific region produced 680,800 mt of shrimp in 1993. Malaysia contributed to only 0.6% of the regional production. Yahaya (1994) identified lack of technical expertise, unsuitable pond construction and production methods, and inadequate public and private financial support as the major constraints

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to shrimp aquaculture development in Malaysia. According to USDC (1992), some of the failures in earlier attempts at shrimp culture development could also be attributed to pond construction in some mangrove areas with acidity in pond water.

Attractive prices and increasing demand for shrimp in Japanese, US and European markets stimulated government and private entrepreneurs to take various steps to develop the shrimp industry during the past decade. Large areas of mangrove forests in west coast of Malaysia were identified as suitable for mariculture development. To capture this potential, especially in Johor state, the number of farms increased tenfold from 1982 to 1992. With the involvement of private sector, the government of Malaysia plans to join the rank of leading shrimp producing countries in the region by the year 2000 by producing 21,000 mt of shrimp from 22,000 ha of converted mangrove areas into aquaculture (USDC, 1992).

Although its share in international market is small, the Malaysian shrimp culture is one of the most productive systems in Asia. NACA data indicates that, in terms of production per hectare, the Malaysian semi-intensive system is the most productive in Asia while its intensive system is as productive as that of Thailand. This high productivity can be attributed to technical and financial support provided by the government, efficient farm management techniques, introduction of new hatchery techniques and more productive ponds located in tidal river at the end of mangrove areas.

Of the two major shrimp production systems practiced in Malaysia, the intensive system is more productive because of adoption of improved practices, such as supplementary feeding and artificial aeration that ensure high survival and growth rates. However, as indicated by Yahaya (1994) and NACA (1995), besides the stocking density, the production characteristics of the two production systems are not substantially different. The intensive system is characterized by high stocking density with the general cut-off level of 30 Pl/m^2. Despite higher production cost per hectare, the intensive system is more profitable than the semi-intensive system because both yield per crop and production per hectare are also higher in the former.

In order to meet the local and export demand, further improvements in the industry are needed. Conversion of large areas of mangrove forests in peninsular Malaysia into shrimp farming is carried out with the involvement of private entrepreneurs and multinational companies. The other observed changes in the industry include increased stocking density, use of formulated feed, mechanical feeding and increased pond area. The NACA reports that more experienced farmers tend to increase the stocking density. Yahaya (1994) also confirms this fact and states that present trend in Malaysia is practicing intensive farms with high stocking density.

Rapid expansion together with increased intensification of shrimp culture in other Asian countries such as in Taiwan and China gave rise to severe environmental deterioration, including destruction of mangrove habitats, coastal water pollution, soil salinization and massive disease outbreaks. Large-scale shrimp farming is relatively new to Malaysia, so it has not yet experienced these problems. However, with the conversion of mangrove lands into ponds, and increasing feed use and stocking density, possibilities of occurrences of environmental and diseases problems are also high in Malaysia. For example, based on NACA report 25% of farmers had water quality problems while 15% had disease problems during 1993. Therefore, identification of appropriate measures that enable Malaysian shrimp farmers to maintain the long-term viability of the industry while enjoying satisfactory profits is imperative. In light of this, this study attempts to examine the production technology of intensive and semi-intensive production systems in Malaysia, with a particular emphasis on efficiency of resource use.

6.2 Theoretical framework

A production function is defined as the locus of maximum possible output that can be produced from a given set of inputs and existing technology. The best-practice function that gives the maximum possible output is known as the production frontier. In his seminal paper Farrell (1957) described the concept of efficiency in terms of deviation from the best-practice frontier. Technical efficiency refers to the ability of a firm to produce maximum possible output using a given set of inputs and available technology. Allocative efficiency deals with the optimum use of input combinations given their prices and is measured in terms of deviation from the input use corresponding to the minimum cost. The product of these two, technical and allocative efficiencies, is defined as economic (or cost) efficiency.

Farrell (1957) provided computational framework for measuring both technical and allocative efficiencies. He suggested two ways to tackle the issue: one is to estimate econometric frontiers such as production or cost frontiers; the other is to estimate a free disposal convex hull of the observed input-output ratios using mathematical programming techniques. During past three decades, techniques for efficiency analysis have been developed around these two competing paradigms.

6.2.1 Parametric approach

The stochastic frontier production function approach was independently proposed by Aigner et al. (1977) and Meeusen and van den Broeck (1977). The essential idea of this method is that the error term is comprised of two components, symmetric random error (statistical noise) that are outside the firm's control and one-sided technical inefficiency term. The stochastic frontier (SF) model can be expressed as:

$$Y_i = f(X_i;\beta)\exp(V_i - U_i) \tag{6.1}$$

where i = 1, ..., n observations in the sample; Y_i is the observed production level of i-th firm; $f(X_i;\ \beta)$ is a suitable production functional form with respect to input vector, X_i, and unknown parameter vector β ; U_i is a non-negative random variable representing technical inefficiency; and V_i is the random error term which is assumed to be distributed independently and identically as $N(0,\ \sigma_v^2)$ and independent of U_i. The frontier output (Y_i^*) is represented by $f(X_i;\beta)\exp(V_i)$.

Several researchers (Aigner et al., 1977; Battese and Corra, 1977) suggested that maximum likelihood estimates of the parameters can be obtained in terms of parameterization, $\sigma_v^2 + \sigma^2 = \sigma_s^2$ and $\gamma = \sigma^2/(\sigma_v^2 + \sigma^2)$ where σ and σ_V are standard deviations of U_i and V_i, respectively. Then the technical efficiency (TE) of the i-th firm is the ratio of the observed output to the corresponding frontier output as:

$$TE_i = Y_i / Y_i^* = \exp(-U_i) \tag{6.2}$$

Following this concept, stochastic frontier models have been applied to estimate TE in a wide variety of agricultural production activities. Reviews of these studies can be found in Bauer (1990) and Battese (1992).

The economic and allocative efficiency scores are derived using the duality theory in which the cost frontier is derived algebraically from the estimated stochastic frontier if the production technology is self-dual such as the Cobb-Douglas form. Then the economically or cost efficient input levels are computed using the Shephard's lemma, and the ratio of cost of economically efficient inputs to actual cost yields a measure of economic efficiency. The ratio of economic efficiency to technical efficiency provides a measure of allocative efficiency. Mathematical details for this approach can be found in Bravo-Ureta and Evenson (1994) and Bravo-Ureta and Rieger (1991).

6.2.2 *Nonparametric approach*

Following Farrell's (1957) proposal on estimating a piece-wise linear convex hull, Charnes et al. (1978) developed a mathematical programming technique to establish a best-practice frontier without imposing restrictions on production technology. This technique is known as data envelopment analysis (DEA). The assumptions of the original DEA model were extended to output-oriented and variable returns to scale specifications (Banker et al., 1984).

If we have K inputs and M outputs on each of the N firms or decision making units (DMUs), then KxN input matrix, X, and MxN output matrix, Y, represent the data pertaining to all N DMUs. For the i-th DMU, inputs and outputs are represented in terms of X_i and Y_i vectors, respectively. Then for the i-th DMU first we obtain a ratio measure $\mu'Y_i / \nu'X_i$ where μ and ν are output and input weights, respectively. The optimal weights are given by following mathematical programming problem.

$$\max_{\mu,\nu} (\mu'Y_i / \nu'X_i) \qquad (6.3)$$

st.

$$(\mu'Y_i / \nu'X_i) \leq 1 \qquad j = 1,2..........N.$$

$$\mu, \nu \geq 0$$

Imposing constraint $\nu'X_i = 1$ to avoid infinite number of solutions to the above and considering the dual problem, the DEA model can be rewritten as:

$$\min_{\theta,\lambda} \theta \qquad (6.4)$$

st.

$$-Y_i + Y\lambda \geq 0$$

$$\theta X_i - X\lambda \geq 0$$

$$\lambda \geq 0$$

where θ is a scalar and λ is a Nx1 vector of optimal weights attached to each of efficient DMUs. The θ represents the technical efficiency (TE) score of the i-th DMU. If $\theta = 1$, the i-th DMU is on the frontier and technically efficient and if $\theta < 1$, the DMU lies below the frontier and it is technically inefficient. Solving the linear programming problem in Eqn. 6.3 N times yields the efficiency index for each of the

N DMUs. The efficiency score obtained from the above model corresponds to the constant returns to scale (CRS). Imposing an additional constraint that optimal weights add up to one ($1'\lambda = 1$) yields the efficiency score under the variable returns to scale (VRS).

The piece-wise linear programming problem for DEA frontier has a problem related to input slacks. A second stage programming technique was suggested by Ali and Seiford (1993) but in most of the studies researchers simply solve the problem in Eqn. 6.3 first ignoring the slacks, and then compute the slacks residually.

The DEA methodology has been extended and applied to a wide range of issues during the past two decades. Detailed reviews can be found in Seiford and Thrall (1990), Ali and Seiford (1993) and Seiford (1996). One useful extension is the cost-minimizing DEA model in order to estimate economic (or cost) efficiency (Färe et al., 1985). This model can be expressed as:

$$\min_{X_i^*,\lambda} W_i^{/} X_i^* \tag{6.5}$$

st.

$$-Y_i + Y\lambda \geq 0$$

$$X_i^* - X\lambda \geq 0$$

$$\lambda \geq 0$$

where X_i^* is the cost-minimizing or economically efficient input vector for the i-th DMU, given its input price vector, W_i and the output vector, Y_i. The economic or cost efficiency (EE) index for the i-th DMU is then computed as:

$$EE_i = W_i^{/} X_i^* / W_i^{/} X_i \tag{6.6}$$

which is the ratio of the minimum cost to the actual cost. The allocative efficiency (AE) index is derived as the ratio between EE and TE.

6.3 Data and empirical procedures

6.3.1 Data

The data were obtained from the Aquaculture Sustainability and Environment survey, conducted by Network of Aquaculture Centers in Asia Pacific (NACA) during September 1994 - February 1995. The survey covered 11% of the total shrimp farms in Malaysia. The objectives of the NACA study were to develop policy guidelines for environmentally sustainable aquaculture and disseminate the results to the target groups to implement action plan to improve the sustainability of the industry and to control the further environmental deterioration at the farm level.

The total number of shrimp farms operating in Malaysia in 1993 were about 752 (intensive 371; semi-intensive 381) which included 530 farms in Peninsular Malaysia and 220 in Sabah and Sarawak (NACA, 1994). The NACA survey drew a sample of 83 farms which covered four major brackish water shrimp production provinces/states (Kedah, Perak, Selangar and Johor) and two production systems/strata (intensive and semi-intensive) in peninsular Malaysia. After excluding possible outliers, 36 farms from each production system (a total of 72 farms) were used for the analysis. In order to account for form and price differentials, production value (US $/ha) was used as the dependent variable. Three major inputs, including labor used (persondays/ha), feed applied (kg/ha) and seed stocked (Pls/ha) were considered. Other inputs (chemicals, fertilizer, etc.) were not included for two reasons. First is the unavailability of data on these inputs in some semi-intensive farms. Secondly, these other inputs did not constitute a significant portion of total production cost.

Table 6.1 Description of output and input variables by production system

	Mean	Standard deviation	Minimum	Maximum
Intensive				
Output ($/ha)	64,277	32,070	7,550	137,350
Labor (persondays/ha)	467	342	74	1,379
Feed (kg/ha)	15,536	9,549	3,636	49,091
Seed (1,000 PL/ha)	808	319	333	1,870
Semi-intensive				
Output ($/ha)	38,782	21,363	2,301	79,784
Labor (persondays/ha)	605	467	45	2,179
Feed (kg/ha)	10,087	4,935	776	20,000
Seed (1,000 PL/ha)	461	167	98	900

As shown in Table 6.1, the mean production value of the intensive system was much higher than that of the semi-intensive system ($64,277/ha vs. $38,782/ha, respectively). The intensive system can be characterized by higher feed and seed use and lower labor use compared with the semi-intensive system. The labor productivity for the intensive system was twice that for the semi-intensive system ($137.6/personday/ha vs. $64.1/personday/ha, respectively) possibly due to utilization of sophisticated technology such as artificial feeding and mechanical aeration. The mean farm sizes for intensive and semi-intensive systems were 3.38 ha and 2.01 ha, respectively.

6.3.2 *Empirical models*

The stochastic frontier (SF) model is defined to be as:

$$\mathrm{Ln}Y_i = \beta_0 + \beta_1 \mathrm{Ln}(X_{1i}) + \beta_2 \mathrm{Ln}(X_{2i}) + \beta_3 \mathrm{Ln}(X_{3i}) + V_i - U_i \tag{6.7}$$

where subscript i (i = 1,2,…, 36) denotes the number of shrimp farms in the sample; Y_i is the production value of black tiger shrimp for the i-th farm in ($/ha); X_1 is labor used in shrimp production (persondays/ha); X_2 is the amount of feed (kg/ha); X_3 is seed stocked in terms of number of post-larvae (Pls/ha); and V_i and U_i are random variables, defined earlier.

The Cobb-Douglas functional form was chosen as attempts at estimating a more flexible functional form (e.g., translog) were unsuccessful due to multicollinearity problem and inconsistent parameter estimates. Production frontiers were estimated separately for intensive and semi-intensive systems, as the preliminary analysis using pooled data revealed that the production structure of Malaysian shrimp industry cannot be represented by a single frontier.

Similarly, the DEA model to calculate technical efficiency of the i-th sample farm in each production system can be expressed as:

$$\min_{\theta,\lambda'} \theta_i \tag{6.8}$$

st.

$$\lambda_1 Y_1 + \lambda_2 Y_2 + \ldots + \lambda_{36} Y_{36} \geq Y_i$$

$$\lambda_1 X_{1,1} + \lambda_2 X_{1,2} + \ldots + \lambda_{36} X_{1,36} \geq \theta_i X_{1,i}$$

$$\lambda_1 X_{2,1} + \lambda_2 X_{2,2} + \ldots + \lambda_{36} X_{2,36} \geq \theta_i X_{2,i}$$

$$\lambda_1 X_{3,1} + \lambda_2 X_{3,2} + \ldots + \lambda_{36} X_{3,36} \geq \theta_i X_{3,i}$$

$$\lambda'(\lambda_1, \lambda_2, \ldots, \lambda_{36}) \geq 0\,.$$

The solution to this problem yields θ (technical efficiency) and optimal weights (λ) for the i-th farm in the sample. Solving the linear programming problem 36 times gives the technical efficiency of all farms. The empirical DEA model for economic or cost efficiency (cost-minimizing DEA) is specified and solved in a similar manner.

The maximum likelihood estimation method, FRONTIER 4.1 (Coelli, 1994) was used to estimate the stochastic production frontiers and technical efficiencies. Based on a derived dual cost frontier, the optimum input levels were obtained using Shephard's lemma to compute the economic and allocative efficiencies. DEA analysis was carried out using DEAP 2.1 (Coelli, 1996) which generates technical, allocative and cost efficiencies as well as optimum input levels.

6.4 Results and discussion

6.4.1 Stochastic frontier estimates

The maximum likelihood estimates of the parameters of Cobb-Douglas stochastic frontiers for intensive and semi-intensive black tiger shrimp production farms in Malaysia are presented in Table 6.2. Since the null hypothesis (H_o: $\gamma = 0$) that there are no technical inefficiencies among the sample shrimp farms was rejected in both cases, the average (OLS) production function models are not adequate representations of the shrimp production in Malaysia. The signs of the coefficients were, as expected, positive in both systems. The coefficients or output elasticity estimates for all the input variables in the intensive system and the coefficient for feed in the semi-intensive system were significant at the 0.01 level. However, labor and seed coefficients for the semi-intensive system were significant at the 0.05 and 0.10 levels, respectively. Output elasticity was the highest for feed, followed by seed and labor in both cases. Output elasticities for seed and labor were higher for the intensive system while feed has higher output elasticity for the semi-intensive system. This implies that, relative to intensive farms, semi-intensive ones are more responsive to the feed application and less responsive to labor and stocking rate. The returns to scale estimates (i.e. the sum of output elasticities of inputs) for intensive and semi-intensive systems were 0.990 and 1.009, respectively and hence both systems exhibit constant returns to scale.

6.4.2 Efficiency estimates

Since the stochastic frontier (SF) model showed linear homogeneity or the constant returns to scale, input-oriented DEA was chosen to obtain nonparametric efficiencies. The mean efficiencies obtained from stochastic frontier (SF) and data envelopment analysis (DEA) for the two production systems are shown in Table 6.3.

Table 6.2 Maximum likelihood estimates of the parameters of the stochastic frontier

Variable	Intensive		Semi-intensive	
Constant	4.109	(4.213)	2.817	(44.129)
Labor	0.173***	(0.055)	0.054*	(0.028)
Feed	0.559***	(0.081)	0.794****	(0.172)
Seed	0.258***	(0.124)	0.161**	(0.103)
σ^2	0.159	(0.045)	0.113	(0.143)
γ	0.951***	(0.039)	0.955***	(0.413)
Log(likelihood)	1.540		7.010	

Figures in parentheses are asymptotic standard errors.
*** Significant at the 0.01 level, ** significant at the 0.05 level, and * significant at the 0.10 level.

Table 6.3 Mean efficiencies obtained from stochastic frontier (SF) and DEA

	Intensive		Semi-intensive	
	SF	DEA	SF	DEA
Technical efficiency	0.763	0.797	0.783	0.804
Allocative efficiency	0.914	0.784	0.841	0.855
Economic or cost efficiency	0.699	0.620	0.663	0.692

The mean and individual efficiency scores were consistent between the two methods with significant correlation except for allocative efficiency in the intensive system. However, the performances of the two systems are not directly comparable, as they do not share the same reference level. A simple t-test employed after testing for equal variances revealed that the cost, technical and allocative efficiencies between the two systems are not statistically different.

Among the four states, Johor is the leading state in shrimp production in Malaysia where more than 50% of the total pond area is located (Yahaya, 1995). Yahaya (1995) further stated that almost all the commercialized farms using high technology and sophisticated management are located in Johor. Twenty-six percent of forest reserves in this state has already been converted to mariculture ponds (Chan, 1989). With the rapid expansion of the industry more mangrove forests in the state are likely to be converted to shrimp farming. With this background, the differences in efficiency levels among four major states were examined (Table 6.4). In the intensive system, the mean economic and technical efficiencies in Perok and Selongar districts were significantly higher than those for Johor and Kedah districts. Allocative efficiencies were similar across states. The semi-intensive farms in four districts were not statistically different in terms of cost, technical and allocative efficiencies.

Table 6.4 Mean efficiencies by system, by method and by state

	Technical efficiency	Allocative efficiency	Economic efficiency

	SF	DEA	SF	DEA	SF	DEA
Intensive						
Johor	0.570 b	0.584 b	0.907	0.802	0.517 b	0.458 b
Kedah	0.626 b	0.635 b	0.899	0.799	0.564 b	0.497 b
Perok	0.842 a	0.895 a	0.891	0.746	0.750 a	0.664 a
Selongar	0.844 a	0.886 a	0.934	0.792	0.790 a	0.702 a
F-statistic	14.24**	12.36**	1.67	0.543	11.97**	5.89**
Semi-intensive						
Johor	0.719	0.721	0.796	0.815	0.571	0.586
Kedah	0.815	0.842	0.834	0.846	0.687	0.721
Perok	0.793	0.822	0.885	0.898	0.703	0.738
F-statistic	1.613	2.059	1.592	1.679	2.480	2.838

** F-statistic significant at the 0.01 level.

In this sample, more small farms and fewer large farms were found in the semi-intensive system compared with the intensive system. As shown in Table 6.5, small and medium farms were found to be allocatively more efficient in the intensive system, while large farms were allocatively more efficient in the semi-intensive system. No differences were found among different farm sizes with respect to the technical and economic or cost efficiencies.

Table 6.5 Mean efficiencies among different farm sizes

	Technical efficiency		Allocative efficiency		Cost efficiency	
	SF	DEA	SF	DEA	SF	DEA
Intensive						
Small	0.783	0.806	0.933 a	0.827 a	0.734	0.663
Medium	0.768	0.790	0.929 a	0.800 a	0.714	0.625
Large	0.732	0.795	0.869 b	0.708 b	0.635	0.558
F-statistic	0.311	0.027	7.532 **	5.814**	1.279	1.558
Semi-intensive						
Small	0.815	0.834	0.799 b	0.815 b	0.657	0.687
Medium	0.727	0.739	0.853 b	0.872 b	0.625	0.647
Large	0.795	0.847	0.973 a	0.969 a	0.775	0.821
F-statistic	1.542	1.558	5.589**	4.992**	1.561	1.779

** F-statistic significant at the 0.01 level. The means denoted by same letter are not significantly different at the 0.05 level. The means that are not followed by lower case letters are not statistically different at any reasonable level of significance.

6.4.3 Optimum input levels

Since we are interested in sustainability of the industry, the optimum input levels (i.e. input levels at full economic or cost efficiency) were estimated. Accordingly, the mean actual and optimum usage of labor, feed and seed by state are presented in Table 6.6.

The means denoted by the same letter are not significantly different at the 0.05 level. In case of semi intensive system, the farms in the Selongar were not included in the analysis of variance due to inadequate number of observations in that sample.

Table 6.6 Actual and optimum input levels by provinces

	Labor (days/ha)			Feed (kg/ha)			Seed (1,000 Pl/ha)		
	Actual	Optimum		Actual	Optimum		Actual	Optimum	
		SF	DEA		SF	DEA		SF	DEA
Intensive									
Johor	412	281	165	9,368	4,632	4,697	657	414	324
Kedah	805	477	370	22,834	11,709	10,527	1,000	924	726
Perok	517	781	420	20,852	12,307	11,961	848	979	824
Selongar	298	299	275	11,612	8,971	7,815	751	707	539
Semi-intensive									
Johor	241	48	83	6,325	5,185	4,762	441	243	322
Kedah	832	128	167	10,379	9,730	9,953	421	328	352
Perok	736	131	187	13,267	11,965	11,728	494	392	516
Selongar	98	148	98	15,585	16,140	15,585	900	565	900

As shown in Table 6.6, in the intensive system all inputs were, on average, overused in Johor and Kedah states in terms of both stochastic frontier and DEA models. In Perok, feed was overused while labor and seed were underused under the stochastic frontier approach and slightly overused under DEA. In Selongar, on average, the sample farms were almost fully efficient in using labor and overused feed and seed, especially under DEA. In the semi-intensive system, the overuse of labor was substantial in Johor, Kedah and Perok states. On average, semi-intensive farms were found to be quite efficient compared to their intensive counterparts. The results reveal that both the intensive and semi-intensive farms could cut down their input use substantially, resulting in the reduction in production costs and improvement in productive efficiencies. The analysis by farm size also produced the similar results.

6.5 Conclusions

Parametric stochastic production frontier analysis and nonparametric data envelopment analysis (DEA) techniques were employed to examine productive efficiencies in the Malaysian shrimp industry. The two approaches yielded fairly consistent results. The elimination of outliers and separation of farms into two systems is believed to minimize the effects of possible measurement errors on results obtained from DEA.

Based the parametric approach, both intensive and semi-intensive systems exhibited constant returns to scale with high output elasticity of feed. The output elasticities of feed for intensive and semi-intensive farms were estimated to be 0.559 and 0.794, respectively. Thus, the results indicate that semi-intensive farms are more responsive to feed than intensive farms. Technical, allocative and cost efficiencies were not much different between the two systems, and the number of farms in each system above their respective means was also fairly similar. Although the comparison was not conducted based on a common reference level, the results implied that intensive farms are not superior to their semi-intensive counterparts in terms of any of the three efficiency scores.

The results further revealed that, Johor state, which is the leading shrimp producing state in Malaysia, is not superior to other states in terms of technical and cost efficiencies. In fact, intensive farms in Perok and Selongar states outperformed intensive farms in Johor and Kedah states. Farm size did not have any impact on technical and cost efficiency but on allocative efficiency. It was found that small and large farms were allocatively more efficient under the intensive system while in the semi-intensive system the results were opposite. The analysis also revealed that operator's experience had no impact on efficiency levels.

The analysis estimated optimum input levels under both approaches and the results were fairly consistent. The comparison of actual and optimum input levels showed substantial overuse of most inputs in the Malaysian shrimp industry irrespective of the system practiced. The intensive system had more potential for cost savings through increased efficiency, especially in Kedah. The results indicated that there is a large room to improve the productive efficiency in the Malaysian shrimp industry without increasing inputs or adopting new technology. The analysis has implications for long-term survival of shrimp industry by improving efficiency and profitability.

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Chapter 7

Export performance of major cultured shrimp producers in the Japanese and US markets

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Abstract

Increase in shrimp farming was stimulated by growth in world market for high-value shrimp products in the 1980s. The major cultured shrimp producers are located in Asia-Pacific and Latin American regions. The revealed comparative advantage (RCA) method is used to provide insights into the export performance of nine selected shrimp producers in the Japan and United States markets, separately. Shrimp is marketed in a wide variety of product forms, and prices vary according to various product attributes, including species, size, taste, quality and origin. The results show that vertical product differentiation concerning different varieties of a good in terms of both quality and price plays an important role on the relative export competition of shrimp products among major shrimp exporting countries. As a result of the geographical advantage, Asia-Pacific producers enjoy comparative advantage in the Japanese imported shrimp market. Joint ventures with the United States provide great benefits to Ecuador and Mexico in exporting fresh shrimp into the United States market.

7.1 Introduction

Over the period 1981-1991, world shrimp harvests increased by 62.5%, from 1,629 thousand metric tonnes (mt) to 2,648 thousand mt. Approximately 35% of the total production was traded in the international market in 1991, compared with about 24% in 1981. This steady expansion is due to a rapid expansion of worldwide shrimp culture and the strong growing demand in the international shrimp market. The world market for shrimp is dominated by Japan, the United States and Western Europe, accounting for about 85% of the world trade. Shrimp imports supply over 80% and 78% of domestic shrimp consumption in Japan and the United States, respectively.

The pattern of global trade for cultured shrimp mainly presents a one-way flow, from developing tropical producer countries to the three main markets in the developed world. Shrimp is marketed internationally in a wide variety of different product forms, and prices vary according to the various product attributes including species, size, taste, quality and country of origin in the market. The purpose of this study is to analyze the comparative advantage in trade performance of nine major cultured shrimp countries which are also major shrimp exporters in the world. The Japan and United States imported shrimp markets are particularly emphasized. Vertical product differentiation concerning different varieties of shrimp products in

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terms of both quality and price serves as a main concept to reveal the relative export competition of shrimp products among major shrimp-exporting countries.

First, the world cultured shrimp industry is reviewed. The revealed comparative advantage (RCA) method, used to measure the relative export performance among shrimp exporters, is followed. Results of RCA indices in the Japan and US markets are summarized and discussed separately in the final section.

7.2 World cultured shrimp industry

7.2.1 The production trend

Increase in shrimp farming is stimulated by the desire to benefit from markets for high-value shrimp products. As global demand for shrimp continues to grow and wild-caught shrimp supplies remain stable or increase only gradually because of the maximum capacity of wild stock, a rapid expansion of shrimp culture is expected to meet the growing demand for shrimp. Total world shrimp production increased from 1,629 thousand mt in 1981 to 2,648 thousand mt in 1991 (Fig. 7.1). Shrimp from aquaculture has increased steadily from about 59,000 mt to 719,000 mt between 1981 and 1991, with the share of total supply increasing from 3.6% to 27.2%. An estimated 80% of cultured shrimp are traded internationally (Weidner and Wildman, 1992).

Production of aquaculture shrimp is dominated by Asian and Latin American countries. Table 7.1 shows the production trends in live weight of nine major cultured shrimp producers between 1983 and 1991, which include the ASEAN region (Thailand, Indonesia, Philippines and Malaysia), China, India, Taiwan, Ecuador and Mexico. Black tiger shrimp (*Penaeus monodon*), Chinese white shrimp (*Penaeus chinensis*) and white-legged shrimp (*Penaeus vannamei*) are three dominant species of cultured shrimp production, accounting for 43%, 18% and 17% of world culture production in 1991 (Rosenbery, 1991).

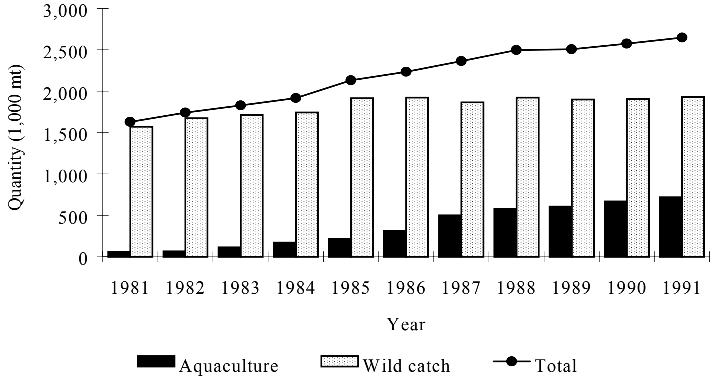

Fig. 7.1 Aquaculture, wild catch and total world shrimp production (FAO, 1993)

Table 7.1 Aquaculture shrimp production in live weight by major producing country,

	Quantity (1,000 mt)		Increase (%)	Market share (%)	
Country	1983	1991	1983-1991	1983	1991
ASEAN-4	63.1	282.5	348	44.1	40.4
Thailand	11.6	110.0	848	8.1	15.7
Indonesia	39.0	140.0	259	27.3	20.0
Philippines	12.1	30.0	148	8.5	4.3
Malaysia	0.4	2.5	525	0.3	0.4
China	9.0	145.0	1,511	6.3	20.7
India	13.0	35.0	169	9.1	5.0
Taiwan	16.8	30.0	79	11.7	4.3
Ecuador	35.7	100.0	180	25.0	14.3
Mexico	2.4	9.2	283	1.7	1.3
Other	3.0	97.3	3,143	2.1	13.9
World total	143.0	699.0	389	100.0	100.0

Source: FAO (1993), Rosenbery (1991).
*1991 is used in order to maintain consistency of data.

In 1983, cultured shrimp production from these nine countries accounted for about 97.9% of the global culture production. Especially, the ASEAN region provided 44.1% of the world shrimp supply from aquaculture production. Indonesia and Ecuador were the top two of largest producers and together comprised about 52.3% of the world aquaculture shrimp production. Due to the success of larval rearing techniques in 1968 and the availability of formulated feeds in 1977, Taiwanese intensive shrimp culture was recognized as the most successful production system, in terms of high productivity and cost-efficiency. Taiwan was the third leading producer and accounted for about 12% of the total world culture production in 1983.

The development of the shrimp culture industry in the tropical developing countries, on the worldwide basis, has been increasing at a dramatic rate since the mid-1980s. In the developing world, governments play an important role in supporting technical and financial assistance for their shrimp culture industries, especially in China, Thailand and Malaysia and Philippines. The shrimp culture industry in most developing countries has not only provided employment of the industry itself, but has also created numerous upstream and downstream industries which are directly or indirectly related to the shrimp industry. In addition, the transfer of capitals and technological advances in hatcheries and more profitable culture systems as well as joint venture multinational investment also benefit the shrimp culture industry within these countries (Ling, 1991; Hirono and Leslie, 1992).

As shown in Table 7.1, China was the leading producer of cultured shrimp in the world in 1991. As a result of the remarkable expansion of the shrimp industry in China, shrimp production has significantly increased from 9 thousand mt to 145 thousand mt between 1983 and 1991, a 1511% increase. Meanwhile, the market share of the global culture production increased from 6.3% in 1983 to 20.7% in 1991. The ASEAN region, accounting for over 40.4% of the world culture production, was dominated by Indonesia and Thailand, with 20.0% and 15.7% of the world market share, respectively. Thailand was the second fastest-growing shrimp producer, next to China, and increased its production by 848% from 1983 to 1991. Because of severe disease problems and high mortality since the mid-1988, the scale of the cultured shrimp industry in Taiwan has been drastically reduced and its market share in world cultured shrimp supply has declined dramatically to 4.3% in 1991. Ecuador was still the largest shrimp producer in the Latin American region, but its market share had fallen from 25% in 1983 to 14.3% in 1991 as a result of the boost expansion of Asian culture shrimp production.

7.2.2 The export trend

Cultured shrimp can provide a more consistent year-round supply than wild-caught shrimp, which is a distinct advantage to meet the demand of a processing industry as well as the export market. As a result of over-supply from aquaculture production, with consequent falling prices recently, cultured shrimp has to compete more effectively with other substitutes, such as lobster, crab, scallop, fish, meat and poultry.

Frozen shrimp, most often headless, shell-on or peeled, is the most common product form, which accounted for 17-20% of world trade in fishery products (Lee and Wickins, 1992). The remaining volume of shrimp products entering world trade channels include live, fresh, chilled, dried, salted, in brine, and value-added shrimp such as Individually Quick Frozen (IQF) and breaded. World exports of frozen, fresh and chilled shrimp products has expanded by more than 120% over the past decade. Fig. 7.2 illustrates export trends in volume of nine major cultured shrimp producer countries from 1981 to 1991. In 1991, these nine exporting countries together accounted for 73.5% by volume and 58.7% by value of world trade in frozen, fresh and chilled shrimp.

As a high-value product, the export of cultured shrimp has provided a valuable source of foreign exchange earnings in developing countries in the 1980s. Shrimp exports of Thailand, Indonesia, Philippines and Ecuador increased at steady growth rates during 1980s. India presented a smooth and stable export trend over the past decade. There have been annual fluctuations with slow growth rate of shrimp exports in Malaysia. The main reason has been attributed to a lack of confidence in quality of Malaysian shrimp exports (Lee et al., 1992). China expanded its exports in the mid 1980s as a result of the boom in the culture of *Penaeus chinensis* and became the top exporter in 1988. Since 1988, a great decrease in volume of shrimp exports in Taiwan results from the dramatic reduction in production suffered from the severe mortality on shrimp farms.

Shrimp exports of each individual country tend to follow a pattern in relation to the domestic production trends. However, a declining rate of growth on shrimp exports might be the result, not of poor production performance, but of growing domestic shrimp consumption and low comparative advantage which would decrease exports to the global shrimp market. Generally speaking, cultured shrimp (mostly tropical warmwater species) competes with coldwater species of shrimp. The supply situation of coldwater shrimp would influence the price of cultured shrimp. In addition, there is also strong competition among cultured shrimp producers of Chinese white, black tiger and white-legged shrimp. The basic elements of competitiveness of global trade in shrimp products including comparative costs on production and marketing, reputations for quality, exchange rates between exporting and importing countries and currency fluctuations in the main importing countries would be expected to affect such real outcomes as export volume, export price, market share and foreign exchange earnings.

Fig. 7.2 Exports of frozen, fresh and chilled shrimp (thousand mt) by country
Sources: FAO (1993), *Fisheries Yearbook Taiwan Area*, ROC, 1981–1991.

7.3 Materials and methods

The literature reports a number of measures of comparative advantage in production and international trade. The two widely used approaches of measurement are the domestic resource cost (DRC) analysis and the index of "revealed" comparative advantage (RCA). The domestic resource cost approach centers on the implications of the comparative advantage for resource allocation, which is based on the concept of social opportunity costs (Chenery, 1961; Pearson and Meyer, 1974; Pearson et al., 1976; Gonzales et al., 1993). However, the lack of appropriate information on production costs across countries and commodities makes cost comparisons for the competitiveness of domestic resource allocation difficult. In addition, product differences in quality as well as non-price factors, which influence the pattern of comparative advantage, are not sufficiently reflected in the cost consideration. The measures of trade performance are recently used to determine comparative advantage in international trade.

The concept of revealed comparative advantage (RCA) was first developed by Balassa (1965). In Balassa's framework, the RCA indices can be measured by the relative export shares of a country in the world exports of individual commodities. In other words, the relative export performance of a particular country can be quantified in the form of an index which indicates the pattern of revealed comparative advantage in the trade of a particular commodity. The RCA index is expressed as follows:

$$\mathrm{RCA} = \frac{X_i^j / Y_i}{X^j / Y} \tag{7.1}$$

where i is a particular export commodity; j is the exporting country; X_i^j denotes country j's export value of commodity i; X^j is country j's export value of all commodities; Y_i is the export value of commodity i from all exporting countries; and Y is the export value of all commodities from all exporting countries.

Equation 7.1 can be rewritten as:

$$\mathrm{RCA} = \frac{X_i^j / X^j}{Y_i / Y} = \frac{x_i^j}{y_i} \tag{7.2}$$

where x_i^j is the export share of commodity i from country j; and y_i is the market share of commodity i from all exporting countries. If the RCA value is greater than unity, the country reveals a comparative advantage in the trade of commodity i. Otherwise, a RCA value of less than unity indicates a disadvantage. Unity of the RCA value reveals comparative neutrality.

The RCA index can be used to evaluate the degree of comparative advantage within a particular country over various commodities and the degree of comparative advantage among various countries with respect to a particular traded commodity (Hillman, 1980; Yeats, 1985). However, the basic assumptions of the RCA approach have been argued. Yeats (1985) pointed out that the RCA index has ordinal properties which merely rank comparative advantage in trade patterns and indicate the relative distribution of the index difference. Balassa (1965) addressed that the trade patterns can be indicated by the RCA index but these patterns may not be fulfilled in the real world. Because all the RCA indices are interrelated, the national different degree of trade intervention such as subsides for export incentives and tariffs for import protection would result in trade distortions and reduce the realities of the RCA index. Vollrath and Vo (1988) argued that the relative export share measure used only export data, excluding imports which embody distortions that are not consistent with the real patterns of comparative advantage.

The global trade of shrimp commodities mainly present a one-way flow. In other words, shrimp products imported into major exporting countries are non-existent or insignificant, when compared to exports. Thus, the relative export performance indicated by the export share ratio will simply represent the inter-country revealed comparative advantage in the shrimp industry. In this study, the RCA index is used to analyze the export performance of shrimp commodities in different processed forms among nine major world shrimp exporting countries.

The availability and consistency of data with more detailed shrimp commodity classification is the limiting factor in the data series. The RCA indices of nine countries exporting shrimp into the Japan and US markets are estimated separately, instead of the world market. Annual data on export values, based on the Standard International Trade Code (SITC) system, are used from 1989 to 1991. The sources of data include Japan Exports and Imports (Japan Tariff Association) and *US* Imports of Merchandise (US Department of Commerce).

Shrimp commodities in Japan are classified into four categories at the 9-digit level: frozen shrimps (SITC 0306.13.000), live shrimps (SITC 0306.23.110), fresh and chilled shrimps (SITC 0306.23.190) and dried/salted/in brine shrimps (SITC 0306.23.200). The US shrimp commodities are grouped into two basic forms: shell-on and peeled. The breakdown of shrimp classifications is based on 10-digit level, including shell-on frozen shrimps (SITC 0306.13.0020), peeled frozen shrimps (SITC 0306.13.0040), shell-on fresh/chilled/dried/salted/in brine shrimps (SITC 0306.23.0020) and peeled fresh/chilled/salted/in brine shrimps (SITC 0306.23.0040).

The indicator in Eqn. 7.2 could be specified as:

RCA_{ij} $i = 1, 2, 3, 4$

$j = 1, 2, 3, 4, 5, 6, 7, 8, 9$

where i is a 9-digit SITC shrimp commodity for the Japan market or a 10-digit commodity for the US market and j is one of nine shrimp exporting countries, including Thailand, Indonesia, Philippines, Malaysia, China, India, Taiwan, Ecuador and Mexico. For instance, in the case of Japan, i = 1 represents frozen shrimp (SITC 0306.13.000) and j = 1 represents Thailand. Then, the revealed comparative advantage of Thailand's frozen shrimp in the Japan market is given as:

$$RCA = \frac{X_1^1 / X^1}{Y_1 / Y} = \frac{x_1^1}{y_1} \tag{7.3}$$

where x_1^1 is the export share of Thailand's frozen shrimp (SITC 0306.13.000), which is the ratio of the export value of Thailand's frozen shrimp to all 4 SITC shrimp commodities taken together; y_1 is the market share of frozen shrimp in the Japan imported shrimp market, which is the ratio of the total export value of frozen shrimp with respect to the total export value of all 4 SITC shrimp commodities from all nine shrimp exporters.

The comparative advantage in trade performance of shrimp exporters is highly related to the quality differentials. Falvey (1981) first concerned the role of vertical product differentiation in the international trade. Recent empirical studies have attempted to explain that vertical differentiated products would be determined by quality differences within an industry producing a range of differentiated products (Flam and Helpman, 1987; Torstensson, 1991; Balance et al., 1992; Golan and Shalit, 1993). Trade prices are considered as a good proxy for quality. By comparing RCA_{ij}, two possible explanations in vertical product differentiation of shrimp commodities could be made. First, for a constant j, a comparison of RCA_{ij} indicates the degree of comparative advantage across differentiated shrimp commodities (i) within a particular country j. Secondly, for a constant i, the relative export competition of a particular traded shrimp commodity i as a result of vertical product differentiation could be compared by the degree of RCA_{ij} among various shrimp exporting countries.

7.4 Results

7.4.1 The Japanese market

Shrimp imports in Japan according to country of origin are shown in Table 7.2 for selected years over the period 1982-1991. Traditionally, shrimp imports from Asian countries dominated the Japanese imported shrimp market. India and Indonesia were the top leading suppliers in 1982, accounting for 26.1% and 15.5%, respectively. In 1991, the ASEAN region provided 43.9% of import supply. Indonesia became the leading exporter in the same year, with a market share of 18.6%. The importance of shrimp from Thailand and China increased rapidly in the late 1980s and accounted for the market share of 16.3% and 12.3% in 1991, respectively. Ecuador and Mexico were insignificant suppliers to the Japanese shrimp import market.

Table 7.2 Japan shrimp imports by country of origin between 1982 and 1991[a]

	Quantity (mt)					Market share (%)	
Country	1982	1988	1989	1990	1991	1982	1991
ASEAN-4	38,194	83,741	110,850	117,853	127,413	25.1	43.9
Thailand	9,224	21,942	38,778	42,505	47,244	6.1	16.3
Indonesia	23,602	38,648	50,032	53,169	53,876	15.5	18.6
Philippines	3,897	19,169	18,973	19,206	23,234	2.6	8.0
Malaysia	1,471	3,983	3,067	2,972	3,059	1.0	1.1
China	7,403	38,382	37,880	43,514	35,719	4.9	12.3
India	39,833	31,965	29,702	35,709	35,867	26.1	12.4
Taiwan	7,842	21,981	11,000	13,240	12,878	5.1	4.4
Ecuador	406	112	70	9	200	0.3	0.1
Mexico	3,888	1,655	1,470	1,312	929	2.6	0.3
Other	54,762	83,465	76,296	56,185	77,330	36.0	26.6
Total	152,327	261,301	267,268	267,821	290,335	100.0	100.0

Source: JTA (1983-92).

Fig. 7.3 compares four categories of product forms of 1991 imported shrimp products in Japan, in terms of the quantity and price per mt. Imports of shrimp totaled 290 thousand mt in 1991, of which more than 98% were frozen, the remainder being live, fresh/chilled and dried/salted/in brine. In view of price characteristics, freshness and quality are two major important determinants in the Japanese imported shrimp market. Consumers normally prefer fresh shrimp product rather than for the preserved shrimp, because most of the preservation techniques in use reduce the taste and texture of shrimp. In 1991, live shrimp commanded the highest price at $17,000/mt, which was about twice as high as that of frozen, fresh and chilled shrimp. Price for dried/salted/in brine shrimp was the lowest, due to the poorest quality in freshness of shrimp.

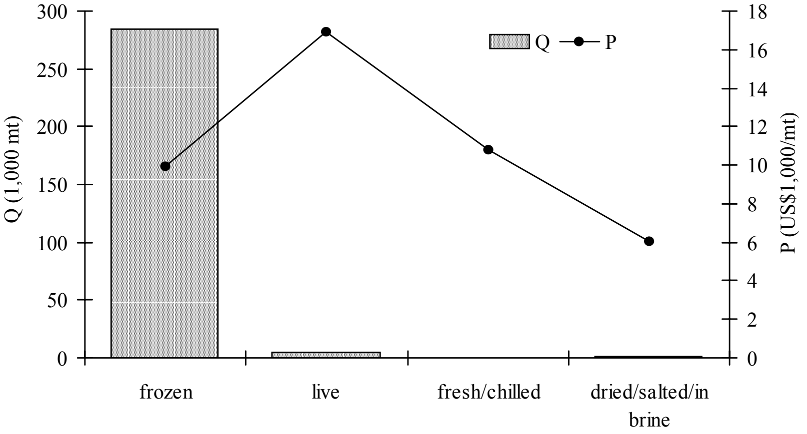

Fig. 7.3 Quantity and price of imported shrimp in Japan by product form, 1991
(Source: JTA 1992). Corresponding SITC codes: frozen shrimp (SITC 0306.13.000); live shrimp (SITC 0306.23.110); fresh/chilled shrimp (SITC 0306.23.190); and dried/salted/in brine shrimp (SITC 0306.23.200)

Table 7.3 summarizes RCA indices of Japanese shrimp imports from nine selected exporting countries during 1989-1991. RCA index values for frozen shrimp products are around unity in all cases of shrimp exporters, except for Taiwan. It indicates the export performances of frozen shrimp products among these countries are comparatively neutral. Following are several possible reasons for this phenomenon. First, the frozen shrimp products have a very high degree of product share in the Japanese imported shrimp market as compared to other product forms, which is indicated in the denominator (y_i) in Eqn. 7.2. A second factor facing the unity value of the RCA index is the export structure of individual country. The export share (x_i^j), shown in the numerator in Eqn. 7.2., is also significantly dominated by frozen shrimp. It implies less product diversification for the exporting country and leads x_i^j to be closer to unity. As Hillman (1980) pointed out, the higher degree of aggregation of the data, the closer y_i and x_i^j are to unity. Hence, the RCA index values will approach unity.

Table 7.3 RCA indices of major shrimp exporters in the Japanese market, 1989 - 1991

Form[a]	Thailand	Indonesia	Philippines	Malaysia	China	India	Taiwan	Ecuador	Mexico
Frozen									
1989	1.0213	1.0213	1.0080	1.0076	1.0202	1.0212	0.7085	1.0215	1.0215
1990	1.0363	1.0366	1.0170	1.0343	1.0264	1.0365	0.6931	1.0366	1.0366
1991	1.0295	1.0298	1.0121	1.0267	1.0228	1.0279	0.5204	1.0298	1.0298
Live									
1989	0.0000	0.0000	0.0000	0.0000	0.0836	0.0000	17.2137	0.0000	0.0000
1990	0.0000	0.0000	0.0000	0.0000	0.1431	0.0000	18.2520	0.0000	0.0000
1991	0.0000	0.0010	0.0000	0.0000	0.1010	0.0000	19.1302	0.0000	0.0000
Fresh/chilled									
1989	0.0000	0.0655	0.0085	0.0537	4.3164	0.0000	0.0346	0.0000	0.0000
1990	0.0000	0.0000	0.0000	0.0000	0.4036	0.0000	0.0000	0.0000	0.0000
1991	0.0000	0.0000	0.0000	0.0000	0.4036	0.0000	0.0000	0.0000	0.0000
Dried/salted/in brine									
1989	0.0980	0.0162	6.8331	7.0211	1.3540	0.1121	2.9795	0.0000	0.0000
1990	0.1187	0.0000	9.9568	1.1517	0.5219	0.0522	2.6154	0.0000	0.0000
1991	0.1069	0.0047	7.4142	1.2933	0.2610	0.0084	4.9023	0.0000	0.0000

[a] Corresponding SITC codes: frozen shrimp (SITC 0306.13.000); live shrimp (SITC 0306.23.110); fresh/chilled shrimp (SITC 0306.23.190); and dried/salted/in brine shrimp (SITC 0306.23.200).

Aside from frozen shrimp products, Thailand, Indonesia, India, Ecuador and Mexico have comparative disadvantage in exporting live, fresh, chilled, dried, salted and in brine shrimp during 1989 - 1991, because of nearly zero values of RCA indices. This is because the export shares of these shrimp forms within each of these countries are close to zero, and the market shares of these product forms in the Japanese imported shrimp market are insignificant.

Among product forms of export shrimp, live shrimp continues to occupy first place on the comparative advantage scale in Taiwan during the period under consideration. The RCA index values increase from 17.2 to 19.1. These results do correspond to expectations. Generally, the quality supplied and the price received by exporters depend on the shape of the demand curve in the different segments of the market. Taiwan mainly concentrates its exporting strategy on the Japanese market segment of live shrimp demand, which accounts for about 1.5% of the total import supply but commands the highest price for premium quality.

The major factor contributing to the Taiwanese remarkable comparative advantage in live shrimp is a well-established, integrated network of live shipping, packing and transporting techniques and facilities, while other shrimp exporters lack the know-how to compete. For instance, modern packing and transporting facilities provided for exports of live shrimp could result in a survival rate above 80% for up to 15 hours during transportation in order to obtain the premium price (Chiang and Liao, 1985). As a result of established reputations for predictable quality, Taiwan captures the dominant share (about 90%) of the live shrimp market in Japan. Consequently, the low degree of the market share of live shrimp imported by Japan and the significant degree of the export share of live shrimp in Taiwan generally lead to the high value of the RCA index.

China experienced the highest position of comparative advantage in fresh/chilled shrimp in 1989, while Philippines, Malaysia and Taiwan enjoyed comparative advantage in dries/salted/in brine shrimp during 1989-1991. The contributing factor for considerable comparative advantage is the relative importance of the export share (x_i^j) of the particular shrimp product among individual exporting countries. In other words, the higher the export share of particular shrimp product in a country, the greater is a country's comparative advantage in exporting this particular product. In the case of Philippines, because of the higher export share of dried, etc. shrimp in relative to other shrimp product form, the RCA index of dried, etc. shrimp is largest, as compared with other competitors such as Malaysia and Taiwan.

7.4.2 The US market

The quantity of shrimp imported by the US increased to 245 thousand mt in 1991 (Table 7.4). Because the cultured shrimp industry has been expanding rapidly in Asia and Ecuador in the 1980s, the relative importance of the various shrimp exporting countries in the US market has changed. By 1991, imports from Asia became the dominant source of shrimp for the US market. The ASEAN region accounted for 27.4% of shrimp imports, which was dominated by Thailand. China was the second largest exporter. Its market share increased from 1% to a peak of 14.3% between 1982 and 1991. Ecuador was the leading shrimp supplier to the US and the market share increased to 20.0% in 1991. However, the importance of shrimp imports from Mexico decreased significantly and it's market share declined to 6.8% in 1991.

Fig. 7.4 illustrates the relationship between the quantity and average price of imported shrimp in the 1991 US market, in terms of four different forms of shrimp. In 1991, about 97.7% of total shrimp imports is provided in the frozen form, which include shell-on frozen shrimp for 59.1% and peeled frozen shrimp for 38.6%. Fresh, chilled, dried, salted and in brine shrimp accounts for the remainder of imports, 2.3%. Price of imported shrimp is largely determined by the supply and demand situations. Generally, price for peeled shrimp is higher than shell-on shrimp, due to the additional processing cost involved in removing the shell. As shown in Fig. 7.4, non-frozen, peeled shrimp has the highest price at $13,000/mt. In terms of the frozen form, however, shell-on shrimp commands a higher price than peeled shrimp. The reason might be because shell-on frozen shrimp is more highly demanded than peeled frozen shrimp. Since the weighed average price here is for all species and sizes of shrimp products, different prices of shrimp products associated with various sizes are neglected.

Comparisons of RCA index distributions within four shrimp products for each individual country for years 1989 to 1991 are shown in Table 7.5. Unlike the Japanese market, variations of the RCA index values can be found in the US market. On one hand, the market structure of US shrimp imports is still immature and complex. Product and species preferences, consumption patterns and market competition facing the shrimp exporters in relation to the Japanese market have been changing for the last few years. On the other hand, the more detailed shrimp commodity classification, shell-on vs. peeled, used in analyzing the US market could bring more complicated but reliable results.

Table 7.4 US shrimp imports by country of origin between 1982 and 1991[a]

	Quantity (mt)					Market share (%)	
Country	1982	1988	1989	1990	1991	1982	1991
ASEAN-4	4,453	18,924	38,236	42,074	66,981	3.6	27.4
Thailand	3,540	10,739	22,039	25,354	45,481	2.8	18.6
Indonesia	469	1,966	6,120	8,597	11,548	0.4	4.7
Philippines	304	3,463	6,458	4,711	6,427	0.2	2.6
Malaysia	140	2,755	3,618	3,412	3,524	0.1	1.4
China	1,261	47,317	46,715	57,442	35,114	1.0	14.3
India	12,212	14,592	13,009	14,212	17,513	9.8	7.2
Taiwan	4,224	7,877	3,369	1,593	1,416	3.4	0.6
Ecuador	16,383	47,161	36,804	38,277	48,834	13.2	20.0
Mexico	36,365	28,814	27,391	16,796	16,647	29.3	6.8
Other	49,329	63,873	62,619	57,015	58,251	39.7	23.8
Total	124,226	228,558	228,143	227,410	244,757	100.0	100.0

[a] Source: NMFS (1983-92).

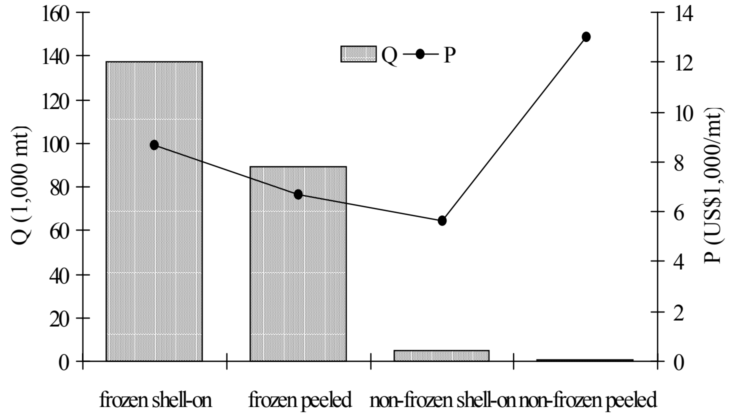

Fig. 7.4 Quantity and price of imported shrimp in the US by product form, 1991 (Source: USDC 1992). Corresponding SITC codes: frozen shrimp, shell-on (SITC 0306.13.0020); frozen shrimp, peeled (SITC 0306.13.0040); fresh/chilled/dried/salted/in brine shrimp, shell-on (SITC 0306.23.0020); and fresh/chilled/dried/salted/in brine shrimp, peeled (SITC 0306.23.0040).

For all exporting countries, shell-on frozen shrimp and peeled frozen shrimp account together for more than 96% of total shrimp exported to the US market, with the exception of Taiwan. Comparative advantage in frozen shrimp is mixed for the following two reasons. First, the relative importance of export shares between shell-on and peeled product forms in each individual exporting country is an important factor contributing to the RCA index. The strong market competition among major exporting competitors from Asia and Latin American countries is considered as the other factor.

While Indonesia, Philippines, Ecuador and Mexico had comparative advantage in exporting shell-on frozen shrimp, Thailand and China appeared to have approximately neutral comparative advantage and Malaysia, India as well as Taiwan had comparative disadvantage during 1989-1991. In turn, India had the highest revealed comparative advantage of all countries in exporting peeled frozen shrimp in that period, followed by Taiwan and Malaysia but with a decreasing rate. On the basis of the average values of the RCA indices during the period under consideration, Thailand and China also revealed comparative advantage.

Table 7.5 RCA indices of major shrimp exporters in the US market, 1989-1991

Form[a]	Thailand	Indonesia	Phil	Malaysia	China	India	Taiwan	Ecuador	Mexico
Frozen, shell-on									
1989	0.9097	1.1246	0.1652	0.6264	0.9310	0.3439	0.1490	1.1262	1.1489
1990	0.8191	1.2044	1.1640	0.5256	1.1314	0.1304	0.0608	1.2046	0.9579
1991	1.0581	1.0163	1.2250	0.6655	0.9213	0.1881	0.4299	1.0848	1.1227
Frozen, peeled									
1989	1.6012	0.3866	0.7234	3.2665	1.4871	4.6302	5.1854	0.1794	0.1367
1990	1.3543	0.7145	0.8169	1.7905	0.8664	2.3880	1.6044	0.5325	1.0934
1991	0.9143	1.0076	0.5503	1.7731	1.2146	2.7774	1.2652	0.7407	0.7733
Fresh/chilled/dried/salted/in brine, shell-on									
1989	0.2364	0.1731	0.3690	0.0000	0.4121	2.6439	0.6464	2.6410	0.0303
1990	0.0486	0.5082	0.0631	0.2241	0.0332	0.4620	4.7746	3.7179	0.0000
1991	0.0610	0.0011	0.0383	0.0000	0.0209	0.7390	2.9702	3.3833	0.0243
Fresh/chilled/dried/salted/in brine, peeled									
1989	0.5693	0.3663	0.0386	0.0000	0.0411	0.5180	17.4271	0.0050	3.2181
1990	0.3252	0.7280	0.0889	1.0421	0.2742	1.4533	35.0293	0.0000	2.7883
1991	0.0699	0.0941	0.0620	0.2656	0.1077	1.7357	98.3470	0.0345	0.1930

[a]Corresponding SITC codes: frozen shrimp, shell-on (SITC 0306.13.0020); frozen shrimp, peeled (SITC 0306.13.0040); fresh/chilled/dried/salted/in brine shrimp, shell-on (SITC 0306.23.0020); and fresh/chilled/dried/salted/in brine shrimp, peeled (SITC 0306.23.0040).

Fresh, chilled, etc. shrimp products are very insignificant in the US import market, with approximately 2.3% of total shrimp import in 1991. Taiwan shows a significantly strong comparative advantage in exporting both of shell-on and peeled fresh, etc. shrimp. Especially, the RCA index in Taiwan increased from 17.4 to 98.3 for peeled, fresh, etc. shrimp, largely because of comparative effect on the efficient packing marketing and transportation techniques for fresh shrimp exports.

Due to the geographical advantage of production location (Armington, 1969), many well-established US importer and distributors had joint venture investment involved in shrimp farming as well as processing in the Latin American countries during the 1980s. Ecuador supplied more than 80% of the US shell-on, fresh, etc. shrimp imports and revealed the strongest comparative advantage in exporting this shrimp product, with the range of RCA index values between 2.6 and 3.7. In the case of Mexico, peeled, fresh, etc. shrimp was the comparative advantage product form, associated with the RCA index value of 3.2 and 2.8 in 1989 and 1990, respectively.

The significant decrease of market share in 1991, however, dropped the RCA index value to 0.2.

7.5 Conclusions

This paper examines the revealed comparative advantage of one-way trade in shrimp commodities between 1989 and 1991. Owing to the absence of statistical information on a more detailed commodity classification breakdown, as well as consistent source of trade data in the major importing countries (Japan, the US and Western Europe), only Japanese and US imported shrimp markets are studied separately. Some preliminary evidence on the role of vertical product differentiation in the trade performance is given within the shrimp industry. The results show that Taiwan has a remarkable comparative advantage in exporting highest-quality shrimp commodities such as live shrimp in Japan and peeled fresh etc. shrimp in the US, due to a well-established, integrated network of shipping, packing, and transporting techniques, which other shrimp exporters lack the know-how to compete. The Philippines and Malaysia enjoy comparative advantage in exporting dried/salted/in brine shrimp to the Japanese market. As a result of the geographical advantage and joint ventures with the US, Ecuador and Mexico experience the relative high positions of comparative advantage in shell-on and peeled fresh etc. shrimp in the US imported shrimp market, respectively.

Further empirical research using the concept of revealed comparative advantage (RCA) is encouraged to cover more different trade flows, both in terms of geographical regions and market demand characteristics. In addition, the domestic resource cost (DRC) approach, focusing on allocation of domestic resources and environmental and socioeconomic effects, relating different shrimp farming systems among major producing countries would be a further important but research area.

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Chapter 8
Behavior of price transmissions in vertically coordinated markets: the case of frozen black tiger shrimp (*P. monodon*)

Bith-Hong Ling, PingSun Leung and Yung C. Shang

Abstract
This study analyzes the behavior of the price transmission process for the leading cultured shrimp species, black tiger shrimp (*Penaeus monodon*), in both forward and backward directions between Thai and Indonesian shrimp packer markets and the Japan Tokyo wholesale market. The bivariate cointegration approach using the Engle-Granger two-stage estimation procedure is applied in this study. The results show that Tokyo wholesale prices appear to have stronger backward influences on the formation of overseas contract prices used by Japanese shrimp importers in the Thai and Indonesian shrimp packer markets. In addition, there is a tendency for the speed of price transmissions in the long run to increase with increasing size class (26-30, 21-25 and 16-20 counts per pound) of black tiger shrimp, regardless of estimation specification in the direction of price transmissions and the shrimp country of origin.

8.1 Introduction

Japan is the largest consumer of shrimp in the world and the country depends heavily on shrimp imports because of its limited domestic supply. The rapid spread of shrimp farming in Asia and the accompanying increase in Japan's imports of shrimp had ended the era of shrimp as luxury goods. The expansion of shrimp imports from Asian cultured shrimp producers has not only led to a fall in shrimp price, but also stimulated the growing demand for imported shrimp in Japan (Ling, et al., 1997). Japanese shrimp importers play an important role in integrating the distribution channels of shrimp imports from Asian shrimp producers to Japanese domestic consumers. However, they frequently face trading risks resulting from the uncertainties of market supply and demand conditions and the fluctuation of foreign exchange rates.

In order to minimize transaction costs and uncertainties resulting from shrimp trading, vertical coordination mechanism such as contractual price is commonly used by Japanese shrimp importers and Asian shrimp packers. The incentive for Japanese shrimp importers to contract is the need for an assured and adequate supply of shrimp products with the desired product attributes and quality. For the Asian shrimp packers, a common incentive for contracting is the assurance of market access and the reduction of risks in exporting shrimp to Japan. The use of contractual prices in the vertical coordination process shifts trade from a spot market to a situation of bilateral

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contracting, which creates a substantial degree of dependence between buyers and sellers.

The purpose of this study is to estimate and compare the behavior of the price transmission process for the leading cultured shrimp species, black tiger shrimp (*Penaeus monodon*), in both forward and backward directions between Thai and Indonesian shrimp packer markets and the Japan Tokyo wholesale market. First, the import demand for frozen shrimp in Japan is outlined to shed light on the basic information used for the empirical analysis of the price transmission process. Methodology using the Engle-Granger two-stage cointegration procedure is then presented. The estimation results are then reported, followed by the concluding remarks.

8.2 Import demand for shrimp in Japan

Shrimp constitute the most important fishery products imported into Japan, both in terms of volume and value. The Japanese shrimp industry refers to shrimp imports by their color or species and further identifies them by their country of origin. The two major species of shrimp imported to the Japanese market are black tiger shrimp and Chinese white shrimp. An overwhelming share of total shrimp imports is supplied in frozen form, averaging about 97%. Frozen shrimp imports increased by 40% from 216.5 thousand metric tonnes (mt) in 1986 to 303 thousand mt in 1994. In 1994, the main supplying countries were Indonesia (21.0% of total imports), followed by Thailand (16.3%), India (14.3%) and China (6.7%). After the large-scale disease outbreak of black tiger shrimp farming in Taiwan since mid-1988, black tiger shrimp farming has spread to and grown in Indonesia, Thailand, the Philippines and other countries of Southeast Asia. Consequently, the main suppliers of black tiger shrimp are Indonesia, Thailand and the Philippines, which together account for 90% of Japan's imports of this variety.

Frozen shrimp is mainly imported by trading companies or marine product dealers from foreign shrimp packers (or exporters) or overseas joint ventures. There are two channels for shrimp distribution from foreign producers to Japanese consumers. First, shrimp can be sent to central wholesale markets under local government control. Buying and selling transactions are carried out by registered primary wholesalers at the central wholesale markets. Then, shrimp are distributed to secondary wholesalers, industry users, hotels, restaurants, processors, supermarkets and other retail outlets. The Tokyo central wholesale market is the biggest market in Japan and is also one of the largest wholesale markets in the world (JETRO, 1984, 1992).

The second distribution channel is handled by specialized primary wholesalers operating outside the central wholesale market system. Due to the fact that international standards have already been established for frozen shrimp, primary wholesalers specializing in shrimp usually import directly from the shrimp producing areas or purchase directly from shrimp importers and then distribute frozen shrimp directly without any transactions in central wholesale markets. Depending on market conditions, specialized primary wholesalers may sell frozen shrimp to central wholesale markets.

Japanese import demand for shrimp is sensitive to changes in shrimp prices, which fluctuate according to various product attributes, such as shrimp species, size, product form and the country of origin (shown later in the Data section). Generally, larger shrimp have a higher price and a rise in the price for large shrimp often results in the increased use of smaller shrimp as substitutes for the more expensive size categories and, hence, driving up the prices also for these sizes. Substitution in consumption based on a choice bundle of shrimp attributes has contributed to the complexity of shrimp price behavior. Furthermore, prices of imported shrimp in Japan are affected by not only competition for supplies on the international shrimp market, but also fluctuations in the relative values of various currencies, particularly between the Japanese Yen and the US dollar.

Moreover, the involvement of Japanese buyers in overseas cooperation through joint ventures or other forms of financial and technical assistance with foreign producers has increased in order to secure shrimp sources and stable prices. On the other hand, shrimp trading companies often engage in speculative trading rather than normal buying and selling. By negotiating the overseas offer prices with foreign shrimp packers, shrimp importers normally initiate business by the means of contracts which are based on their expectations of future market demand and supply, price levels, interest rates and currency fluctuations. Purchase contracts may involve either immediate delivery or arrangements for future shipments from shrimp packers in the country of origin. Purchases for future delivery may be made with shipment periods ranging from one month to one year and with the contract price fixed for three to four months (Saito et al., 1985).

8.3 Methodology

8.3.1 The concept of cointegration

The standard classical methods of estimation in applied econometric work are based on the assumption of stationarity of time series, where the mean, the variance and covariance are independent of time. Consider the data-generation process of a series x_t as:

$$x_t = \alpha + \beta x_{t-1} + \mu_t \,; \qquad \mu_t \sim \text{iid}\,(0, \sigma_u^2) \tag{8.1}$$

$$x_0 = 0$$

where x_{t-1} is the previous one-period lagged value of x_t and u_t represents a series of identical and independent and normally distributed random variables with zero mean and constant variance. If $|\beta| < 1$, the series x_t is said to be stationary. If $|\beta| = 1$, the series x_t becomes the simplest example of an autoregressive process integrated of order one and represents a random walk process generating x_t, which is nonstationary with a unit root.

The nature of nonstationary series produces a pattern which rarely returns to a particular mean and infrequently crosses the mean. The variance of x_t is not constant but explode with time. Consequently, the series would tend to drift farther apart from equilibrium levels if shocks are imposed. Ordinarily, stationarity can be achieved by differencing a series. Following the definition developed by Engle and Granger

(1987), a nonstationary series which can be transformed to a stationary series by differencing d times, is said to be integrated of order d and conventionally denoted as $x_t \sim I(d)$. Furthermore, given two nonstationary process series of economic data, x_t and y_t, they are said to be cointegrated of order d, b, denoted $x_t, y_t \sim CI(d, b)$, if (i) both x_t and y_t are I(d) and; (ii) there exits a linear combination of x_t and y_t, say $\alpha x_t + \beta y_t$, which is integrated of order (d, b). The vector $[\alpha, \beta]$ is called the cointegrating vector. For instance, if x_t and y_t are both $I(1)$ and the error term ε_t of their linear regression becomes a stationary process, $I(0)$, x_t and y_t are said to be cointegrated of order (1,1). Moreover, the cointegration regression can be viewed as a technique to estimate the long-run equilibrium relationship between nonstationary series, where deviations from this long-run equilibrium path are stationary.

8.3.2 Unit root tests for stationarity

Establishing the order of integration of a series for a variable, x_t, revolves around a test of whether x_t follows a random walk with a unit root and hence is I(1). Findings of unit roots would imply nonstationarity in the series. The Dickey-Fuller (DF) test and the Augmented Dickey-Fuller (ADF) test are introduced to test the presence of unit roots in series (Dickey and Fuller, 1981; Said and Dickey, 1984). The null hypothesis of the DF test is that β in Eqn. 8.1 is equal to unity and hence x_t follows a random walk. By subtracting x_{t-1} from each side, Eqn. 8.1 can be rewritten as:

$$x_t - x_{t-1} = \alpha + \beta x_{t-1} - x_{t-1} + \mu_t$$

$$\Delta x_t = \alpha + (\beta - 1)x_{t-1} + \mu_t$$

$$\Delta x_t = \alpha + \gamma x_{t-1} + \mu_t \tag{8.2}$$

where Δx_t is the first difference of x_t and γ is equal to $(\beta - 1)$. γ will be zero if x_t follows a random walk. On the other hand, γ will be negative and significantly different from zero if x_t is stationary, I(0). Thus, the null hypothesis to be tested is as follows:

$$H_0 : \gamma = 0 \text{ and } x_t \text{ is not } I(0) \qquad \text{vs.} \qquad H_1 : \gamma < 0 \text{ and } x_t \text{ is } I(0)$$

The DF test statistic is constructed from the ratio of the ordinary least squares (OLS) estimate of γ to its estimated standard error (as t-ratio). The null hypothesis of a unit root is rejected if the value of γ is significantly different from zero.

The ADF test provides a simple generalization of the DF test to allow for the possibility of higher order autoregressions as follows:

$$\Delta x_t = \alpha + \gamma x_{t-1} + \sum_{i=1}^{n} \gamma_i \Delta x_{t-i} + \varepsilon_t \tag{8.3}$$

where n is the large enough number of lagged difference so that the error term, ε_t, is a white noise process.

8.3.3 Empirical specification

The empirical framework of a vertical market system for black tiger shrimp which are produced in Thailand and Indonesia and consumed in Japan is illustrated in Fig. 8.1. It provides insight to understanding the relationship underlying price adjustments between market levels. From the point of Japanese demand for shrimp, Thai and Indonesian shrimp producers are viewed as foreign shrimp producers in the study. This market system has five linkage points of adjacent market levels: foreign shrimp farm (F) market, foreign shrimp packer (P) market, foreign shrimp export (E) market, Japan shrimp import (I) market and Tokyo wholesale (W) market. Price established at each market level through the vertical system passes supply information forward to consumers and demand information backward to producers. Market prices play an essential role in not only directing the flows of resources into alternative uses and of goods and services to consumers, but also in guiding producers in their choice of production and in their use of factors of production. The extent to which price changes are transmitted through the vertical market system is particularly important market information.

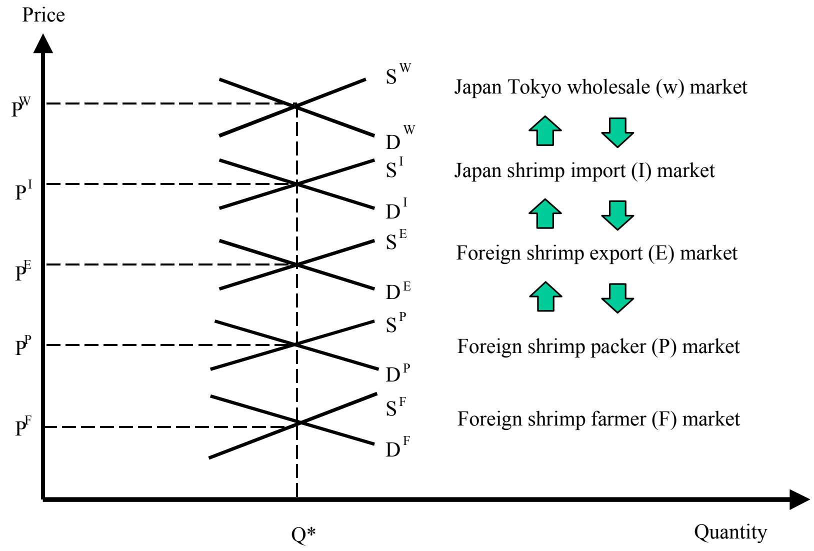
According to the Stigler's (1969) arbitrage-based definition of a market, prices of close substitutes move together and the arbitrage process leads to the Law of One Price for close substitutes. Engle and Granger (1987) also state that prices of the same commodity in different, related markets or close substitutes in the same market are expected to move together so that they do not drift from each other. Several empirical studies in the literature investigate the causal and interdependent relationship between prices on integrated markets and suggest the connection between this price behavior and market integration. (Ravallion, 1986; Adams et al., 1987; Kinnucan and Forker, 1987; Ardeni, 1989; Gordon et al., 1993; von Cramou-Taubadel et al., 1995; Asche and Sebulousen, 1998; von Cramou-Taubadel, 1998).

The static relationship form of shrimp price series (in the logarithm form) on the separately integrated markets across two countries is given in Eqn. 8.4 for the forward transmission direction and in Eqn. 8.5 for the backward transmission direction as follows:

$$\mathrm{Ln}P_t^j = f_1(\mathrm{Ln}\,P_t^i, \omega_t^{ij}) \tag{8.4}$$

$$\mathrm{Ln}P_t^i = f_1(\mathrm{Ln}\,P_t^j, \omega_t^{ji}) \tag{8.5}$$

where P_t^i represents the overseas contract prices in US dollars for black tiger shrimp in the Asian shrimp packer market i , Thailand or Indonesia; P_t^j represents the black tiger shrimp price converted from Japanese Yen to U.S. dollars in the Tokyo wholesale market j; ω_t^{ij} and ω_t^{ji} represent other influences such as the change in the foreign exchange rate between two trading countries and the change in demand for and supply of black tiger shrimp on spatial markets.



Notes: ⇧ indicates the forward direction of price transmission in the study
⇩ indicates the backward direction of price transmission in the study

Fig. 8.1 Directions of price transmissions for cultured black tiger shrimp within the vertical market system

The bivariate cointegration approach using the Engle and Granger (1987) two-stage procedure is applied in the study. The first stage begins with the estimation of parameters of the cointegrating regression on the level of price series, which is representative of the presupposed long-run equilibrium relationship in Eqns. 8.4 and 8.5 by the OLS in Eqns. 8.6 and 8.7 as follows:

$$\mathrm{Ln}P_t^j = \alpha_1^{ij} + \alpha_2^{ij}\mathrm{Ln}P_t^i + \varepsilon_t^{ij} \tag{8.6}$$

$$\mathrm{Ln}P_t^i = \alpha_1^{ji} + \alpha_2^{ji}\mathrm{Ln}P_t^j + \varepsilon_t^{ji} \tag{8.7}$$

where parameters α_1^{ij} and α_1^{ji} represent shifting effects such as import tariffs and/or marketing margins to capture an *ad valorem* mark-up between two price series in Eqns. 8.6 and 8.7; parameter α_2^{ij} (or α_2^{ji}) is the coefficient of forward (or backward) transmission and represents the relative degree of the change in $\mathrm{Ln}P_t^j$ (or $\mathrm{Ln}P_t^i$) resulting from the change in $\mathrm{Ln}P_t^i$ (or $\mathrm{Ln}P_t^j$); ε_t^{ij} and ε_t^{ji} represent the residual error terms, deviating from the long-run equilibrium value in time t. If ε_t^{ij} (or ε_t^{ji}) is stationary, then the linear combination of two price series is said to be cointegrated.

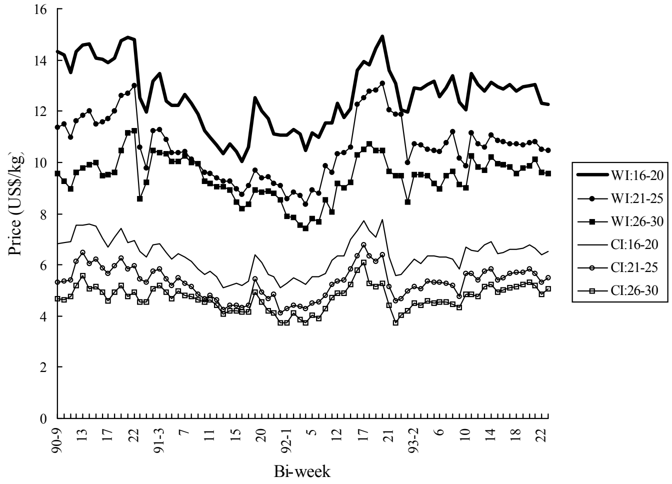


Fig. 8.2 Tokyo wholesale (WT) and Thai overseas contract prices (CT) for black tiger shrimp, by size (FAO, 1990 - 1994).

When price transmissions between spatial markets are performed efficiently, α_2^{ij} and α_2^{ji} will tend to approach unity and follow the Law of One Price. If the static long-run cointegration regression is valid, the dynamic error correction model (ECM) can take the form of regressing prices series in their first differences as in Eqn 8.8 for the short-run forward price transmission and in Eqn. 8.9 for the short-run backward price transmission (Banerjee et al., 1993, pp. 146 - 152):

$$\Delta \mathrm{LnP}_t^j = \beta_1^{ij} + \beta_2^{ij} \Delta \mathrm{LnP}_t^i + \beta_3^{ij} \hat{\varepsilon}_{t-1}^j + \sum_{k=1}^{p} \gamma_k^{ij} \Delta \mathrm{LnP}_{t-k}^i + \sum_{l=1}^{q} \Phi_l^{ij} \Delta \mathrm{LnP}_{t-l}^j + \mu_t^{ij} \tag{8.8}$$

$$\Delta \mathrm{LnP}_t^i = \beta_1^{ji} + \beta_2^{ji} \Delta \mathrm{LnP}_t^j + \beta_3^{ji} \hat{\varepsilon}_{t-1}^i + \sum_{k=1}^{p} \gamma_k^{ji} \Delta \mathrm{LnP}_{t-k}^i + \sum_{l=1}^{q} \Phi_l^{ji} \Delta \mathrm{LnP}_{t-l}^j + \mu_t^{ji} \tag{8.9}$$

where $\hat{\varepsilon}_{t-1}^{ij}$ and $\hat{\varepsilon}_{t-1}^{ji}$ are one period lagged values of the error terms in Eqns. 8.6 and 8.7, respectively, and are so-called the error correction terms of which coefficients, β_3^{ij} and β_3^{ji}, represent the speed of dynamic price adjustments of the two price series from their long-run cointegrating relationship in the previous period. β_2^{ij} and β_2^{ji} measure the magnitude of the short-run price transmission in the backward and forward flows, respectively. $\sum_{k=1}^{p} \gamma_k \Delta \mathrm{LnP}_{t-k}^i$ and $\sum_{l=1}^{q} \phi_l \Delta \mathrm{LnP}_{t-l}^j$ represent the autoregressive (AR) components of $\Delta \mathrm{LnP}_t^i$ and $\Delta \mathrm{LnP}_t^j$, respectively, which are added Eqns. 8.8 and 8.9 in order to ensure that the residual error terms, μ_t^{ij} and μ_t^{ji} , are white noises.

8.3.4 Data

The long- and short-run price transmissions between the Tokyo wholesale market and foreign shrimp packer markets in Thailand and Indonesia are investigated for black tiger shrimp using the bi-weekly data from June 1 1990 to December 15 1993. Both wholesale shrimp prices reported for the Tokyo central wholesale market and overseas contract prices negotiated by Japan shrimp importers and Thai and Indonesian shrimp packers are collected from INFOFISH Trade News (FAO, 1990-1994). Shrimp prices are broken down by shrimp size class, which includes three major sizes: 16-20, 21-25, and 26-30 counts per pound. All shrimp price series, in US dollars, and are shown in Figs. 8.2 and 8.3 for Thai and Indonesian black tiger shrimp, respectively.

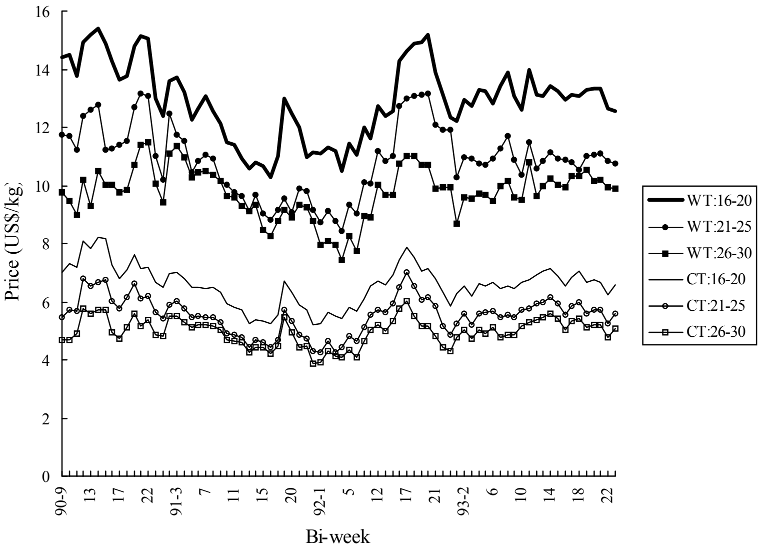


Fig 8.3 ***Tokyo wholesale (WI) and Indonesian overseas contract (CI) prices for black tiger shrimp by size (FAO, 1990-1994)***

8.4 Results

The econometric package PcGive 9.0 (Doornik and Hendry, 1996) is used to generate the properties of the data and all cointegration estimations for the study. The DF and ADF unit root tests based on Eqns. 8.2 and 8.3 are used to test whether the price series are nonstationary. Table 8.1 shows the results of the DF and ADF unit root tests for the underlying price series in levels and in first differences, respectively. The null hypothesis of stationarity cannot be rejected for each of the price variables in the level and thus, it is concluded that all of the series are nonstationary with the presence of a unit root. However, the null hypothesis is rejected at the 0.01 level of significance for all price series in their first differences. This indicates that stationarity is attained for all price series after first differencing.

Table 8.1 Unit root tests for price series of black tiger shrimp

	Prices in levels		Prices in first differences	
Country of origin & shrimp size	DF test	ADF test	DF test	ADF test
Tokyo wholesale prices of				
Thailand black tiger shrimp:				
size of 16-20	-0.249	-0.139	-8.658**	-7.002**
size of 21-25	-0.142	-0.048	-10.344**	-7.498**
size of 26-30	0.088	0.280	-11.482**	-7.371**
Indonesia black tiger shrimp:				
size of 16-20	-0.265	-0.145	-8.369**	-7.970**
size of 21-25	-0.149	-0.050	-9.441**	-7.266**
size of 26-30	0.090	0.193	-9.894**	-7.622**
Overseas contract prices of				
Thailand black tiger shrimp:				
size of 16-20	-0.197	-0.163	-8.391**	-6.961**
size of 21-25	-0.076	-0.059	-8.725**	-7.355**
size of 26-30	0.066	0.006	-8.873**	-7.909**
Indonesia black tiger shrimp:				
size of 16-20	-0.096	-0.113	-8.499**	-7.319**
size of 21-25	-0.004	-0.009	-9.005**	-7.334**
size of 26-30	0.096	0.042	-8.493**	-7.755**

Notes: 1. DF = Dickey-Fuller test; and ADF = augmented Dickey-Fuller test.
2. The critical value at the 0.05 level are: -1.948 for DF test; -1.945 for ADF test.
The critical value at the 0.01 level are: -2.593 for DF test; -2.594 for ADF test.
3.** Significance at the 0.01 level.

In the estimations of long-run relationship, $\Delta \mathrm{LnP}^{i}_{t-k}$ and $\Delta \mathrm{LnP}^{j}_{t-k}$ do not enter Eqns. 8.8 and 8.9 as white noises are already obtained for μ^{ij}_{t} and μ^{ji}_{t} without these lagged terms added. Furthermore, the Wald test is used to test the long-run and short-run cointegration between any pair of price series in Eqns. 8.6, 8.7, 8.8 and 8.9

(Doornik and Hendry, 1996, pp. 241-242). The results show the rejection of the null hypothesis of no cointegration at the 0.01 level of significance, which indicates every pair of price series under consideration are cointegrated (Tables 8.2 and 8.3).

8.4.1 Forward price transmission

Table 8.2 presents the cointegrating relationship in the forward direction of transmission such that overseas contract prices in the foreign shrimp packer market have impacts on the price formation in the Tokyo wholesale shrimp market. The results suggest that with the consideration of country of origin, the coefficients (α_2^{ij} for the long-term and β_2^{ij} for the short-term) for all sizes of Thai black tiger shrimp are larger than that for Indonesian black tiger shrimp.

In fact, Thailand was the world's leading producer and exporter of black tiger shrimp in the 1990s. In 1994, Thailand accounted for 59.8% of the world black tiger shrimp production, as compared to 23.7% for Indonesia. If the Japanese market is not optimistic, Thai shrimp packers may look into market diversification and make marketing strategies in other target markets, such as the US and the EU. In addition, export market information may be more complete and readily assimilated at the Thai shrimp packer market. Consequently, Thai overseas contract prices tend to have a stronger link with Tokyo wholesale prices and result in more rapid responses of Tokyo wholesale prices. In particular, the more rapid adjustment of forward price transmission for Thai black tiger shrimp can be found in the coefficients (β_3^{ij}) of the error correction term ($\hat{\varepsilon}_{t-1}^{i}$). For the case of 21-25 counts per pound, a one-unit increase in the oversea contract price for Thai and Indonesian black tiger shrimp will, respectively, lead to 0.4710 and 0.3693 units of price increase in the Tokyo wholesale market in the short term. Moreover, for the same size class any remaining disequilibrium will be eliminated by an error correction factor of 0.5325 in the next period for Thai black tiger shrimp compared to 0.4189 for that of Indonesia.

Regarding the shrimp size effect, the magnitude of forward price transmission in the long term tends to increase with increasing size class of black tiger shrimp. In the short term, the findings suggest that there exits a greater difference in the degree of forward price transmission between the size classes of 16-20 and 21-25 counts of shrimp. In addition, the relatively slower speed of error correction in forward price adjustment is found for the 21-25 counts of shrimp, regardless of the country of origin. Although beyond the scope of this analysis, a detailed study of consumption and production substitution effects in different sizes of shrimp could add more insight into this observed relationship.

8.4.2 Backward price transmission

The results of price adjustments in the backward transmission process from the Tokyo wholesale market to Thai and Indonesian shrimp packer markets are presented in Table 8.3. When compared with the forward price transmission in Table 8.2, the values of coefficients in both long term (α_2^{ji}) and short term (β_2^{ji}) are greater in the backward price transmission and the difference is more distinct in the short-term relationship. This suggests that the speed of price adjustments is faster in the backward flow, where the impact of price changes in the Tokyo wholesale market is transmitted more completely into price changes in the foreign shrimp packer market. In other words, the change in overseas contract prices induces less impact on the price formation at the Tokyo wholesale market. The result may be a consequence of cold storage holdings against price fluctuations used by shrimp importers and/or wholesalers in the Japanese shrimp distribution system. In addition, the Tokyo wholesale market may quickly assimilate market signals from both consuming and producing sides and therefore Tokyo wholesale prices can cause more influences on the formation of overseas contract prices in Thailand and Indonesia.

In terms of the country of origin, the results indicate roughly the same magnitude of long-term backward price transmission for both 16-20 and 21-25 counts of shrimp from either Thailand (0.9955 and 0.9091) or Indonesia (1.0160 and 0.9169). In the short-term, the change in Tokyo wholesale prices only for Thai black tiger shrimp with a 21-25 count induces a relatively smaller degree (0.7490) of contemporaneous reaction in its contract prices at the shrimp packer market, as compared with Indonesian black tiger shrimp (0.8633). However, the adjustment to the long-term equilibrium is corrected by a greater factor as indicated by higher β_3^{ji} for all size classes of Thai black tiger shrimp, which is consistent with the behavior of forward price transmission. It suggests that market information for black tiger shrimp between the Thai shrimp packer market and Tokyo wholesale market may be more dynamic and the speed of price adjustments between the two markets from the long run equilibrium is more rapid**.**

Table 8.2 Estimates of forward price transmission: from Thai and Indonesian shrimp packer markets to Tokyo wholesale market

	Equation 8.6: Long-run price relationship				Equation 8.8: Short-run price relationship				
	Constant	LnP_t^i			Constant	$\Delta\mathrm{LnP}_1$	$\hat{\varepsilon}_{t-1}^{i}$ [b]		
Dependent variables	α_1^{ij}	α_2^{ij}	R^2	Wald test[c]	β_1^{ij}	β_2^{ij}	β_3^{ij}	R^2	Wald test[c]
Contract price for Thai black tiger shrimp in the packer market (LnP_t^j)[a]					Independent variable: Tokyo wholesale price for Thai black tiger shrimp (LnP_t^i)				
16-20 count shrimp	0.9438**	0.8648**	0.856	404.61**	-0.0008	0.6316**	-0.5731**	0.682	141.82**
	(0.0853)	(0.0429)			(0.0037)	(0.0619)	(0.0991)		
21-25 count shrimp	1.0292**	0.8042**	0.727	181.37**	-0.0009	0.4710**	-0.5325**	0.494	64.423**
	(0.1082)	(0.0597)			(0.0059)	(0.0785)	(0.0957)		
26-30 count shrimp	1.1308**	0.7336**	0.651	126.89**	0.0002	0.3687**	-0.5725**	0.525	72.858**
	(0.1112)	(0.0651)			(0.0050)	(0.0671)	(0.0911)		
Contract price for Indo. black tiger shrimp in the packer market (LnP_t^j)[a]					Independent variable: Tokyo wholesale price for Indo. black tiger shrimp (LnP_t^i)				
16-20 count shrimp	1.0924**	0.7910**	0.796	265.60**	-0.0012	0.5349**	-0.5013**	0.617	106.13**
	(0.0946)	(0.0485)			(0.0040)	(0.0648)	(0.0926)		
21-25 count shrimp	1.1210**	0.7570**	0.691	152.48**	-0.0006	0.3693**	-0.4189**	0.465	57.41**
	(0.1086)	(0.0613)			(0.0049)	(0.0697)	(0.0806)		
26-30 count shrimp	1.2779**	0.6464**	0.614	108.22**	0.0004	0.3416**	-0.4649**	0.463	56.94**
	(0.1027)	(0.0621)			(0.0049)	(0.0702)	(0.0893)		

[a] Dependent variables in the their first differences are used for Eqn. 8.8. [b] $\hat{\varepsilon}_{t-1}^{i}$ is the one-lagged error correction term. [c] Wald statistics show the cointegration test (Hendry and Doornik, 1996, pp. 49). ** Significance at the 0.01 level. Numbers in parentheses are standard errors.

Table 8.3 Estimates of backward price transmission: from Tokyo wholesale market to Thai and Indonesian shrimp packer markets

	Equation 8.7: Long-run price relationship				Equation 8.9: Short-run price relationship				
	Constant	LnP_t^j			Constant	$\Delta\mathrm{LnP}_t^j$	$\hat{\varepsilon}_{t-1}^{j}$ [b]		
Dependent variables	α_1^{ji}	α_2^{ji}	R^2	Wald test[c]	β_1^{ji}	β_2^{ji}	β_3^{ji}	R^2	Wald test[c]
Tokyo wholesale price for Thai black tiger shrimp (LnP_t^i)[a]					Independent variable: contract price for Thai black tiger shrimp in the packer market (LnP_t^j)				
16-20 count shrimp	-0.6634**	0.9955**	0.858	406.83**	0.0004	0.9550**	-0.5541**	0.642	118.16**
	(0.1311)	(0.0494)			(0.0044)	(0.0882)	(0.1178)		
21-25 count shrimp	-0.4482**	0.9091**	0.735	185.51**	0.0008	0.7490**	-0.5057**	0.423	48.32**
	(0.1659)	(0.0667)			(0.0066)	(0.1126)	(0.1160)		
26-30 count shrimp	-0.3988*	0.8838**	0.653	126.00**	0.0004	0.9157**	-0.6345**	0.450	54.00**
	(0.1877)	(0.0787)			(0.0068)	(0.1297)	(0.1265)		
Tokyo wholesale price for Indo. Black tiger shrimp (LnP_t^i)[a]					Independent variable: contract price for Indo. Black tiger shrimp in the packer market (LnP_t^j)				
16-20 count shrimp	-0.7268**	1.0160**	0.800	268.50**	0.0008	0.9513**	-0.4516**	0.554	81.99**
	(0.1632)	(0.0620)			(0.0051)	(0.1052)	(0.1130)		
21-25 count shrimp	-0.4860**	0.9169**	0.696	153.26**	0.0009	0.8633**	-0.4296**	0.383	40.92**
	(0.1823)	(0.0741)			(0.0068)	(0.1378)	(0.1124)		
26-30 count shrimp	-0.5757**	0.9494**	0.6139	106.55**	0.0007	0.8533**	-0.4155**	0.370	38.75**
	(0.2158)	(0.0920)			(0.0070)	(0.1395)	(0.1137)		

[a] Dependent variables in the their first differences are used for Eqn 8.9. [b] $\hat{\varepsilon}_{t-1}^{i}$ is the one-lagged error correction term. [c] Wald statistics show the cointegration test (Hendry and Doornik, 1996, pp. 49). ** Significance at the 1% level and * significance at the 0.05 level. Numbers in parentheses are standard errors.

8.5 Concluding remarks

The results obtained using the Engle-Granger two-stage procedure for the period 1990-1993 provide evidence that the Tokyo wholesale market and Thai and Indonesian black tiger shrimp packer markets are vertically integrated in the sense that price shocks in one of these markets will have significant impacts on price formation in the other market. The Tokyo wholesale prices appear to have more backward influences on the formation of overseas contract prices used by Japanese shrimp importers in Thai and Indonesian shrimp packer markets. Cold storage holdings in the Japan shrimp import and/or wholesale shrimp markets might be used against price fluctuations and contribute to the relatively slow price response at the Tokyo wholesale market. Furthermore, there is a tendency for the speed of price transmissions in the long term to increase with increasing size class (from 26-30 to 21-25 to 16-20 counts per pound) of black tiger shrimp, regardless of the direction of price transmissions and country of origin. However, behavior of price transmissions relating to shrimp size in the short term as well as the corresponding adjustment to the long-term equilibrium tends to be rather complex.

Information on price transmission behavior generated by this study can be of considerable value to Thai and Indonesia black tiger shrimp packers in making decision on production and export strategies in response to the change in black tiger shrimp price of the forward and/or backward market level, of other competitors, and/or of different shrimp sizes. In addition, the information can also assist Japanese black tiger shrimp importers and wholesalers in understanding the linkages between overseas contract prices in foreign shrimp packer markets and Tokyo wholesale prices, which can serve as a guide for making future importing and distribution decisions. Further empirical research on interdependent price relationships could be extended to include other relatively integrated markets over space (such as the US and the EU markets) and over time (such as futures market in the US Minneapolis Grain Exchange). In addition, more detailed classifications of shrimp attributes in terms of size, species, product form and country of origin could be included in order to capture the complex interactions of price linkages among different shrimp attributes.

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Chapter 9

A logistic regression of risk factors for disease occurrence on Asian shrimp farms

PingSun Leung, Liem T. Tran and Arlo W. Fast

Abstract

Serious shrimp-disease outbreaks have reduced shrimp production and slowed industry growth since 1991. This paper tests factors such as farm siting and design and farm-management practices for relationships with disease occurrence. Logistic regression is used to analyze farm-level data from 3,951 shrimp farms in 13 Asian countries. Disease occurrence is modeled as a 0-1 variable, where 1 = disease loss of ≥ 20% to any one crop, and 0 = losses of < 20%. Logistic regression is performed for each of three levels of shrimp culture intensity – extensive, semi-intensive and intensive. Attempts to apply logistic regression models to each country were not successful due to insufficient data for most countries. Factors affecting disease occurrences were quite different for different farming intensities. Farms that had larger pond production areas, with larger number of farms discharging effluent into their water supply canals, and removed silt had greater disease occurrence. On the other hand, farms that practiced polyculture, and took water from the sea through a canal had lower disease occurrence.

9.1 Introduction

Globally, the shrimp-farming industry enjoyed phenomenal growth during the 1980s, mainly due to technological breakthroughs (such as hatchery seed and improved feed), high profit from farmed shrimp and public support. Farmed shrimp production was 660,200 metric tonnes (mt) in 1997, which was about 22% of total world shrimp production. The eastern and western hemispheres produced 70% and 30% of farmed shrimp, respectively. Thailand was the leading producer during 1997, followed by Ecuador, Indonesia, China, India, Bangladesh, Vietnam, Taiwan and the Philippines. Black tiger shrimp (*Penaeus monodon)* was the most important species farmed in the eastern hemisphere, while the western white shrimp *(Penaeus vannamei)* dominated western hemisphere production (Rosenbery, 1997).

Diseases have emerged as a major constraint to shrimp-aquaculture sustainability. Serious outbreaks of shrimp diseases have occurred in most of the major producing countries. Especially since 1991, shrimp viral diseases have reduced production and slowed industry growth. Many diseases are linked to environmental deterioration and stress associated with shrimp-culture intensification. High profits from shrimp-farming and increasing coastal land prices pushed shrimp farmers towards more intensive operation (first in Taiwan followed by Thailand and other countries). Conditions associated with intensification included: increased farm densities in shrimp-culture areas, greatly increased feed and other inputs per unit of pond area, increased effluent waste loads and increased disease occurrences from various causes. Frequent disease outbreaks often resulted in widespread crop failures.

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Shrimp-culture industry collapses in Taiwan during 1988 and in China in 1993 are two dramatic examples.

A solution of disease problems will involve both prevention and cure. However, because treatment options for many shrimp diseases are either non-existent or ineffective, current emphasis is on prevention. Disease prevention now focuses on use of specific-pathogen free (SPF) or specific-pathogen resistant (SPR) seed stock, seed stock pre-screened for specific pathogens, appropriate site selection and farm design, and application of sustainable farm-management practices. While many of these practices are widely adopted as beneficial for disease prevention, few studies have documented these benefits.

To better understand disease problems faced by Asian shrimp farms, a regional study was conducted during 1994 and 1995 by the ADB (Asian Development Bank) and NACA (Network of Aquaculture Centers in Asia-Pacific). This study was a result of a recommendation by a previous ADB/NACA study (1990) which concluded that aquatic plant and animal diseases are closely linked to environmental issues. Specific objectives of the 1994 study were to assist governments in assessing policy options and in formulating policies to improve aquaculture sustainability. The study included in-depth surveys of 11,000 shrimp and carp farms in 16 Asian countries and territories. The shrimp farm portion of the survey included 2,898 extensive, 1,022 semi-intensive and 870 intensive farms.

The 1994 survey documented that shrimp disease caused significant monetary losses to shrimp farmers. Conservative estimates indicated US$332.2 million per year total losses caused by shrimp diseases, including $143.3 million for intensive farms, $111.8 million for semi-intensive farms and $77.1 million for extensive farms. All countries surveyed suffered in various degrees from shrimp disease problems. For example, the percentage of intensive farms affected by disease losses ≥ 20% of at least one crop ranged from 12% in Malaysia to 100% in China. Semi-intensive and extensive farms also reported significant disease losses (ADB/NACA, 1996). The ADB/NACA survey also found that virtually all countries reported ‘unknown’ as the main cause of shrimp diseases (a clear indication that shrimp diseases are poorly identified). Research and improved extension activities are needed to properly identify shrimp diseases, a necessary step leading to prevention and cure.

With the above in mind, we attempted to identify factors affecting shrimp disease occurrence through further analysis of the ADB/NACA farm survey data. We evaluated logistic-regression models for predicting disease occurrence from a set of 31 variables, including site characteristics, farming systems and farming practices. Logistic regression was performed separately for extensive, semi-intensive and intensive shrimp farms for all countries.

9.2 Methodology

The logistic regression model has emerged as the technique of choice for predicting dichotomous medical outcomes (Tu, 1996). Recently, Johnson-Iferulundu and Kaneene (1998) used logistic regression model to identify management practices that posed risk factors for *M. paratuberculosis* infection of dairy herds in Michigan. While disease-prediction models are widely used to predict incidence of either pests or pathogens in the field for crop protection and disease of land animals, application of disease-prediction models in aquaculture is non-existent.

9.2.1 Logistic regression

A dichotomous outcome, Y, (for example, Y = 1 if disease loss ≥ 20% of crop, or Y = 0 if < 20%) has an expected value, E(Y), assumed to be P (P = the probability that the outcome occurs). The NACA survey defined serious disease outbreaks as those causing more than 20% of stock loss in any one crop. This might underestimate the true total impact of disease because this definition excludes the long-term effects of disease which may cause low-level losses and reduced harvests.

One can usually assume that P is related to a set of potential explanatory variables in the form:

$$Y = P + \varepsilon = \beta_o + \beta_1 X_1 + \beta_2 X_2 + ... + \beta_k X_k + \varepsilon \tag{9.1}$$

where β_0 is the intercept, $\beta_1,...,\beta_k$ are the coefficients associated with each explanatory variable $X_1,....,X_k$ and ε is an error term. Regressing Y on Xs using ordinary least squares will lead to three problems. First, the error term, ε, is obviously not normally distributed as is generally assumed, and more importantly, estimated probabilities can lie outside the range (0,1). Furthermore, the error variance is not constant across levels of the Xs. However, one can assume that P follows a logistic distribution:

$$P = 1/(1 + \exp[-(\beta_o + \beta_1 X_1 + \beta_2 X_2 + ... + \beta_k X_k)] \tag{9.2}$$

Rearranging terms, Eqn. 9.2 can be expressed as:

$$P/(1-P) = \exp[(\beta_o + \beta_1 X_1 + \beta_2 X_2 + ... + \beta_k X_k)] \tag{9.3}$$

where P/(1 – P) is the 'odds' of the outcome such as the occurrence of disease. It is clear from Eqn. 9.3 that the logarithm of the odds, or simply log odds, is a linear function of the explanatory variables, Xs, as:

$$\log[P/(1-P)] = \beta_o + \beta_1 X_1 + \beta_2 X_2 + ... + \beta_k X_k \tag{9.4}$$

Since P is assumed to follow a logistic distribution, maximum-likelihood methods can be used to estimate the coefficients $\beta_1,...,\beta_k$. The logistic-regression procedure in the SPSS package was used in this analysis (SPSS, 1992).

9.2.2 Data and variables

Data for our analyses came from the 1994/1995 ADB/NACA farm survey mentioned previously. Of the 4,855 shrimp farms surveyed by ADB/NACA, we used only 3,951 farms in our analyses due to incomplete observations, as well as observations with large outliers with 904 farms. Of the 3,951 farms analyzed, 779 farms were intensive, 910 were semi-intensive and 2,262 were extensive (Table 9.1). Thirty-one variables including 13 continuous and 18 nominal (categorical) variables describing the site, farming system and farming practice were used as potential factors in explaining disease occurrence. A list of 31 variables is shown in Appendix 9.1 and summary statistics of these variables are presented in Appendix 9.2.

The choice of the 31 explanatory variables was based partly on existing theory and 'hunches' about explanations of shrimp disease occurrences. In general, two approaches can be found in the literature regarding the choice of variables to be included in a model (Hosmer and Lemeshow, 1989). One approach is to include all scientifically relevant variables into the model and the other approach is to use a stepwise procedure in which variables are selected either for inclusion in or removal from a model in a sequential manner based on statistical criteria only. Proponents of the stepwise procedure argue that the parsimonious model is generally more stable numerically and is more easily generalized. On the other hand, others, particularly econometricians, criticize the stepwise procedure as an admission of ignorance about the phenomenon being studied (Studenmund and Cassidy, 1987). Menard (1995, p. 54) sums it up very nicely as follows: 'Without going too deeply into the arguments about the use of stepwise procedures, there appears to be general agreement that the use of computer-controlled stepwise procedures to select variables is inappropriate for theory testing because it capitalizes on random variations in the data and produces results that tend to be idiosyncratic and difficult to replicate in any sample other than the sample in which they were originally obtained.'

Table 9.1 Sample distribution used in analyses by country and by culture intensity

Country	Intensive	Semi-intensive	Extensive	Total
Bangladesh	0	13	93	106
Cambodia	29	0	1	30
China	33	63	83	179
India	6	142	734	882
Indonesia	147	353	884	1,384
Korea	9	0	0	9
Malaysia	40	40	0	80
Myanmar	0	0	68	68
Philippines	31	101	113	245
Sri Lanka	35	124	17	176
Taiwan	62	0	0	62
Thailand	387	0	2	389
Vietnam	0	74	267	341
Total	779	910	2,262	3,951

It is well known in the econometric literature that pre-test estimators resulting from step-wise procedures yield worse estimators than least-squares estimators derived from an accurate prior specification (Charemza and Deadman, 1997). Because the sample size is relatively large in our study, we chose to use the first approach by including all thirty-one variables for which we have data and which we believe might be relevant in our model estimations. Besides not running into pre-test bias as in step-wise procedures, this approach also provides a complete control of confounding. However, the major problem with this approach is that of the possibility of over-fitted model producing numerically unstable estimates with large standard errors. We will elaborate on this aspect in the results and discussion section below. Finally, the choice of approach in variable selection varies by disciplines and is usually driven by the analytic philosophy of the analysts and the problems at hand.

9.3 Results and discussion

Logistic regression models were fitted for each level of shrimp culture intensity (using all 31 variables described above). We also fitted a model combining all farms and with an additional variable representing culture intensity. However, it became apparent from resulting statistical analyses that factors as well as their levels affecting shrimp disease occurrence vary with different culture intensity. Thus, such a formulation is not deemed appropriate and we decided to fit separate models for each culture intensity. The χ^2 values of all three models are statistically significant ($p = 0.0000$), implying that the fitted models (containing the constant and the explanatory variables) fit the data quite well. In other words, there is a significant relationship between the log of odds of a disease occurrence with the explanatory variables.

Table 9.2 shows the estimated βs for the logistic regressions and their significance levels (p-values). Given the insignificance of some important variables, collinearity checks among explanatory variables were conducted. While presence of multicollinearity does not affect the unbiasedness of the estimates, high collinearity may cause the estimates to be extremely imprecise and unstable (Greene, 1990). Bivariate correlation and variance inflation factors among the explanatory variables indicated that there is no serious multicollinearity. This is also supported by the robustness of the estimates from both forward and backward stepwise estimations. These led us to believe that no strong presence of multicollinearity exists in the sample.

These estimated coefficients (βs) reflect the effects of corresponding explanatory variables on the log odds of a disease occurrence. A negative coefficient indicates a positive (decreased) effect on disease occurrence (i.e. an increase in the level of that variable will reduce disease occurrence, ceteris paribus). Conversely, a positive coefficient suggests that an increase in the corresponding variable will increase disease occurrence (again given that all other variables remain the same). Because we cannot confirm that the linearity assumption is met [The log odds is assumed to be linear across the observed ranges of the continuous variables in our formulation. We did not test this assumption because of the exploratory nature of this analysis and the fact that with the large number of continuous variables, the testing and the subsequent remedies can become exceedingly tedious.], our odds ratios for continuous variables should not be interpreted literally. Rather, they can be used to tell the direction of the association and perhaps to see if the association is likely to be strong. This later can be told if the implied changes across the range of values of the risk factor is relatively large. Had we been able to confirm that our coding met the underlying assumptions, the interpretation would have been different. For example, with intensive shrimp culture, for each additional year shrimp farming occurs at the same site, the log odds of disease occurrence increases by 0.04. Put another way, the odds of disease occurrence increases by a factor of 1.04 [= exp(0.04)] for every year shrimp farming occurs at a given site (Table 9.3). Exp(β) represents the expected change in the odds of disease occurrence versus no disease per unit change in the explanatory variable, other things being equal.

Table 9.2 Fitted logistic-regression models for intensive, semi-intensive and extensive shrimp farms, all countries combined

Variable	Intensive		Semi-intensive		Extensive	
	β	p	β	p	β	p
Site characteristics						
1. No. of years of shrimp farming at site	0.04	0.01	-0.004	0.84	-0.03	0.00
2. Inter-tidal zone (mangrove land as base)[a]		0.00		0.05		0.00
Wetland	-0.04	0.91	0.77	0.03	-1.69	0.00
Salt pan	1.03	0.02	1.03	0.04	-0.47	0.19
Other	0.90	0.00	0.19	0.49	-1.15	0.00
3. Supra-tidal zone (mangrove land as base)		0.00		0.27		0.00
Rice farming	0.46	0.17	0.01	0.99	-1.04	0.01
Coconut	-0.74	0.08	1.00	0.12	-6.38	0.21
Upland crops	0.05	0.95	1.05	0.15	-0.92	0.07
Other	-0.03	0.93	0.46	0.28	0.36	0.30
4. Soil (clay soil as base)		0.30		0.00		0.00
Acid-sulphate soil	0.61	0.07	-1.11	0.05	-0.04	0.91
Sandy soils	0.42	0.12	0.97	0.00	-0.02	0.90
Peat/organic rich soil	0.02	0.96	-6.78	0.53	-0.85	0.11
Loam soil	0.38	0.13	-0.37	0.24	-0.45	0.01
Other	-0.03	0.94	1.23	0.00	1.11	0.00
5. Farm operator (owner operator as base)		0.35		0.01		0.07
Cooperative	-0.53	0.28	-1.69	0.07	-0.19	0.71
Lessee/tenant	0.15	0.55	0.12	0.71	0.23	0.34
Share/contract farmer	-0.70	0.14	-0.97	0.07	0.85	0.04
Manager	-0.32	0.36	-1.09	0.00	-0.84	0.08
6. Area of production ponds	0.004	0.81	0.03	0.01	0.03	0.00
7. Salt/brackish water (saltwater creek as base)		0.00		0.00		0.00
Estuary/river	0.28	0.41	-0.47	0.10	-0.76	0.00
Direct from sea	1.03	0.00	0.25	0.49	-0.13	0.71
Canal from sea	-0.52	0.04	-1.53	0.00	0.05	0.75
Other	-6.78	0.45	-0.23	0.61	-1.18	0.00
8. Wet-season salinity of intake water	-0.05	0.80	-0.24	0.29	0.30	0.04
9. Dry-season salinity of intake water	-0.28	0.17	0.23	0.37	-0.07	0.64
10. No. of farms within 3 km	-0.01	0.05	-0.004	0.19	-0.0002	0.74
11. No. of farms share water supply	0.003	0.58	-0.04	0.05	-0.01	0.10
12. No. of farms discharge effluent into water supply canal	0.003	0.50	0.06	0.01	0.02	0.00
13. Measures taken to reduce environmental impacts	-0.13	0.07	-0.44	0.00	-0.08	0.37

Table 9.2 (Continued)

Variable	Intensive		Semi-intensive		Extensive	
	β	p	β	p	β	p
Farming systems and practices						
14. Stocking density	1.87E-07	0.40	1.35E-06	0.22	-5.1E-07	0.69
15. Polyculture (monoculture as base)						0.00
Polyculture - shrimps only	0.14	0.83	-1.02	0.03	-0.89	0.00
Polyculture - Shrimp and fish					-0.66	0.00
16. Dry pond	0.49	0.19	0.16	0.77	-0.74	0.00
17. Silt removal (no removal as base)		0.02		0.05		0.00
Flushing, deposit silt on-farm	0.28	0.42	0.15	0.71	1.53	0.00
Flushing, deposit silt off-farm	0.29	0.47	0.05	0.91	1.40	0.00
Flushing, deposit on and off-farm	1.51	0.01	1.12	0.04	2.35	0.00
Mechanical or manual removal	0.65	0.07	-0.30	0.49	0.40	0.06
18. Maintain/repair dykes	0.45	0.03	-0.04	0.87	0.004	0.98
19. Turn soil (tilling)	-0.22	0.31	-0.39	0.10	-0.57	0.00
20. No. of days after filling to stock shrimp	-0.003	0.66	-0.02	0.31	-0.01	0.01
21. Aeration	-0.09	0.74	0.76	0.01	0.15	0.67
22. Some forms of screening water	0.74	0.02	-0.16	0.57	0.58	0.00
23. Apply chemical	-0.16	0.83	-1.73	0.02	-0.26	0.24
24. Apply fertilizers (not using fertilizer as base)		0.26		0.34		0.07
Inorganic	0.14	0.50	-0.41	0.09	0.34	0.05
Organic	-0.42	0.22	0.16	0.72	0.59	0.04
Inorganic and organic	-0.32	0.25	-0.09	0.79	0.13	0.49
25. Frequency of water exchange	-0.03	0.00	0.02	0.09	0.01	0.05
26. Amount of water added each time	-0.01	0.03	0.01	0.26	0.001	0.32
27. Discharge (no discharge as base)		0.22		0.00		0.00
Discharge to settlement pond	0.46	0.33	-0.22	0.68	0.41	0.50
Discharge to drainage canal	0.57	0.03	-0.46	0.12	0.83	0.00
Discharge to intake/drainage canal	0.62	0.08	0.16	0.64	0.79	0.00
Reuse water on farm	0.01	0.97	-1.24	0.17	1.22	0.10
Some forms of discharge	0.44	0.11	0.89	0.03	0.77	0.01
28. Feed (no supplemental feed as base)		0.04		0.00		0.14
Simple diet	0.69	0.24	0.99	0.24	-0.20	0.41
Formulated	0.74	0.05	0.36	0.63	-0.16	0.50
Mixed	0.23	0.55	1.43	0.06	0.29	0.25
29. No. of shrimp management/monitoring measures	0.62	0.00	0.09	0.55	0.07	0.41
30. No. water monitoring measures	0.15	0.01	0.10	0.13	-0.18	0.00
31. No. of feeding and cost measures	-0.22	0.07	0.10	0.43	0.41	0.00
Constant	-4.55	0.00	-0.82	0.52	-0.66	0.19
Model χ^2	221.7	0.00	411.2	0.000	950.2	0.00
Number of observations	779		910		2,262	

[a] Level of significance (p-value) is also presented for each nominal variable as a group.

Interpretation of the dummy (nominal) variables relates to the base category. For example, after controlling for the effects of all other variables, the odds of disease occurrence with intensive farms increases by a factor of 2.79 [= exp(1.03)] and 2.45 [= exp(0.90)] respectively if the intensive farm was situated in inter-tidal zone previously used as salt pan or as other, when compared with mangrove land (Table 9.3). In other words, the chance of disease with intensive farms in the inter-tidal zone is lower for converted mangrove when compared with converted salt pan or other.

9.3.1 Site characteristics

Odds of disease occurrence increased with time farmed at a given site for intensive culture while the opposite was true for extensive culture (Table 9.3). As with all other variables, our models do not tell us why a relationship exists, only whether one does and its relative magnitude and direction of impact on disease. Perhaps old, intensive farms were more susceptible to disease because they were built in areas where shrimp farms already existed.

While converted mangrove in the inter-tidal zone had lower odds of disease occurrence compared to other previous land use for intensive and semi-intensive farms, the reverse was true for extensive farms. For intensive and semi-intensive farms situated in supra-tidal zone, prior land use did not seem to affect disease occurrence (Table 9.3). For extensive farms, odds were lower for farms that were previously used for rice farming and upland crops, compared to converted mangrove. No overall pattern can be discerned for soil types vs. disease occurrence; although of 15 soil comparisons with clay as the base, only one showed less chance of disease compared with clay, indicating that, overall, clay may be a desirable soil type.

There was no difference in odds of disease occurrence with different types of operators for intensive farms. With semi-intensive and extensive farms, manager had lower odds of disease compared with owner operator, while lessee/tenant (semi-intensive) or share/contract farmer (extensive) had higher odds.

Farms with larger total pond production areas had greater chance of disease with semi-intensive and extensive cultures (Table 9.3).

Intensive and semi-intensive farms that took salt and brackish water through a canal from the sea tended to have lower odds of disease. Extensive farms that took water from estuary/river and other sources tended to have lower odds of disease. Intake-water salinity during both the wet and dry seasons showed no association with disease for all culture intensities. [The salinity variable as used here is a dummy variable, which takes on a value of 1 if salinity is between 5 to 35 ppt (generally considered to be the desirable range), and 0 for salinity outside this range.]

We expected that farm density would increase odds of disease occurrence. However, the number of farms within 3 km did not show any effect for semi-intensive and extensive, and a positive effect for intensive farms. In other words, for intensive operations, more farms within the vicinity can lead to less disease occurrence. Similarly, one might expect that more farms sharing a given water supply might lead to higher disease occurrence. However, this did not appear so. On the other hand (as we expected), the number of farms discharging effluent into a common water supply canal led to higher odds of disease occurrence for both semi-intensive and extensive farms.

Finally, semi-intensive farms that took more measures during design and planning to reduce impacts on the adjacent environment had lower odds of disease but with no effect on intensive and extensive farms (Table 9.3). These measures include environmental-impact assessment, site selection to avoid impacts on other users, site selection to avoid impacts of other users, design of separate water supply/drainage system, retention of mangrove buffer zone, and use of effluent treatment pond.

9.3.2 Farming systems and practices

Stocking densities within each farm type did not have significant associations with disease occurrence (Table 9.3). However, polyculture in semi-intensive and extensive cultures was protective.

Pond preparation and water management

Extensive farms that dried pond soils between crops were found to be less prone to disease, while pond drying had no effect on disease with intensive and semi-intensive culture. The association of silt removal with disease was one of the most revealing analyses: in no cases was silt removal beneficial (Table 9.3). This finding suggests several possible relationships. First, silt removal either exposes disease-producing sediments; or perhaps newly exposed sediments somehow stress shrimp (thus leading to disease problems). Secondly, farms located in areas with low sediment loads in source waters have less disease potentials.

Contrary to our expectation, intensive farms that maintained/repaired dykes had greater odds of disease. As expected, extensive farms that turned soil between crops showed lower odds of disease (Table 9.3), presumably due to the sterilization of soils by UV light. The longer extensive farmers waited to stock shrimp after filling the pond, the lower the odds of disease. Contrary to our expectation, aeration increased odds of disease occurrence in semi-intensive operations, while some form of screening influent waters increased disease occurrence with intensive and extensive operations. Perhaps what we observed with aeration and screening were the results of disease, rather than the cause. Farms with disease problems might be more likely to use aerators, intake screens, and/or other remediations compared with farms without disease problems.

Semi-intensive farms which applied chemicals had lower odds of disease compared with no chemical applications. Again, chemical applications might have been a response to disease problems by the farmers. Fertilizer application with extensive farms increased the odds of disease compared to no fertilizer application. Perhaps fertilizers were more likely used in ponds with water quality problems related to inability to establish healthy algal blooms.

Although water exchange frequency during the last month of crop grow-out might lower odds of disease with intensive culture, the reverse was found with semi-intensive and extensive culture. Similarly, although amount of water added during each water exchange might lower the odds with intensive culture, no association was found with extensive culture. As with sediment removal, the nature of water discharge had only negative or no association with disease compared with the no-discharge option (Table 9.3). These relationships suggest that disease organisms are perhaps re-cycled or transferred between farms more readily when farms discharge more. This suggests that use of SPF or SPR shrimp coupled with minimal discharge may reduce disease.

Table 9.3 Factors with significant positive (less disease; odds ratio < 1.0) and negative (greater disease; odds ratio > 1.0) effects on disease occurrences[a]

Variable	Intensive	Semi-intensive	Extensive
Site characteristics			
1. No. of years of shrimp farming at site	1.04	-	0.97
2. Inter-tidal zone (mangrove land as base)[b]			
Wetland	-	2.16	0.18
Salt pan	2.79	2.79	-
Other	2.45	-	0.32
3. Supra-tidal zone (mangrove land as base)			
Rice farming	-	-	0.35
Coconut	-	-	-
Upland crops	-	-	-
Other	-	-	-
4. Soil (clay soil as base)			
Acid-sulphate soil	-	-	-
Sandy soils	-	2.65	-
Peat/organic rich soil	-	-	-
Loam soil	-	-	0.64
Other	-	3.43	3.04
5. Farm operator (owner operator as base)			
Cooperative	-	-	-
Lessee/tenant	-	-	-
Share/contract farmer	-		2.33
Manager	-	0.34	-
6. Area of production ponds	-	1.04	1.03
7. Salt/brackish water (saltwater creek as base)			
Estuary/river	-	-	0.47
Direct from sea	-	-	-
Canal from sea	0.59	0.22	-
Other	-	-	0.31
8. Wet-season salinity of intake water	-	-	-
9. Dry-season salinity of intake water	-	-	-
10. No. of farms within 3 km	0.995	-	-
11. No. of farms share water supply	-	0.96	-
12. No. of farms discharge effluent into water supply canal	-	1.06	1.02
13. Measures taken to reduce environmental impacts	-	0.64	-
Farming systems and practices			
14. Stocking density	-	-	-
15. Polyculture (monoculture as base)			
Polyculture - shrimps only	-	0.36	0.41
Polyculture - shrimp and fish	-	-	0.52
16. Dry pond	-	-	0.48
17. Silt removal (no removal as base)	-	-	-
Flushing, deposit silt on-farm	-	-	4.60
Flushing, deposit silt off-farm	-	-	4.07
Flushing, deposit on and off-farm	4.52	3.06	10.53
Mechanical or manual removal	-	-	-
18. Maintain/repair dykes	1.57	-	-
19. Turn soil (tilling)	-	-	0.57
20. No. of days after filling to stock shrimp	-	-	0.99
21. Aeration	-	2.13	-
22. Some forms of screening water	2.09	-	1.78
23. Apply chemical	-	0.18	-
24. Apply fertilizers (not using fertilizer as base)			
Inorganic	-	-	-

Organic	-	-	1.80
Inorganic and organic	-	-	-

Table 9.3 (Continued)

Variable	Intensive	Semi-intensive	Extensive
25. Frequency of water exchange	0.97	-	1.01
26. Amount of water added each time	0.99	-	-
27. Discharge (no discharge as base)			
Discharge to settlement pond	-	-	-
Discharge to drainage canal	-	-	2.29
Discharge to intake/drainage canal	-	-	2.20
Reuse water on farm	-	-	-
Some forms of discharge	-	-	2.15
28. Feed (no supplemental feed as base)			
Simple diet	-	-	-
Formulated	2.11	-	-
Mixed	-	-	-
29. No. of shrimp management/monitoring measures	1.85	-	--
30. No. of water monitoring measures	1.16	-	0.83
31. No. of feeding and cost measures	0.80	-	1.50

[a] Only values significant at the 0.05 level are shown.

[b] Values for the individual items of each nominal variable are not shown if the significance level for the nominal variable as a group is not significant at the 0.05 level.

Feed

Intensive farms that used only formulated diet had greater odds of disease compared to farms with no supplementary feed. However, supplemental feeding in any form did not increase the odds of disease with semi-intensive and extensive farms.

Regular management activities

Most shrimp-culture practitioners might assume that increased management activities on a farm would decrease the chance of disease occurrence. Shrimp management and monitoring included regular monitoring of stock survival, daily monitoring of shrimp behavior, and on-farm and off-farm shrimp-health checks. Pond water-quality monitoring parameters included pH/alkalinity, salinity, dissolved oxygen, nutrients (N and/or P), water color and turbidity, sediment condition, and quality of influent and effluent waters. Feeding and cost measures included use of feeding tray to check feed consumption, regular FCR calculations, and regular production/operating cost analyses. More shrimp-management and monitoring measures and more water-monitoring measures increased odds of disease occurrence in intensive farms (Table 9.3). Farms with disease problems might have performed more of these measures in an effort to reduce disease problems. Thus, these measures may be a direct result of disease rather than a cause of disease. Also, contrary to expectation, more feeding and cost measures were associated with increased disease occurrence with extensive farms. However, more water-monitoring measures in extensive farms, and more feeding and cost measures in intensive farms were associated with reduced disease odds. None of these management activities seemed to affect disease occurrence in semi-intensive farms.

9.4 Concluding remarks

Common factors associated with higher odds of disease occurrence with at least two of the three levels of culture intensity were: silt removal between crops versus no removal; larger area of production ponds; and larger number of farms discharging pond effluents into water supply canals.

Common factors associated with lower odds of disease occurrence for at least two of the three levels of culture intensity were if farmers used polyculture; and took water from the sea through a canal versus from a saltwater creek.

While most disease-related factors identified here were perhaps intuitive, others were not so apparent. It is also interesting to note that factors associated with disease occurrence were often different for the three levels of shrimp culture intensity. Logistic regression analyses as used herein can provide meaningful insights into causal relationships between shrimp disease problems and shrimp culture practices. These analyses are unable to establish cause and effect relationships, but they are able to draw attention to certain culture practices which need further evaluation. Some of our findings could be artifacts of data collection techniques, interviewer or farmer biases, or the way questions were worded. However, we are convinced that most of the significant relationships that we identified have some underlying biological, physical or chemical basis, and that the nature of these relationships can be discovered through further analysis. Logistic regression analyses can therefore be of considerable value to shrimp researchers, policy makers and commercial venturists alike. Our findings should also help refine future farm surveys and thereby provide even greater insights into causes of shrimp diseases on shrimp farms.

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Appendix 9.1 List of explanatory variables

Explanatory variable	Variable type[a]	Variable description
Site characteristics		
1. No. of years of shrimp farming at site	C	
2. Prior land use – inter-tidal zone	N	1: mangrove land; 2. Wetland; 3: salt pan; 4: other
3. Prior land use –supra-tidal zone	N	1: mangrove land; 2: Rice farming; 3: coconut; 4: upland crops; 5: other
4. Dominant soil type	N	1: clay soil; 2: acid-sulphate soil; 3: sandy soil; 4: peat/organic rich soil; 5: loam soil; 6: other
5. Farm operator	N	1: owner; 2: cooperative; 3: lessee/tenant; 4: share/contract farmer; 5: manager
6. Area of production pond	C	ha
7. Source of farm water (salt/brackish water)	N	1: saltwater creek; 2: estuary/river; 3: direct from sea; 4: canal from sea; 5: other
8. Wet-season salinity of intake water	N	1: within the range of 5 - 35 ppt; 0: otherwise
9. Dry-season salinity of intake water	N	1: within the range of 5 - 35 ppt; 0: otherwise
10. No. of farms within 3 km	C	
11. No. of farms sharing water supply	C	
12. No. of farms discharging effluent into water supply canal	C	
13. No. of measures to reduce the environmental impacts	C	
Farming systems and practices		
14. Stocking density	C	PL/m^2
15. Polyculture	N	0: monoculture; 1: polyculture, shrimp only; 2: polyculture, shrimp with fish
16. Dry pond	N	1: yes; 0: no
17. Silt removal	N	0: no silt removal; 1: flushing, deposit silt on-farm; 2: flushing, deposit silt off-farm; 3: flushing, deposit on and off-farm; 4: mechanical or manual removal
18. Maintain and repair dykes	N	1: yes; 0: no
19. Turn soil (tilling)	N	1: yes; 0: no
20. No. of days after filling to stock shrimp	C	
21. Aeration	N	1: yes; 0: no
22. Some forms of screening water	N	1: yes; 0: no
23. Apply chemical	N	1: yes; 0: no
24. Apply fertilizers	N	0: no; 1: inorganic; 2: organic; 3: mixed - inorganic and organic
25. Frequency of water exchange	C	times/month
26. Amount of water added each time	C	cm/time
27. Discharge	N	0: no discharge; 1: discharge to settlement pond; 2: discharge to drainage canal; 3: discharge to intake/drainage canal; 4: reuse water on farm; 5: mixed - some forms of discharge
28. Feed	N	0: no supplemental feeding, 1. simple diet; 2: formulated diet; 3: mixed
29. No. of measures for management and monitoring of shrimp	C	0 - 4 depending on number of activities
30. No. of measures for pond water quality monitoring	C	0 - 8 depending on number of activities
31. No. of measures for feeding and costs	C	0 - 3 depending on number of activities

[a] C denotes continuous variables and N denotes nominal variables.

Appendix 9.2 Summary statistics of variables used in logistic regression models for intensive, semi-intensive and extensive shrimp farms, all countries.

Variable	Intensive (n = 779)			Semi-intensive (n = 910)			Semi-intensive (n = 910)		
	5th per-centile	Median or % in category[a]	95th per-centile	5th per-centile	Median or % in category[a]	95th per-centile	5th per-centile	Median or % in category[a]	95th per-centile
Site characteristics									
1. No. of years of shrimp farming at site	0.0	3.0	95.0	1.0	4.5	17.5	1.0	7.0	25.0
2. Inter-tidal zone									
Mangrove land		20			35			34	
Wetland		13			15			16	
Salt pan		6			4			4	
Other		61			46			46	
3. Super-tidal zone									
Mangrove land		9			6			3	
Rice farming		34			12			21	
Coconut		10			3			2	
Upland crops		1			2			2	
Other		45			76			71	
4. Soil									
Clay		42			40			39	
Acid-sulphate soil		9			4			4	
Sandy soil		19			18			15	
Peat/organic rich soil		5			3			1	
Loam soil		19			23			22	
Other		6			11			18	
5. Farming operator									
Owner		69			71			86	
Cooperative		3			2			2	
Lessee/tenant		16			12			6	
Share/contract farmer		4			6			3	
Manager		8			10			2	
6. Area of production ponds (ha)	0.4	1.4	9.5	0.3	2.0	16.7	0.3	2.0	16.0
7. Salt/brackish water									
Saltwater creek		36			33			38	
Estuary/river		9			29			27	
Direct from sea		34			15			3	
Canal from sea		20			15			26	
Other		2			8			6	
8. Wet-season salinity of intake water		57			51			36	
9. Dry-season salinity of intake water		34			20			41	
10. No. of farms within 3 km	0	9	100	0	10	140	0	20	300
11. No. of farms share water supply	0	0	30	0	5	70	0	12	95

Appendix 9.2 Summary statistics of variables used in logistic regression models for intensive, semi-intensive and extensive shrimp farms, all countries (continued).

Variable	Intensive (n = 779)			Semi-intensive (n = 910)			Semi-intensive (n = 910)		
	5th per-centile	Median or % in category[a]	95th per-centile	5th per-centile	Median or % in category[a]	95th per-centile	5th per-centile	Median or % in category[a]	95th per-centile
12. No. of farms discharging effluent into water supply canal	0	0	56	0	4	61	0	10	90
13. Measures taken to reduce environmental impacts	0	2	5	0	1	3	0	1	3
Farming systems and practices									
14. Stocking density (1,000 PL/ha)	129	600	1200	50	100	300	6	29	148
15. Polyculture									
Mono		98			93			62	
Poly - shrimp only		2			7			29	
Poly - shrimp and fish		0			0			9	
16. Dry pond		93			97			88	
17. Silt removal									
No silt removal		9			11			27	
Flushing, deposit silt on-farm		41			46			35	
Flushing, deposit silt off-farm		13			10			11	
Flushing, deposit silt on and off-farm		5			6			4	
Mechanical or manual removal		31			27			23	
18. Maintain/repair dykes		46			66			67	
19. Turn soil (tilling)		40			60			42	
20. No. of days after filling to stock shrimp	0	7	30	0	7	20	0	10	30
21. Aeration		87			42			4	
22. Some forms of screening water		85			79			66	
23. Apply chemicals		98			98			88	
24. Apply fertilizers									
No use of fertilizer		45			50			62	
Inorganic		28			31			16	
Organic		11			5			6	
Mix some forms of organic inorganic		16			14			16	
25. Frequency of water exchange (times/month)	0	4	30	0	6	30	0	3	31.7
26. Amount of water added each time (cm/time)	0	10	40	0	25	60	0	20	60

Appendix 9.2 Summary statistics of variables used in logistic regression models for intensive, semi-intensive and extensive shrimp farms, all countries. (continued).

Variable	Intensive (n = 779)			Semi-intensive (n = 910)			Semi-intensive (n = 910)		
	5th percentile	Median or % in category[a]	95th percentile	5th percentile	Median or % in category[a]	95th percentile	5th percentile	Median or % in category[a]	95th percentile
27. Discharge									
No discharge		25			21			30	
Discharge to settlement pond		4			4			1	
Discharge to drainage canal		36			42			14	
Discharge to intake/ drainage canal		8			25			47	
Reuse of water on farm		7			2			1	
Mix some forms of discharge		20			6			7	
28. Feed									
No supplement feed		7			2			44	
Simple diet		4			5			13	
Formulated		59			74			28	
Mixed		31			19			16	
29. No. of shrimp management /monitoring measures	1	3	4	1	2	4	0	2	3
30. No. of water monitoring measures	2	5	8	1	4	8	0	2	6
31. No. of feeding and cost measures	0	2	3	0	2	3	0	1	3

[a] This column shows the median for continuous variables or % in each category for nominal variables.

Chapter 10

Predicting shrimp disease occurrence: artificial neural networks vs. logistic regression

PingSun Leung and Liem T. Tran

Abstract

Predicting the occurrence of disease outbreaks in aquacultural farms can be of considerable value to the long-term sustainable development of the industry. Prior research on disease prediction has essentially depended upon traditional statistical models with varying degrees of prediction accuracy. Furthermore, the application of these models in sustainable aquaculture development and in controlling environmental deterioration has been very limited. In an attempt to look for a more reliable model, we develop a probabilistic neural network (PNN) to predict shrimp disease outbreaks in Vietnam using farm-level data from 480 Vietnamese shrimp farms, including 86 semi-intensive and 394 extensive farms. We also compare predictive performance of the PNN against the more traditional logistic regression approach on the same data set. Disease occurrence (a 0-1 variable) is hypothesized to be affected by a set of nearly seventy variables including site characteristics, farming systems and farm practices. Results show that the PNN model has a better predictive power than the logistic regression model. However, the PNN model uses significantly more input (explanatory) variables than the logistic regression. The logistic regression is estimated using a stepwise procedure starting with the same input variables as in PNN model. Adapting the same input variables found in the logistic regression model to the PNN model yields results no better than the logistic regression model. More importantly, the key factors for prediction in the PNN model are difficult to interpret, suggesting besides prediction accuracy, model interpretation is an important issue for further investigation.

10.1 Introduction

The global shrimp farming industry had a phenomenal growth in the 1980s mainly due to technological breakthroughs (such as in hatchery practices and feed formulation), high profitability and public support. Farmed shrimp amounted to about 660,200 metric tonnes (mt) in 1997, which accounted for about 22% of total shrimp production from both wild-caught and farm-raised sources. Asia produced about 70% of farmed shrimp and Western countries 30%. Thailand was the leading producer, followed by Ecuador, Indonesia, China, India, Bangladesh, Vietnam, Taiwan and the Philippines in 1997. Black tiger shrimp (*Penaeus monodon)* was the most important species farmed in the eastern hemisphere while the western white shrimp *(Penaeus vannamei)* dominated the western hemisphere (Rosenbery, 1997).

Diseases have emerged as a major constraint to the sustainable growth of the shrimp aquaculture industry. Serious outbreaks of shrimp diseases have been reported in most of the major producing countries. Viral diseases have reduced shrimp production and have slowed the growth of the industry since 1991. Many diseases are linked to environmental deterioration and stress associated with farm intensification. High profits in shrimp farming and increasing coastal land prices pushed shrimp

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farmers towards more intensive operation, first in Taiwan, followed by Thailand and other countries. Without effective control, intensive operations usually increase the nutrient and organic matter load to the ecosystem well beyond the carrying capacity of the environment. This often results in self-pollution which leads to more frequent disease outbreaks followed by crop failure. The collapse of the shrimp culture industry in Taiwan in 1988 and China in 1993 are apparent examples.

Solution to the disease problems involves both prevention and cure. However, since treatment options for many shrimp diseases are either non-existent or ineffective, current emphasis is on prevention. Thus, the solution to the problem must deal with site selection, design and sustainable farm management. The economics of alternate disease control methods (applying drugs and vaccines, fallowing the ponds after each harvest, etc.) need to be assessed and compared for sustainable development. In the long run, genetic improvement of the cultured species is likely to result in disease-resistant strains, greater tolerance to environmental variation and faster growth. Improved virus-free fry may also reduce the disease problems in the grow-out stage.

In response to the serious disease problems faced by the shrimp industry in Asia, a regional study was initiated in 1994 by ADB (Asian Development Bank) and NACA (Network of Aquaculture Centers in Asia-Pacific) aimed at providing a clearer understanding on environmental problems and their economic impacts through a farm level survey. The 1994 study was a result of a recommendation by a previous ADB/NACA regional study (1990), which concluded that the diseases of aquatic animals and plants are closely linked to the environment and that environmental issues, including fish disease control, must be considered in the broader context of fish farming systems, design, site selection and management. The specific objective of the 1994 study was to assist governments in assessing policy options and formulating policies designed to improve the sustainability of the aquaculture industry. A detailed survey of almost 11,000 shrimp and carp farms was undertaken covering 16 countries and territories in the region. The shrimp survey covered a total of 2,898 extensive, 1,022 semi-intensive and 870 intensive shrimp farms.

The survey results show that shrimp disease contributed to significant regional losses. A conservative US$332.2 million per year was estimated as the total loss attributed to shrimp diseases: $143.3 million to intensive farms, $111.8 million to semi-intensive farms and $77.1 million to extensive farms. The countries involved in the survey all suffered in various degrees from disease problems. For example, the proportion of intensive farms affected by disease (defined as more than 20% stock losses) was high in most countries, ranging from 12% in Malaysia to 100% in China. Semi-intensive and extensive farms were also reporting significant losses due to disease problems (ADB/NACA, 1996).

The survey results also indicate that virtually all countries reported ‘unknown’ as the cause of the shrimp disease problems. As the causes of shrimp disease are poorly understood, research and improved extension activities are needed in properly identifying shrimp disease problems, and their prevention and cure. In this paper, we attempt to predict the occurrence of shrimp diseases based on farm site selection, design and farm management practices. Prior research on disease prediction has essentially depended upon traditional statistical models with varying degrees of prediction accuracy. Furthermore, the application of these models in sustainable aquaculture development and in controlling environmental deterioration has been very limited. In an attempt to look for a more reliable model, we develop a probabilistic neural network (PNN) to predict shrimp disease outbreaks in Vietnam using the NACA/ADB farm-level data from 480 Vietnamese shrimp farms. We also compare predictive performance of the PNN against the more traditional logistic regression approach on the same data set.

10.2 Methods and data

Statistical regression models are the most commonly used techniques for disease prediction. The logistic regression model has emerged as the technique of choice in predicting dichotomous medical outcomes (Tu, 1996). While disease prediction models have been widely used to predict incidence of either pests or pathogens in the field for crop protection and diseases in land animals, disease prediction models applied to aquaculture are almost non-existent.

For predicting dichotomous outcomes such as the occurrence of disease, logistic regression has been the most appropriate technique. However, the recent development of artificial neural networks (ANNs) provides a new alternative to logistic regression, particularly in situations where the dependent and independent variables exhibit complex nonlinear relationships. There are numerous applications of ANNs in the literature ranging from business and finance to agriculture and ecology. The performance of ANNs in predicting dichotomous outcomes compared to logistic regression has also been evaluated in several areas of applications. All reported cases in the literature seem to show the inclination that ANNs out-performed the traditional logistic regression approach. Starrett et al. (1997) used both ANNs and logistic regression to predict percentage of applied nitrogen leached under turfgrass. Paruelo and Tomasel (1997) compared the performance of ANNs and logistic regression models in predicting ecosystems attributes. Horimoto et al. (1997) evaluated the prediction performance of ANNs, logistic regression and principal components in classifying microbial defects in milk. In the area of finance, Maher and Sen (1997) compared the prediction accuracy of ANNs and logistic regression in predicting bond ratings. All the cases cited above have demonstrated the superior predictability of ANN models over logistic regression models. A brief discussion of logistic regression and ANNs follows.

10.2.1 Logistic regression

Logistic regression or logit analysis is a popular statistical modeling technique in which the probability of a dichotomous outcome is related to a set of potential explanatory variables in the form:

$$\log [P/(1-P)] = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + ...+ \beta_k X_k \qquad (10.1)$$

where P is the probability of the outcome, $\beta_1,...,\beta_k$ are the coefficients associated with each explanatory variable $X_1,....,X_k$. The dependent variable is the logarithm of the odds, which is the logarithm of the ratio of two probabilities: the probability that a disease outbreak will occur and the probability that it will not occur. The logarithm of the odds {log[P/(1-P)]} is related in a linear manner to the potential explanatory variables. Where there is no available theoretical model, explanatory variables are usually selected through some specific techniques such as backward or forward stepwise regression with different criteria to include or to reject an explanatory variable. Although different techniques might give different regression models, they are often very similar. The maximum-likelihood method is used to estimate the coefficients $\beta_1,...,\beta_k$ in the logistic regression. The logistic regression procedure in the SPSS package was used in this analysis (SPSS, 1992).

10.2.2 Probabilistic neural network (PNN)

ANNs are algorithms patterned after the structure of the human brain (Harston, 1990). In an ANN, processing elements – units analogous to biological neurons – are organized into groups called layers. An ANN includes a sequence of inputs, hidden layer(s) between input and output layers and output layers, interconnected in many different ways (Maren, 1990a, 1990b). Data are introduced at the input layer and the ANNs response in accordance to the input data is generated at the output layer. The hidden layers allow the network to generate numerous relationships (mapping functions) between the inputs and outputs so that the desired outputs can be produced using a given set of inputs. Interaction between processing elements occurs along connection paths at different connection strengths called weights. By changing the weight values (through training), an ANN can collectively reproduce the complex overall behavior of a system. There are several different types of ANN based on their architectures and training (learning) algorithms. Since we have a classification problem, probabilistic neural network (PNN) is considered the most appropriate form of ANN and is used in this study (Specht, 1990; Ward Systems Group, Inc., 1995).

PNN is a feedforward neural network developed by Specht (1990), in which the response to an input pattern is processed from one layer to the next with no feedback paths to previous layer(s). To provide a general solution to pattern classification, PNN is based upon an approach developed in statistics called Bayesian classifiers. Bayesian classifiers take into account the relative likelihood of events and use a priori information to improve prediction (Specht, 1996). They provide an optimum approach to classification in terms of minimizing the expected risk of wrongly classifying an object, and the estimator gets closer to the true underlying class density functions as the number of training samples increases. Since the underlying class density function is unknown, PNN relies on a class of probability density function (PDF) estimator, developed by Parzen and extended by Cacullos, which asymptotically approaches the underlying class density as long as it is continuous (Specht, 1996).

A PNN often has three layers: input, pattern (hidden) and output layers. The number of elements in the input layer is equal to the number of separable parameters needed to describe the objects to be classified. In our case, the number of input elements corresponds to the 68 variables describing the farm site selection and design, and farm management practices of the 480 Vietnamese shrimp farms. A scale function is often used to normalize the input vector, if the inputs are not already normalized before they enter the network. In the pattern layer, the training set is organized such that each input vector is represented by an individual processing element. The pattern layer essentially comprises of the Bayesian classifiers in which the unknown underlying class density functions are estimated through a non-parametric approach using the PDF estimators described above. The output layer has as many processing elements as there are classes to be classified. In our case, the output layer would have only two classes, farms with disease outbreaks and farms with no disease outbreaks. More details on PNN can be found in Specht (1990, 1996). The PNN used in this analysis is from the "NeuroShell2" package developed by the Ward Systems Group, Inc. (1995).

10.2.3 Data

The data used in this paper are a part of a large-scale survey of almost 5,000 shrimp farms in 16 countries conducted in 1994/1995 by the Network of Aquaculture Centers in Asia-Pacific (NACA) and the Asian Development Bank (ADB) under a regional technical assistance program. Detailed on-farm surveys were conducted in each country assisted by a common questionnaire. The shrimp farming questionnaire has questions grouped into five sections: site description, farming system, problem analysis, economics and social factors. Site description included information about age of farm, nature of aquaculture activities, type of land use, soil type, operation, water source and site-selection considerations. In the section about farming system, information on shrimp species and farming techniques were collected. The third section identified problems related to water and sediments, diseases and their consequences. The economic section gathered information about inputs, costs, revenue, and production and profit trends. The final section identified social aspects of conflict and their resolution. In this analysis, 480 shrimp farms in Vietnam, including 86 semi-intensive and 394 extensive farms, are used. With the purpose of analyzing the cause-effect relationship of environmental and management factors tied to aquaculture disease outbreaks, only information in the first three sections of the questionnaire – site description, farming system and problem analysis – are used.

Data were randomly divided into two sets: an estimation set with 369 observations (about three-quarters of the whole data set) used to develop the logistic regression model and the PNN model, and a validation set with 111 observations. The partition of the data was arbitrary, balancing the need to have enough data for parameter estimation in the training data set while maintaining a reasonable number of observations for validation.

10.3 Results

10.3.1 Logistic regression

The logistic regression was estimated using both forward and backward stepwise procedures with 68 variables consisting of 16 continuous and 52 categorical variables (a complete listing of all the variables can be found in the Appendix 10.1). The categorical variables with n attributes were converted into n – 1 binary variables in estimation and they were forced into or out of the regression collectively in one step. The Wald statistics was used for selecting variables to enter and leave the regression. The significance level for entering was set at 0.05 and for deletion at 0.10. The backward procedure is generally considered to be more preferable since the forward approach might exclude some important variables from the model. However, in our case, the results of both the backward and froward approach were similar in terms of the variables selected and the predictive accuracy. At the end, we decided to use the results of the forward approach as several selected variables with the backward approach exhibited the wrong signs that were not easily interpretable. Six variables were chosen in the final model (Table 10.1). All of them are categorical variables.

Table 10.1 Results of the logistic regression model[a]

Variable[b]	Estimates of β	Standard error	p-value	Exp(β)	Probability (P)
POLYCULTURE	-1.0961	0.3055	0.0003	0.3342	0.250
DRY POND	-1.0393	0.3957	0.0086	0.3537	0.261
I/D_CANAL	1.3984	0.3560	0.0001	4.0486	0.802
WATER_SOURCE:			0.0002		
Estuary/River	-2.1598	0.5288	0.0000	0.1154	0.103
Direct_from_Sea	0.0606	0.6094	0.9208	1.0625	0.515
Canal_from_Sea	-0.0479	0.3884	0.9018	0.9532	0.488
Other	-1.3885	0.5887	0.0184	0.2495	0.200
SITE_SELECTION	-1.6936	0.4026	0.0000	0.1839	0.155
SILT_DEPOSIT	1.0638	0.3001	0.0004	2.8975	0.743
Constant	1.1428	0.5079	0.0244		

[a] Model χ^2 = 204.42

[b] Variables: POLYCULTURE: yes = 1, 0 otherwise; DRY POND: yes = 1, 0 otherwise; I/D_CANAL: water discharge into intake/drainage canal; yes = 1, 0 otherwise; WATER_SOURCE: the main salt/brackish water source. The effect of the four categories in the table are compared to the category of 'Saltwater creek.

SITE_SELECTION: site selection to avoid impacts of other users; yes = 1, 0 otherwise; and SILT_DEPOSIT: deposit silt on-farm; yes = 1, 0 otherwise.

Table 10.2 Classification accuracy of the logistic regression model

		Estimation subset			Validation subset		
		Predicted		Percent Correct	Predicted		Percentt Correct
Correct		0	1		0	1	
Observed	0	162	33	83.08	45	13	77.59
	1	30	144	82.76	9	44	83.02
Overall				82.93			80.18

0 denotes "no disease occurrence", 1 denotes "disease occurrence."

The model χ^2 value of 204.42 is statistically significant (p = 0.0000), implying that the estimated model, containing the constant and the six explanatory variables, fits the data. In other words, there is a significant relationship between the logarithm of odds of a disease occurrence with the explanatory variables. Coefficients of all the six selected variables are significant at the 0.01 level except that for the variable WATER_SOURCE, suggesting that there are no significant differences whether the water came directly from sea or through a canal as compared to water from a saltwater creek. The parameter estimates also suggest that, as expected, the effects of POLYCULTURE, DRY POND and SITE_SELECTION on the logarithm of the odds of a disease occurrence are negative, and the effects of SILT_DEPOSIT and

I/D_CANAL are positive. I/D_CANAL and SILT_DEPOSIT are the two most influential positive variables affecting the odds of a disease occurrence. The logarithm of the odds of a disease occurrence, after controlling for the effects of other variables, increases by 1.40 and 1.06 for the farms which discharge water into intake/drainage canal and deposit silt on-farm, respectively. Restated, after controlling for all other variables, the odds of a disease occurrence increases by 4.05 and 2.90 times for the farms that discharge water into intake/drainage canal and deposit silt on-farm, respectively.

Table 10.1 also provides the estimated probability of disease occurrence for each explanatory variable when all the other variables are set at 0. For example, the chance of a disease occurrence for farms which discharge water into an intake or drainage canal is about 80% if the farms do not practice polyculture, do not dry ponds, do not exercise careful site selection, do not deposit silt on-farm and obtain their water from saltwater creek. The estimated probability will be higher or lower depending on the combination of values of all the other explanatory variables. Similarly, the chance of a disease occurrence is about 74% for farms depositing silt on-farm. On the other hand, the chance of a disease occurrence is quite low, 16%, 25% and 26% for farms which exercise careful site selection, practice polyculture and dry ponds, respectively. Farms which obtain their water from river or estuary seems to have a lower chance of disease occurrence as compared to those obtaining their water from a saltwater creek, directly from the sea or through a canal from the sea.

The estimated logistic regression model was then applied to the estimation and validation data sets. The predictive accuracy as applied to each of the data set is shown in Table 10.2. The table shows the number of farms predicted to have disease outbreak, i.e. farms with estimated probability of disease occurrence of more than 0.5. The estimated model appears to have good predictive power, correctly classifying 82.93% and 80.18% of the observations in the estimation and validation subsets, respectively.

10.3.2 Probabilistic neural network (PNN)

First, we constructed a PNN model using the same estimation data set as in the logistic regression procedure. Then the PNN model was applied to the estimation and validation subsets. Its prediction accuracy is shown in Table 10.3.

Table 10.3 Classification accuracy of the PNN model, using full set of input variables

		Estimation subset			Validation subset		
		Predicted		Percent Correct	Predicted		Percent Correct
		0	1		0	1	
Observed	0	179	16	91.79	50	8	86.21
	1	17	157	90.23	7	46	86.79
Overall				91.06			86.49

0 denotes “no disease occurrence”, 1 denotes “disease occurrence.”

Recall that only six variables were chosen in the final logistic regression model. These same six variables were used to build another PNN model. Table 10.4 shows the classification accuracy of this PNN model on the estimation and validation subsets.

Table 10.4 Classification accuracy of the PNN model, using the same six input variables as in the final logistic regression model

		Estimation subset			Validation subset		
		Predicted		Percent Correct	Predicted		Percent Coorect
		0	1		0	1	Correct
Observed	0	145	50	74.36	41	17	70.69
	1	24	150	86.21	12	41	77.36
Overall				79.95			73.87

0 denotes “no disease occurrence”, 1 denotes “disease occurrence.”

10.4 Discussion

Results show that the PNN model using the full set of input (explanatory) variables have a better predictive power than the final logistic regression model with six explanatory variables (Table 10.2). However, if the same six input variables as in the final logistic regression model were used, results from PNN are worse than those of logistic regression model (Table 10.3). With 62 more variables, the prediction accuracy of the full PNN model improves by only 8.13% in the estimation subset and 6.31% in the validation subset. One point which is often used to explain the better prediction power of PNN is the ability to detect all possible interactions between explanatory variables (Tu, 1996). It is interesting to note by forcing all input variables into the logistic regression model, a prediction accuracy of 90.24% in the estimation subset and 74.77% in the validation subset were attained.

While the prediction accuracy for the estimation subset is very similar to the full PNN model including all input variables (90.24% vs. 91.06%), the prediction accuracy for the validation subset is significantly lower than the full PNN model (74.77% vs. 86.49%). In fact, the full logistic regression model including all explanatory variables performs even worse than the final logistic regression model with six input variables for the validation subset (74.77% vs. 80.18%). This is probably due to over-fitting of the full logistic regression whereby the prediction accuracy of the out-of-sample validation set is significantly worse than that of the in-sample estimation subset.

Furthermore, most of estimated coefficients in this full regression model are not significantly different from zero and exhibit high degree of multicollinearity. Hence the model would not provide meaningful parameter estimates. The better out-of-sample performance of the full PNN model over the full logistic regression model in this case may be explained by the fact that the disease prediction problem at hand does exhibit some degree of nonlinearity when all variables are considered. PNN is often superior to conventional statistical tools to detect complex nonlinear relationship between independent and dependent variables.

A benefit of the logistic regression model is its parameters are transparent, aiding identification of factors that affect the dependent variable. In this problem, all input variables extracted in the logistic regression model appear to be explainable on a biological basis, although they were never tested statistically. For example, polyculture in shrimp farming reduces the chance of shrimp disease. Discharging water into intake/drainage canal increases the chance of getting disease. Furthermore, from values of parameters in the logistic regression model, one can estimate the probability of disease occurrence when one input variable increases or decreases by one unit.

On the other hand, the PNN model is a black box. Although there are contribution factors (or weights) associated with each input variable in PNN model, they are generally not so useful in explaining the level of contribution of each variable. In the optimization process of the PNN, several scale functions are usually tested in the input layer to choose the one giving the best prediction. In our case, prediction accuracy from models with different scale functions differs only by a couple of percentages. Weights of input variables however change significantly from model to model. One input variable can have a very high weight in one model but very low in another, suggesting that weights in PNN are not reliable in explaining the contribution of input variables. Besides methodological issues as described above, PNN model development requires much more time and greater computational resources as compared with those for conventional statistical models.

10.5 Conclusions

In this paper, we evaluated the potential of PNN as an alternative to the traditional logistic regression model for the purpose of predicting disease occurrence in shrimp farms. A sample of shrimp farms in Vietnam was used as a test case. Results indicate that PNN can outperform the logistic regression model when the full set of input variables was used. However, if the same set of variables was used as in the final logistic regression resulting from a stepwise procedure, the predictive power of the PNN is worse than that of the logistic regression. Even with similar predictive power, one would usually prefer logistic regression over PNN because of the non-parametric nature of the PNN. Logistic regression provides meaningful parameter estimates which can have insightful policy implications. For example, we found that farms that practice polyculture, dry ponds and conduct careful site selection have a smaller chance of a disease outbreak while farms that deposit silt on the farm and discharge water into intake and drainage canal have a much higher chance of a disease outbreak. Furthermore, chance of disease occurrence is lower for farms that obtain their water from river and estuary than from other sources.

While most recent applications of PNN demonstrate their predictive superiority over logistic regression, it is, however, not conclusive in our case. One reason could be that there is not much nonlinearity exhibited in the relationship between shrimp disease occurrence with the six chosen explanatory variables in the final logistic regression model. In fact, given the black-box nature of the PNN, logistic regression appears to be the preferred choice for the purpose of shrimp disease explanation. While it is too early to generalize these results until further evidence from analysis of shrimp farms in other countries is observed, the Vietnam case demonstrates the potential of logistic regression in predicting and identifying major factors affecting shrimp disease outbreaks.

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Appendix 10.1 List of variables

No.	Variable	Variable description
1	Farm type	0: extensive;1: semi-intensive
2	Farm status	1: active; -1: abandoned; 0: no answer
SITE DESCRIPTION		
3*	Number of years farming	
4	Site previously used for aquaculture	1: yes; 0: no
5	Continuous use	1: yes; 0: no
6	Alternative cropping	1: yes; 0: no
7	Change of culture species	1: yes; 0: no
8	Change in intensity	1: yes; 0: no
9	Expansion of area cropped	1: yes; 0: no
10	Contraction of area cropped	1: yes; 0: no
11	Land-use before using for aquaculture	1: mangrove land; 2: wetland; 3: salt pan; 4: other in inter-tidal zone; 5: mangrove land (in supra-tidal zone); 6: rice farming; 7: coconut; 8: upland crops; 9: other in supra-tidal zone
12	Dominant soil type	1: peat/organic rich soil; 2: acid-sulphate soil; 3: sandy soil; 4: clay soil; 5: loam soil; 6: other
13	Who operates farm ponds	1: owner; 2: cooperative; 3: lessee/tenant; 4: share/contract farmer; 5: manager
14*	Total farm area	ha
15*	Area of dykes, other uses or unused	ha
16	Source of farm water (salt/brackish water)	1: saltwater creek; 2: estuary/river; 3: direct from sea; 4: canal from sea; 5: other
17	Source of farm water (fresh water)	1: groundwater; 2: rain-fed; 3: lake/reservoir; 4: river/freshwater stream; 5: irrigation canal
18*	Average wet season salinity of intake water	in parts per million (PPM)
19*	Average dry season salinity of intake water	in PPM
20*	Number of farms within 3 km	
21*	Number of farms share water supply	
22*	Number of farms discharge effluent into water supply	
Measures to reduce the environmental impacts		
23	Environmental impact assessment	1: yes; 0: no
24	Site selection to avoid impacts on other users	1: yes; 0: no
25	Site selection to avoid impacts of other users	1: yes; 0: no
26	Design of separate water supply/drainage system	1: yes; 0: no
27	Retention of mangrove buffer zone	1: yes; 0: no
28	Effluent treatment pond	1: yes; 0: no
29	Other measure to reduce impacts	1: yes; 0: no

Appendix 10.1 List of variables (cont'd)

No.	Variable	Variable description
FARMING SYSTEM		
30	Having a water storage pond	1: yes; 0: no
Water treatment		
31	Screen inflow water	1: yes; 0: no
32	Short/medium/long-term storage	1: yes; 0: no
33	Apply chemicals	1: yes; 0: no
34	Aeration	1: yes; 0: no
35	Biological treatment	1: yes; 0: no
Pond management before stocking		
36	Drain pond	1: yes; 0: no
37	Dry pond	1: yes; 0: no
38	Remove pond silt	1: yes; 0: no
39	Deposit silt on-farm	1: yes; 0: no
40	Deposit silt off-farm	1: yes; 0: no
41	Maintain/repair dykes	1: yes; 0: no
42	Turn soil (tilling)	1: yes; 0: no
43	Apply chemical	1: yes; 0: no
44	Mechanical screening of inflow water	1: yes; 0: no
45	Other activities	1: yes; 0: no
Treat/manage water on farm after stocking		
46*	Number of days after filling pond to stock shrimp	days
47	Aeration	1: yes; 0: no
48	Mechanical screening of inflow water	1: yes; 0: no
49	Apply chemical	1: yes; 0: no
50	Apply inorganic fertilizer	1: yes; 0: no
51	Apply organic fertilizer	1: yes; 0: no
52	Other treatments	1: yes; 0: no
53	Drainage through central drain	1: yes; 0: no
54*	Frequency of water exchange	times/month
55*	Amount of water added each time	cm/time
56*	Estimated seepage and evaporation losses	cm water/month
57	Discharge to settlement pond	1: yes; 0: no
58	Discharge to drainage canal	1: yes; 0: no
59	Discharge to intake/drainage canal	1: yes; 0: no
60	Biological treatment	1: yes; 0: no
61	No discharge - reuse water on farm	1: yes; 0: no
62	Other treatment	1: yes; 0: no
Feed management		
63	Simple diet	1: yes; 0: no (including barns, oil cakes, kitchen/food processing waste, fresh fish/meat, plant material, and others)
64	Formulated diet	1: yes; 0: no (including dry ground mixture, wet mixture, imported commercial pelleted feed, locally produced commercial pelleted feed, and others)
Other management activities		
65*	Management and monitoring of shrimp	1 - 4 scale depending on number of activities
66*	Pond water quality monitoring	1 - 8 scale depending on number of activities
67*	Feedings and costs	1 - 3 scale depending on number of activities
68*	Main information sources	1 - 4 scale depending on number of activities

* Denotes continuous variables.

Part Two

Carp

Chapter 11

Technical efficiency of carp pond culture in South Asia: an application of a stochastic meta-production frontier model

Khem R. Sharma and PingSun Leung

Abstract

A stochastic meta-production frontier model is estimated to examine the inter-country differences in levels of technical efficiency of semi-intensive/intensive and extensive carp pond culture systems among the major carp producing countries in South Asia, namely India, Bangladesh, Pakistan and Nepal. The mean technical efficiencies for semi-intensive/intensive farms vary from 0.68 for Nepal to 0.79 for India, with an overall average of 0.75 and those for extensive farms vary from 0.48 for Bangladesh to 0.62 for Pakistan, with an overall mean of 0.57. Differences in efficiency levels are explained in terms of various farm-specific and country-specific factors by estimating a model for technical inefficiency effects. The adoption of recommended fish, water, and feed management practices is found to be critical for improved performance of carp producers. For each country, the study also compares the efficiency scores based on its own production frontier with those obtained from the meta-production frontier.

11.1 Introduction

Aquaculture, once practiced as a subsistence activity, has become an increasingly important sector in all South Asian countries. In 1995, South Asia produced 1.96 million metric tonnes (mt) or 7.1% of global aquaculture production. In fact, in 1995, two of the countries in the region, namely India and Bangladesh, were respectively the second and ninth largest aquaculture producing countries in the world. Within South Asia, India is the largest producer, contributing to 82% of total regional aquaculture production in 1995. The contributions of other countries were: Bangladesh 16.4%; Pakistan 0.8%; and Nepal 0.5%. Between 1984 and 1995, aquaculture production in the region increased by 206% while capture fisheries production increased only by 42%. The share of aquaculture in total fisheries production also increased significantly from 15.2% in 1984 to 27.8% in 1995 (FAO, 1997). In view of limited prospects for significant growth of capture fisheries production, aquaculture will play an even more important role in the future in meeting the growing demand for food fish in the region.

Recognizing its huge potential for contributing to food security and nutrition, generating employment and foreign exchange and elevating socio-economic status of rural communities, South Asian countries have given high priority to aquaculture in their development plans. Despite its long history in the region, aquaculture still remains a relatively minor contributor to these national economies relative to their crop and livestock sectors. However, the growth of this sector has been significantly higher than that of crop and livestock sectors. During 1984 to 1995, aquaculture

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production in Nepal, India, Bangladesh and Pakistan increased, respectively, by 396.6%, 215.5%, 174.7% and 77.8% (FAO, 1997). The corresponding figures for crop and livestock production were, respectively, 40.2%, 36.3%, 21.5% and 59.1% (FAO, 1998). Increased fish production in the past mainly came through expansion in production area and, to some extent, improvement in yield associated with intensification of aquacultural practices.

Despite high priority given to aquaculture, a number of problems still continue to constrain the development of this sector in many countries of the region. These include, but are not limited to, limited water supply of appropriate quality, inadequate supply of seeds and other inputs, disease outbreaks, poor infrastructure, limited capacity of institutions, lack of appropriate technical know-how and inadequate credit opportunities for farmers (FAO/NACA, 1997). Aquaculture, like many other farming activities, is dependent upon the use of natural resources, such as water, land, seed and feed. As countries continue to intensify their efforts to increase aquaculture production, the demand for these resources will rise, resulting in increased competition for limited resources and negative environmental impacts. These problems can be detrimental to the long-term economic viability and sustainability of the production system and environment.

Despite the above problems to be addressed, South Asia has a good future growth potential for aquaculture production for several reasons. First, the increasing demand for food fish will require more production from aquaculture as the supply from capture fisheries is stagnating. Secondly, aquaculture has emerged as a growth sector of economic importance in terms of its contribution to food security and nutrition, foreign exchange and employment generation and poverty alleviation in the rural communities. Thirdly, there is a good potential for increasing productivity, i.e. through improvement in technical efficiency at the farm level and through technological progress both at the national as well as regional levels such as genetic improvement of stocks. Fourthly, there is potential for expanding production area by converting lands unsuited to agriculture to fish farming and by promoting the use of rain-fed ponds, lakes/reservoirs and irrigation systems for aquaculture. Finally, the region is endowed with numerous fish species suitable for aquaculture. However, only a few species are currently cultured commercially. Farming of other species on a commercial scale has yet to be developed.

Aquaculture in South Asia is dominated by freshwater fish, contributing 94.2% of production in 1995. Freshwater fish production in the region increased from 0.62 million mt in 1984 to 1.83 million mt in 1995, growing at an annual rate of 10.3% (FAO, 1997). Carp are the main species cultured in the region. They include Indian major carp, Chinese carp and other minor carp species. Carp are mainly produced in ponds, often integrated with crops and livestock. Carp do have a number of advantages over other fish species. First, they can use feeds with moderate protein and fishmeal content, grow faster and be integrated with crops and livestock. Secondly, they can be reared in ecologically efficient and environmentally benign polyculture systems that make optimum use of the natural productivity of ponds and water bodies where they are stocked. Thirdly, they have good markets in Asian countries, due to a huge and growing consumer base, traditions and relatively low prices. Finally, they have lower production costs, less input requirements, fewer environmental problems and smaller risks for disease outbreaks.

If aquaculture is to play a vital role in ensuring future fish availability for food security and nutrition in the region, this sector has to develop and grow in an economically viable and environmentally sustainable fashion. Among many other factors, increasing the efficiency of resource use and productivity at the farm level is indispensable to sustainable aquaculture (FAO, 1997). Improved water management, better feeding strategies, genetic improvement of stocks and improved health management are some of the ways to enhance productive efficiency of aquaculture at the farm level. Accordingly, measuring technical efficiency at the farm level, identifying important factors associated with efficient production and assessing the potential for and sources of future improvements are essential for developing sustainable aquaculture. Instead of increasing the use of inputs to increase production, efforts should be made toward output growth through improved technical efficiency, i.e. producing more by utilizing inputs at hand more efficiently. Increasing technical efficiency will not only enhance profitability but also will contribute to environmental quality as incremental production does not involve additional inputs.

Against this background, the main objective of this study is to estimate and compare the levels and determinants of farm-level technical efficiencies in carp pond culture systems among the major carp producing countries in South Asia, namely India, Bangladesh, Pakistan and Nepal. A stochastic frontier meta-production function involving the Battese and Coelli (1995) model for technical inefficiency effects is applied to the cross-sectional data on semi-intensive/intensive and extensive carp production systems, collected by the Network of Aquaculture Centers in Asia-Pacific (NACA) Aquaculture Sustainability and Environment Survey during 1994/95. The proposed model forms the basis for estimating technical efficiency of sample farms relative to a single common regional frontier or ‘best-practice’ technology and hence for identifying potential for and sources of efficiency improvements.

The concept of stochastic meta-production frontier is similar to that of standard meta-production function approach proposed by Hayami (1969) and Hayami and Ruttan (1971) except that the error term in the former is comprised of two components, namely a symmetric random error and a non-negative technical inefficiency term similar to that in the stochastic production frontier model originally proposed by Aigner et al. (1977) and Meeusen and van den Broeck (1977). Lau and Yotopolous (1989) provide a number of econometric advantages of using the meta-production function approach in empirical work. Besides the seminal work of Hayami and Ruttan (1971), several other economists have also employed this approach in inter-country comparison of agricultural productivity (Mundalk and Hellinghausen, 1982; Kawagoe and Hayami, 1985; Binswanger et al., 1987; Lau and Yotopolous, 1989). To our knowledge, except for two studies based on nonparametric production frontiers (Arnade, 1998; Fulginiti and Perrin, 1997) and one study based on the parametric frontier (Gunaratne and Leung, 1996), production frontiers have not been applied to situations involving multiple countries. The main advantage of using the meta-production frontier over the separate production frontier for each country is that the efficiency scores obtained from the former are comparable across countries while those from the latter are not.

The meta-production function approach assumes that all countries have similar access to the technology and hence share a common underlying production structure for a given industry. However, each country may operate on different part of the production possibility curve depending upon resource endowments, adoption and diffusion of technology, relative factor prices and economic environments. Lau and Yotopolous (1989) noted that the lack of comparable data and presence of inherent differences across countries are the two major limitations in using the meta-production function approach.

However, these limitations do not pose a serious problem to this study. First, the data sets involved are comparable and consistent across countries as they were collected simultaneously using exactly the same procedures. Secondly, in view of close geographical proximity, relatively similar climatic/ecological features and fairly similar access to aquacultural technologies the assumption of a common underlying production structure does not seem to be unreasonable in studying carp pond culture in South Asia using the meta-frontier approach. Moreover, semi-intensive/intensive and extensive systems are analyzed separately and the study also provides the key results based on country-specific frontiers.

11.2 The stochastic meta-production frontier

Following the standard assumption that farmers maximize expected profits (Zellner et al., 1966) and Aigner et al. (1977) and Meeusen and van den Broeck (1977) the general form of the stochastic frontier production model for each country can be defined as:

$$Y_i = f(X_i;\beta)\exp(V_i - U_i) \tag{11.1}$$

where subscripts i refer to the i-th farm in the sample; Y denotes output, X is a (1 x k) vector of functions of input quantities; β is a (k x 1) vector of unknown parameters to be estimated; V_i is an independently and identically distributed $N(0, \sigma_v^2)$ random error; and the U_i is a non-negative random variable, associated with technical inefficiency in production, which is assumed to be an independently and identically distributed exponential or half-normal variable $[U_i \sim (|N(0, \sigma_u^2)|)]$.

Both exponential and half-normal distributions are criticized for arbitrarily restricting the mean of technical inefficiency effects to zero. A few researchers have proposed alternative specifications for the technical inefficiency effects, such as the truncated-normal distribution $[U_i \sim \text{iid } (|N(\mu, \sigma_u^2)|)]$ (Stevenson, 1980), the two-parameter gamma distribution (Greene, 1990) and the model for technical inefficiency effects (Battese and Coelli, 1995). Although there is generally no a priori justification for the choice of any particular distributional forms for the technical inefficiency effects, the generalized truncated-normal distribution has been most frequently used in empirical applications because of its computational simplicity. However, in recent years, the Battese and Coelli (1995) model for the technical inefficiency effects has become more popular because of its computational simplicity as well as its ability to examine the effects of various firm-specific variables on technical efficiency in an econometrically consistent manner, as opposed to a traditional two-step procedure (see Bravo-Ureta and Pinheiro, 1993).

Following Battese and Coelli (1995), technical inefficiency effects, U_is in Eqn. 11.1 are assumed to be independently distributed and truncations (at zero) of the normal distribution with mean, $Z_i\delta$, and variance δ_u^2 $[(|N(Z_i\delta, \sigma_u^2)|)]$, where Z_i is a (1 x m) vector of observable firm-specific variables hypothesized to be associated with technical inefficiency, and δ is an (m x 1) vector of unknown parameters to be estimated. The technical efficiency of the i-th sample firm, denoted by TE_i, is derived as follows:

$$TE_i = \exp(-U_i) \tag{11.2}$$

The prediction of technical efficiencies is based on the conditional expectation of expression (11.2), given the model specifications (Battese and Coelli, 1988).

Similar to a meta-production function model (Hayami and Ruttan, 1971), a meta-production frontier, also referred to an envelop frontier, is obtained by pooling all the sample observations across countries. Then the technical efficiency index for each of the sample firms in each country is estimated relative to a single common efficient or 'best-practice' frontier. Moreover, in addition to a common vector of farm-specific factors, country-specific factors can also be included in the Zs variables in order to examine the inter-country differences in technical efficiencies in an econometrically sound manner, as opposed to a traditional two-step procedure.

11.3 Data and variables

11.3.1 Data sources

The data for this study came from the NACA Aquaculture Sustainability and Environment Survey, conducted during 1994/95. The survey covered more than 6,300 carp farms and about 4,800 shrimp farms in 16 countries in Asia. NACA (1994) provides details for sampling and data collection procedures used in the survey. This study focuses on carp pond culture in four South Asian countries, namely Nepal, India, Bangladesh and Pakistan. The total number of carp farms surveyed and those included in various analyses for each of these countries are summarized in Appendix 11.1. Depending upon the levels of inputs (especially, feed, fertilizer and seed) as well as yields per hectare, the survey categorized the pond fish operations into semi-intensive/intensive and extensive systems. Extensive farms applied fewer inputs and produced smaller yields. Due to a lack of clear-cut distinction between semi-intensive and intensive systems these two were combined into one category.

11.3.2 Sample characteristics

Of the sample farms analyzed, the average pond area was largest in Pakistan (2.68 ha), followed by India (2.22 ha), Bangladesh (0.60 ha) and Nepal (0.42 ha). Except for India, where extensive farms were bigger than semi-intensive/intensive farms, the average pond area was similar for the two systems in other countries. Fifty-five percent of sample farms in India and 85-88% of those in other three countries were owner-operated.

The proportion of sample farms pursuing aquaculture as a primary activity was highest in Bangladesh (85%), followed by India (73%), Pakistan (66%) and Nepal (18%). The proportion of farms practicing integrated farming varied from 18% in Bangladesh to 26% in Pakistan, the majority of which integrated fish with livestock. The dominant land use forms prior to carp culture included rice farming in Nepal and Bangladesh (respectively, 71% and 30%), wetland/swamp areas in India (46%) and low-yielding agricultural land in Pakistan (56%). The most frequently reported sources of water for fish ponds were irrigation canals and rain water in Nepal (33% and 29%), rain water and tube/shallow wells in India (41% and 38%), rain water in Bangladesh (92%) and tube/shallow wells and irrigation canals in Pakistan (47% and 46%).

Almost all of the sample farms in the region practiced polyculture of Indian and Chinese carp species. Chinese carp, namely common carp (*Cyprinus carpio*), silver carp (*Hypophthalmichthys molitrix*) and grass carp (*Ctenopharyngodon idella*) were more dominant species in Nepal, while Indian major carp, namely (*Labeo rohita*), mrigal (*Cirrhinus mrigala*) and catla (*Catla catla*) were more dominant in India, Bangladesh, and Pakistan. The stocking density varied from about 0.5 pieces/m^2 in Pakistan to 1.7 pieces/m^2 in Bangladesh. The stocking rate was higher on semi-intensive/intensive than on extensive farms in Nepal, while, contrary to expectation, it was opposite for Bangladesh. For India and Pakistan the stocking rates were quite similar for the two systems.

The adoption of various recommended fish, water and feed management and monitoring practices among the sample carp farms are summarized in Table 11.1.

Under fish management and monitoring, multiple stocking and multiple harvesting were the most frequently reported practices in Nepal, while daily observation of fish behavior was most prevalent in Pakistan. Health monitoring was quite low in all countries. Except adding chemical fertilizer and organic manure to improve pond water fertility, the adoption of other water quality management and monitoring practices was generally low in all countries. The proportion of farms using supplementary diets was generally high, but the use of other feed and cost management practices was very low. Except for a higher proportion of semi-intensive/intensive farms adding chemical fertilizer and organic manure to improved pond water fertility and feeding supplementary diets, the adoption of fish, water and feed management practices was quite similar under the two systems.

Of the sample farms included in the economic analysis, the average yield under semi-intensive/intensive system varied from 2,328 kg/ha in Nepal to 3,415 kg/ha in India. Similarly, the average yield under extensive system varied from 1,267 kg/ha in India to 2,631 kg/ha in Pakistan. Note that these output figures are slightly different from output variables presented in Table 11.3 below due to the difference in sample sizes involved in economic and technical efficiency analyses. In all countries, yields were significantly higher in the semi-intensive/intensive system than in extensive system. The average net return (i.e. total value of production less total costs, but not including family labor) in semi-intensive/intensive system varied from US$ 1,101/ha in India to $2,167/ha in Pakistan. Similarly, average net return for extensive system varied from $293/ha in India to $2,275/ha in Pakistan. Higher net return in Pakistan can be attributed to higher market price for fish, perhaps associated with larger fish size, and also higher yield, especially for the extensive system.

11.3.3 Output, input and farm-specific variables

For the efficiency analysis, all output and input variables are measured in per hectare terms for several reasons. First, using total output and total inputs and area of ponds as an additional input in the production frontier may result in a problem of multicollinearity. Secondly, there is a wide variation in pond area across countries, indicating the need for normalization of output and input variables, especially when estimating a meta-production frontier model. Thirdly, the production frontier involving output and input variables in per hectare terms provides the estimate of farm-specific frontier output also in per hectare basis, which is a customary measure used in describing productivity in aquaculture.

Table 11.1 Adoption of various management and monitoring practices by carp farmers in South Asia

Management and monitoring practices	**Nepal** (n = 370)	**India** (n = 906)	**Bangladesh** (n = 393)	**Pakistan** (n = 660)
Management and monitoring of fish		Percent		
Manipulate filter-feeding/foraging ratio	40.3	17.5	20.4	10.5
Continuous/multiple stocking	87.8	57.2	43.5	20.8
Continuous/multiple harvesting	85.9	60.7	55.2	14.5
Culture yearling in production pond as seed for next crop	18.4	15.9	8.9	11.2
Daily observation of carp behavior	55.9	55.0	30.3	74.7
Regular on farm health analysis	10.8	20.6	10.2	10.5
Management and quality monitoring of pond water				
Mechanical filtration/screening of water inflow	14.6	22.1	1.0	24.2
Water purification	9.7	33.1	10.4	7.6
Add chemical fertilizer to increase pond water fertility	42.7	68.7	69.0	50.6
Add organic fertilizer to increase pond water fertility	52.4	79.5	70.5	67.9
Remove weeds	44.9	25.6	27.7	36.5
Water level management during culture	35.4	31.9	14.0	55.5
pH/alkalinity	1.4	39.4	21.9	34.4
Dissolved oxygen level	17.3	7.4	9.7	10.6
Nutrients (N and/or P)	7.8	1.9	3.1	6.2
Water color and turbidity	10.3	37.2	39.9	41.7
Check pond sedimentation	1.1	18.4	5.9	1.1
Feeding and cost management				
Supplementary feeding	74.6	91.8	73.0	74.2
Feeding enclosure for floating feeds	0.5	23.4	16.5	6.5
Submerged, but liftable feeding tray	10.8	18.8	6.1	5.6
Daily check of feeding/left-over	4.9	21.1	13.5	16.7
Daily removal of left-over	0.5	8.9	2.5	13.9
Regular feed conversion ratio (FCR) calculation	1.1	3.1	4.8	0.3
Regular production cost analysis	5.1	3.1	8.9	0.8

The output and input variables involved in the stochastic meta-production frontier for carp pond culture in the region as well as the production frontiers for individual countries are described in Table 11.2. Also presented in Table 11.2 are various farm-specific variables included in the model for technical inefficiency effects. The mean values of output, input, and farm-specific variables for both semi-intensive/intensive and extensive farms are given in Table 11.3.

Table 11.2 Description of output, input, and farm-specific variables involved in the stochastic meta-production frontier and technical inefficiency model for carp pond culture in South Asia

Variable	Description
Output (Y)	Aggregated quantity of fish production (in kg/ha)[1]
Input	
Seed (X_1)	Total number of fish seeds or fingerlings stocked (in no. of pieces/ha)
Labor (X_2)	Hired plus family labor used in carp production (in person days/ha)
Chemical fertilizer (X_3)	Amount of chemical fertilizers used in carp culture (in kg/ha)
Organic manure (X_4)	Amount of organic manure used in carp production (in kg/ha)
Feed (X_5)	Total dry weight of formulated feed, feed ingredients, and green feed applied in carp ponds (in kg/ha)[2]
Other input (X_6)	Other inputs (chemicals, water, maintenance, fuel, etc.) and depreciation on fish pond, housing, and machinery used in carp culture (in US$/ha)[3]
Fertilizer dummy (D_1)	Value 1 if chemical fertilizer was used in carp culture, 0 otherwise[4]
Manure dummy (D_2)	Value 1 if organic manure was used in carp culture, 0 otherwise[4]
Feed dummy (D_3)	Value 1 if feed was used in carp culture, 0 otherwise[4]
Other input dummy (D_4)	Value 1 if other input is positive, 0 otherwise[4]
Farm-specific[5]	
Primary activity (Z_1)	Value 1 if carp culture is undertaken as a primary activity, 0 otherwise
Farmer's experience (Z_2)	Number of years the farmer has been engaged in carp production
Pond area (Z_3)	Total area of fish pond in hectares
Fish management index (Z_4)	Total number of fish management and monitoring practices used[6]
Water management index (Z_5)	Total number of water management and quality monitoring practices used[6]
Feed management index (Z_6)	Total number of feed management and monitoring practices used[6]

[1] It should be noted that the total quantity of fish production is not an ideal measure of output variable in the production frontier analysis due to the multi-output production structure of fish polyculture. A more appropriate measure would be a geometric mean or quantity index based on revenue shares or prices for different fish species. Unfortunately, information on production, revenue and prices by species to compute the geometric mean or quantity index was not available.

[2] Following Tan (1970) one kilogram of green feed was assumed to be equivalent to 0.2 kg of dry feed.

[3] In estimating depreciation, the economic life of pond and building structures was assumed to be 20 years and that of farm machinery and equipment to be 15 years.

[4] Without these dummy variables, the estimators for output elasticities of fertilizer, organic manure, feed, and other input obtained from the Cobb-Douglas production function will be biased (Battese, 1996). Following Battese et al. (1996), elasticities of production for other inputs are assumed to be same for farmers using fertilizer, organic manure, feed, and other input as those not using these inputs.

[5] A few other relevant farm-specific variables, such as age and education level of the farmer were not available. Although information on land ownership was available, this could not be included in the meta-production frontier as almost all of the Pakistani farmers involved in the analysis were owner-operated.

[6] The practices included under different management indices are listed in Table 11.1.

Table 11.3 Mean values of output, input and farm-specific variables for sample farms involved

Variable	Nepal	India	Bangladesh	Pakistan	All countries
Semi-intensive/intensive system					
No. farms analyzed	213	732	282	378	1,605
Output (kg/ha)	2,404	3,415	3163	3,060	3,153
Inputs					
Seed (no. of pieces/ha)	16,858	14,978	15,722	4,726	12,944
Labor (days/ha)	666	349	739	618	523
Chemical fertilizer (kg/ha)	185	606	510	512	511
Organic manure (kg/ha)	2,705	9,174	6,243	5,021	6,823
Feed (kg/ha)	1797	4,654	3,229	3,751	3,812
Other input ($/ha)	172	222	186	400	251
Fertilizer dummy (0 or 1)	0.57	0.75	0.93	0.79	0.77
Manure dummy (0 or 1)	0.56	0.83	0.85	0.39	0.69
Feed dummy (0 or 1)	0.69	0.88	0.99	0.99	0.90
Other input dummy (0 or 1)	0.89	0.91	0.76	0.99	0.90
Farm-specific					
Primary activity (0 or 1)	0.23	0.75	0.88	0.61	0.67
Experience (years)	9.77	5.87	4.87	4.99	6.01
Pond area (ha)	0.48	2.00	0.62	1.98	1.55
Fish management index	2.82	2.38	1.90	1.57	2.16
Water management index	2.60	3.96	3.28	3.48	3.55
Feed management index	1.52	1.87	1.56	1.54	1.69
Extensive system					
No. farms	73	85	70	224	452
Output (kg/ha)	1,836	1,267	1,993	2,639	2,151
Inputs					
Seed (no. of pieces/ha)	9,251	16,023	20,365	4,415	9,849
Labor (days/ha)	538	399	624	506	510
Chemical fertilizer (kg/ha)	97	131	190	362	249
Organic manure (kg/ha)	2,207	4,143	4,794	5,076	4,394
Feed (kg/ha)	1,195	645	24	69	352
Other input ($/ha)	166	118	106	234	181
Fertilizer dummy (0 or 1)	0.37	0.31	0.30	0.54	0.43
Manure dummy (0 or 1)	0.56	0.62	0.49	0.33	0.45
Feed dummy (0 or 1)	0.64	0.72	0.06	0.04	0.27
Other input dummy (0 or 1)	0.81	0.84	0.63	0.95	0.85
Farm-specific					
Primary activity (0 or 1)	0.18	0.61	0.74	0.70	0.61
Experience (years)	9.32	6.01	6.30	6.49	6.83
Pond area (ha)	0.50	2.35	0.54	2.75	1.97
Fish management index	2.44	1.89	1.01	1.27	1.54
Water management index	2.42	2.07	1.04	2.79	2.33
Feed management index	1.48	1.05	0.21	0.45	0.69

11.4 Empirical model

The stochastic meta-production frontier for the sample fish pond producers in semi-intensive/intensive and extensive systems was specified to be as:

$$\mathrm{LnY}_i = \beta_0 + \sum_{k=1}^{6} \beta_k \mathrm{LnX}_{ki} + \beta_7 D_{1i} + \beta_8 D_{2i} + \beta_9 D_{3i} + \beta_{10} D_{4i} + V_i - U_i \tag{11.3}$$

where subscript i refers to the i-th farm in the pooled sample; Ln represents the natural logarithm; Y is output variable and Xs and Ds are input and related dummy variables, defined in Table 11.2; V_i and U_i are the random variables, defined earlier. Following Battese and Coelli (1995) the mean of technical inefficiency component (U_i), μ_i, was defined as:

$$\mu_i = \delta_0 + \sum_{m=1}^{6} \delta_m Z_{mi} \tag{11.4}$$

where Zs are various farm-specific variables, defined earlier and δs are unknown parameters to be estimated. Since the dependent variable in Eqn. 11.4 is defined in terms of technical inefficiency, a farm-specific variable associated with the negative (positive) coefficient will have a positive (negative) impact on technical efficiency.

Besides estimating the meta-production frontier by pooling four countries together, individual country-specific production frontiers were also estimated for both semi-intensive/intensive and extensive farms in order to compare the efficiency levels obtained from the meta-production frontier with those obtained from country-specific frontiers for each country. Thus, because of the limited sample size available to estimate a large number of parameters under a more flexible functional form (such as translog), particularly for estimating the country-specific frontiers for extensive farms, the Cobb-Douglas functional form was chosen. Even if the sample size were not limiting, the use of the translog form may not be appropriate in this study due to the presence of a large number of zero values for several input variables and hence their squared and cross-product terms. Furthermore, the precision of estimation of the maximum likelihood estimators of the parameters for the translog form would be poorer than for the Cobb-Douglas form. Despite its well-known limitations, the Cobb-Douglas form has been widely used in farm efficiency analysis (see Battese, 1992; Bravo-Ureta and Pinheiro, 1993). Moreover, a few studies examining the impact of functional form on efficiency have shown that functional specification does not have a significant impact on estimated technical efficiency (Kopp and Smith, 1980; Battese and Broca, 1997).

The technical inefficiency model (11.4) was also estimated with country-specific factors as well as six common farm-specific variables to formally test the inter-country differences in efficiency levels relative to the meta-production frontier. Country specific factors were represented by three country dummies, namely India dummy (Z_7), Bangladesh dummy (Z_8) and Pakistan dummy (Z_9), each taking on value 1 if the carp farm is from the corresponding country and 0 otherwise. Nepal was treated as the reference or default country.

The parameters for the stochastic production frontier model in Eqn. 11.3 and those for the technical inefficiency model in Eqn. 11.4 are estimated simultaneously using the maximum-likelihood estimation (MLE) program, FRONTIER 4.1 (Coelli, 1994), which estimates the variance parameters of the likelihood function in terms of $\sigma^2 = \sigma_u^2 + \sigma_v^2$ and $\gamma = \sigma_u^2 / \sigma^2$. In terms of its value and significance, γ is an important parameter in determining the existence of a stochastic frontier; rejection of the null hypothesis, H_0: $\gamma = 0$, implies the existence of a stochastic production frontier. Similarly, $\gamma = 1$ implies that the all deviations from the frontier are due entirely to technical inefficiency (Coelli et al., 1998).

Besides the magnitude and significance of the variance parameter, γ, it is also of interest to examine various null hypotheses, such as: technical inefficiency effects are not present, i.e. H_0: $\gamma = \delta_0 = \delta_1 = \ldots = \delta_6 = 0$; technical inefficiency effects follow a standard truncated-normal distribution, suggested by Stevenson (1980), i.e. H_0: $\delta_1 = \ldots = \delta_6 = 0$; and technical inefficiency effects follow a half-normal distribution originally proposed by Aigner et al. (1977), i.e. H_0: $\delta_0 = \delta_1 = \ldots = \delta_6 = 0$. These and other relevant null hypotheses can be tested using the generalized likelihood-ratio statistic, λ, given by

$$\lambda = -2[\mathrm{Ln}\{L(H_0)\} - \mathrm{Ln}\{L(H_1)\}] \tag{11.5}$$

where $L(H_0)$ and $L(H_1)$ denote the values of likelihood function under the null (H_0) and alternative (H_1) hypotheses, respectively. If the given null hypothesis is true, λ has approximately χ^2 distribution or mixed χ^2 distribution when the null hypothesis involves $\gamma = 0$ (Coelli, 1995).

11.5 Results

The maximum-likelihood estimates of the parameters for the stochastic meta-production frontier model and those for the technical inefficiency model for semi-intensive/intensive and extensive carp production systems for South Asia are presented in Table 11.4. Due to space limitation, similar results for country-specific stochastic production frontiers are not presented.

11.5.1 Parameter estimates and tests of hypotheses

As shown in Table 11.4, all slope coefficients of the stochastic meta-production frontier or output elasticities of inputs for semi-intensive/intensive carp pond culture in South Asia have expected signs. Except for other input, the estimated coefficients for seed, labor, chemical fertilizer, organic manure, and feed are significant at the 0.01 level. Similarly, also for the extensive system most of the slope coefficients have expected signs, except for a negative but insignificant value for other input. The coefficient associated with labor is significant at the 0.01 level, while the coefficients for organic manure and seed are significant only at the 0.10 level. Given the low levels of feed and fertilizer use among the extensive farms, insignificant coefficients for these inputs are not unexpected. Comparing the two systems, feed has highest elasticity in the semi-intensive/intensive system, while labor has highest elasticity for the extensive system.

For both systems, the value of variance parameter, γ, in the stochastic meta-production frontier model is estimated to be greater than 0.8 and highly significant, suggesting that technical inefficiency effects are important in explaining the levels and variations in carp production in South Asia. Furthermore, as shown in Table 11.5, the null hypothesis that technical inefficiency effects are not present in carp production is also rejected for both systems. Thus, the traditional average (OLS) production function is not an appropriate representation of the sample data. Similarly, the rejection of the second and third null hypotheses suggest that, given the stochastic frontier with the model for technical inefficiency effects (Eqns. 11.3 and 11.4), the standard stochastic error component model is also not appropriate for both half- and truncated-normal distributions of the technical inefficiency effects. These hypotheses were also rejected for each of the individual country production frontiers, although these results are not presented here due to space limitation.

Table 11.4 Maximum-likelihood estimates of stochastic meta-production frontier and technical inefficiency models for carp pond culture in South Asia

		Semi-intensive/intensive		Extensive	
	Parameter	Coefficient	T-ratio	Coefficient	T-ratio
Production frontier					
Constant	β_0	7.298	51.07	7.222	18.56
Ln (Seed)	β_1	0.051	3.76	0.066	1.64
Ln (Labor)	β_2	0.053	5.16	0.117	4.28
Ln (Chemical fertilizer)	β_3	0.074	5.91	0.024	0.62
Ln (Organic manure)	β_4	0.034	3.23	0.050	1.70
Ln (Feed)	β_5	0.133	14.62	0.043	0.98
Ln (Other input)	β_6	0.000	0.02	-0.007	-0.32
Fertilizer dummy	β_7	-0.344	-4.40	-0.205	-0.88
Manure dummy	β_8	-0.300	-3.18	-0.654	-2.52
Feed dummy	β_9	-0.856	-11.47	-0.709	-2.35
Other input dummy	β_{10}	-0.038	-0.63	-0.058	-0.46
Technical inefficiency model					
Constant	δ_0	0.189	0.27	1.271	6.39
Primary activity	δ_1	0.189	0.27	-0.280	-1.75
Experience	δ_2	0.029	4.63	-0.014	-1.15
Pond area	δ_3	-0.107	-16.14	0.024	2.01
Fish management index	δ_4	-0.140	-3.74	0.014	0.21
Water management index	δ_5	-0.202	-5.57	-0.398	-4.17
Feed management index	δ_6	-0.491	-8.41	-0.030	-0.26
Variance parameters					
	σ^2	0.670	7.33	0.568	5.42
	γ	0.874	44.62	0.817	12.59
Log(likelihood)		-808.44		-361.69	
Mean of exp $\tilde{}(U_i)$		0.754		0.573	

T-ratios are asymptotic t-ratios.

Given the data and model specifications, the results indicate that the farm-specific variables included in the technical inefficiency model contribute significantly to the explanation of the technical inefficiencies in carp production in South Asia. With the exception of the adoption of fish management index under extensive system, all the coefficients associated with the adoption of recommended fish, water and feed management practices have expected signs, implying that the adoption of these practices has a negative (positive) impact on technical inefficiency (efficiency) in carp pond culture.

As shown in Table 11.4, all three management coefficients for the semi-intensive/intensive system and the water management coefficient for the extensive system are highly significant. Thus, the results indicate that the use of recommended fish, water and feed management practices is particularly critical under the intensive system. Pond area has a negative (positive) significant effect on technical inefficiency (efficiency) of semi-intensive/intensive farms and a positive (negative) significant effect on inefficiency (efficiency) of extensive farms. As expected the coefficient for experience is negative, although insignificant, for the extensive system. However, the positive coefficient for experience for semi-intensive/intensive farms is somewhat unexpected. The choice of carp farming as a primary activity has a moderate negative (positive) impact on technical inefficiency (efficiency) of extensive farms, while it had no impact on semi-intensive/intensive farms.

Table 11.5 Generalized likelihood-ratio tests of hypotheses involving some estimates of stochastic meta-production frontier model for carp producers in South Asia

Null hypothesis (H_0)	Log (likelihood)	Test statistic (λ)	**Decision**
$\gamma = \delta_0 = \ldots = \delta_6 = 0$	14.85		
Semi-intensive/intensive	-927.71	238.54	Reject Ho
Extensive	-415.67	107.96	Reject Ho
$\delta_0 = \delta_1 = \delta_2 = \ldots = \delta_6 = 0$	$\chi^2_{7,0.95} = 14.07$		
Semi-intensive/intensive	-884.58	152.27	Reject Ho
Extensive	-406.70	90.02	Reject Ho
$\delta_1 = \delta_2 = \ldots = \delta_6 = 0$	$\chi^2_{6,0.95} = 12.59$		
Semi-intensive/intensive	-861.91	106.94	Reject Ho
Extensive	-405.13	86.88	Reject Ho

The correct critical value for the first null hypothesis is obtained from Table 1 of Kodde and Palm (1986, p. 1246) for 8 degrees of freedom.

11.5.2 Technical efficiencies

The estimated technical efficiency scores for the sample semi-intensive/intensive farms in South Asia range from 0.107 to 0.941, with a regional mean efficiency score of 0.754. Similarly, the technical efficiency scores for the extensive farms vary from 0.052 to 0.910, with a regional mean of 0.573. Thus, the results indicate that, on the average, semi-intensive/intensive carp farms are technically more efficient than extensive farms, relative to their respective technologies. The estimated technical efficiency measures show more variations in the extensive system than in the semi-intensive/intensive system. The technical efficiencies of semi-intensive/intensive and extensive systems obtained from the respective meta-production frontiers for individual countries are summarized in Table 11.6. Also presented in the table are estimated technical efficiency scores for each of the four countries based on their respective country-specific production frontiers.

The frequency distributions of the technical efficiency estimates of individual countries obtained from the meta-production frontiers are depicted for semi-intensive/intensive and extensive farms in Figs. 11.1 and 11.2, respectively. The distributions of the estimated scores for the two carp production systems are quite different. For the semi-intensive/intensive culture, the majority of the sample farms in each country have the efficiency index between 0.8 and 0.9. For the extensive system, the majority of farms in India and Bangladesh have the efficiency score of less than 0.4, while those from Nepal and Pakistan show a fairly uniform distribution except for the range of the efficiency scores of 0.9 and above.

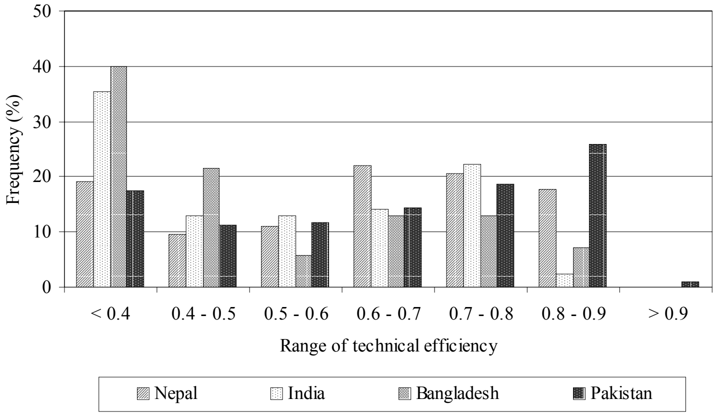

Fig. 11.1 Frequency distributions of technical efficiency scores of semi-intensive/intensive carp pond culture by country based on the meta-production frontier model

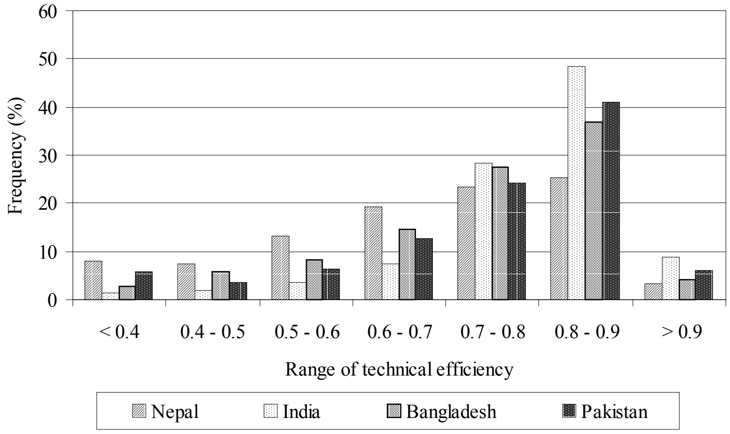

Fig. 11.2 Frequency distribution of technical efficiency scores of extensive carp pond culture by country based on the meta-production frontier

Comparing across countries, relative to the regional or meta-production frontier the mean technical efficiency score for semi-intensive/intensive carp farms is highest for India (0.790), followed by Pakistan (0.740), Bangladesh (0.738) and Nepal (0.676). With the exception between Pakistan and Bangladesh these differences are statistically significant. As shown in Table 11.6, the mean efficiency scores for the extensive system vary from 0.475 for Bangladesh to 0.624 for Pakistan, with farmers from Pakistan and Nepal being technically more efficient than those from India and Bangladesh.

Table 11.6 Summary statistics of technical efficiency estimates of carp pond culture in South Asia

	Mean	Standard deviation	Minimum	Maximum	Rank correlation coefficient
Semi-intensive/intensive					
Nepal	0.676 (0.778)	0.172 (0.145)	0.155 (0.183)	0.935 (0.944)	0.906**
India	0.790 (0.805)	0.112 (0.125)	0.219 (0.157)	0.941 (0.955)	0.957**
Bangladesh	0.738 (0.857)	0.140 (0.109)	0.226 (0.471)	0.930 (1.000)	0.580**
Pakistan	0.740 (0.726)	0.165 (0.160)	0.107 (0.103)	0.941 (0.933)	0.884**
Extensive					
Nepal	0.597 (0.765)	0.212 (0.158)	0.119 (0.220)	0.888 (0.941)	0.602**
India	0.502 (0.585)	0.206 (0.237)	0.101 (0.112)	0.829 (1.000)	0.707**
Bangladesh	0.475 (0.389)	0.202 (0.255)	0.131 (0.066)	0.850 (1.000)	0.942**
Pakistan	0.624 (0.555)	0.211 (0.245)	0.052 (0.031)	0.910 (0.940)	0.958**

Numbers in parentheses are estimates from country-specific production frontiers. Rank correlation coefficient shows the correlation between the rankings of sample farms based on technical efficiency scores obtained from the meta-production and country-specific production frontiers. ** Significant at the 0.05 level.

The presence of these intercountry differences in technical efficiencies relative to the meta-production frontier was also confirmed by including country dummies in the technical inefficiency model and then conducting the generalized likelihood-ratio test that the coefficients associated with country dummies are all zeros. The coefficients associated with country dummies in the technical inefficiency model had expected signs, although these results are not presented due to space limitation. With country dummies in the technical inefficiency model, the log(likelihood) values for intensive and extensive meta-production frontier models were respectively –788.27 and –356.17. Accordingly, the test-statistics were 40.34 and 11.04, which are less than 7.82, the 95% critical value for the χ^2 distribution with 3 degrees of freedom.

Relative to country-specific technologies, the average technical efficiency indices for semi-intensive/intensive farms vary from 0.726 for Pakistan to 0.857 for Bangladesh (Table 11.6). Likewise, the average technical efficiencies for extensive farms varied from 0.389 for Bangladesh to 0.765 for Nepal. In most cases the sample carp producers show a better performance relative to their own production frontiers than to the regional or meta-production frontier, with the exception of both systems in Pakistan and extensive system in Bangladesh that perform relatively better in terms of the meta-production frontier. However, in each system the efficiency rankings of the sample farms based on their own production frontier and the meta-production frontier are highly positively correlated in all countries, with the rank correlation coefficients ranging from 0.580 for semi-intensive/intensive farms in Bangladesh to 0.958 for extensive farms in Pakistan (Table 11.6). Relative to both meta-production and country-specific production frontiers, for all countries semi-intensive/intensive farms are, on average, technically more efficient than extensive farms, relative to their respective technologies.

There are a very few studies in the literature that have analyzed technical efficiency in carp production. Using the data envelopment analysis (DEA) approach, Sharma et al. (1999) have analyzed technical, allocative and economic efficiencies for a sample of Chinese carp farms. The mean technical efficiency was estimated to be 0.83. In terms of the level of feed applied to fish ponds, the Chinese farms are regarded as of the semi-intensive/intensive type for comparison with the present study. Relative to Chinese farms and their best-practice technology, carp farms in all of the four South Asian countries involved in this study exhibit a lower level of technical efficiency based on the meta-production frontier.

Table 11.7 Mean values of actual and potential output levels (kg/ha)

	Semi-intensive/intensive system			Extensive system		
	Actual output	Potential output relative to		Actual output	Potential output relative to	
		Country frontier	Meta-frontier		Country frontier	Meta-frontier
Nepal	2,404	2,995	3,429	1,836	2,325	3,085
	(1,175)	(1,111)	(995)	(898)	(921)	(932)
India	3,415	4,114	4,190	1,267	2,190	2,594
	(1,492)	(1,376)	(1,418)	(552)	(538)	(739)
Bangladesh	3,163	3,641	4,126	1,993	5,589	4,178
	(1,408)	(1,462)	(1,262)	(1,073)	(1,228)	(1,050)
Pakistan	3,060	4,089	3,987	2,639	4,725	4,007
	(1,526)	(1,518)	(1,393)	(1,516)	(1,346)	(1,312)
All countries	3,153	3,877	4,030	2,151	3,995	3,619
	(1,483)	(1,446)	(1,358)	(1,335)	(1,744)	(1,276)

Figures in parentheses are standard deviations.

This also holds for the results obtained from the country-specific production frontiers, with an exception of Bangladesh where the technical efficiencies for semi-intensive/intensive farms are, on average, slightly higher than those for the Chinese farms. Using a similar methodology as in the present study, Iinuma et al. (1999) have estimated the mean technical efficiency for a sample of extensive and semi-intensive carp farms in peninsula Malaysia to be 0.42. Using the same data set as used in the present study but slightly different specifications, Sharma and Leung (1998) and Sharma and Leung (2000) have analyzed the technical efficiency of carp production in Nepal and India, respectively, while Sharma (1999) has conducted the similar analysis for Pakistan. The results provided in these studies are very similar to those obtained from their respective country-specific production frontiers (Table 11.6).

11.6 Study implications

A number of interesting implications can be drawn from the empirical findings discussed above. The results indicate that there are substantial technical inefficiencies in carp production in each country as well as in the region as a whole, especially in the extensive system. Given the levels of existing technologies and resources, the sample semi-intensive/intensive farms could improve their average regional pond yield from about 3.2 to 4.0 mt/ha, while extensive farms could increase their regional yield from about 2.2 to 3.6 mt/ha by operating at full technical efficiency levels (Table11.7). Improvements in efficiency could mainly come from the improvements in the adoption of recommended management practices, especially for the semi-intensive/intensive farms.

As indicated in Table 11.1, the proportion of farms in the region practicing the recommended fish, water and feed management measures is very low. While the feed management is found to be the most critical factor affecting productive efficiency for the semi-intensive/intense system, very few farms (ranging from 0.3% in Pakistan to 4.8% in Bangladesh) even performed regular FCR calculations. By identifying the best feed management practice in own country as well as in the region, respective governments can provide guidance to farmers in reducing FCR and pollution and hence in increasing profits. Similarly, very few farms in the region practiced water monitoring measures regularly although it is found to be a significant factor affecting productive efficiency. Again, by identifying the best water management practices in own country and in the region, respective governments can develop guidelines for optimal water use, economical and practical ways of water quality and effluent management. Lastly, only 10 to 20% of the farms in the region performed regular on-farm health analysis although fish management is found to be an important factor affecting productive efficiency. The limited farmer capacity to diagnose disease problems suggests that it is important for governments to enhance the provision of extension services on health management by establishing disease diagnostic laboratories and/or developing procedures for on-farm rapid disease diagnosis. All these point to the need of the respective governments to improve and strengthen the aquacultural research and extension services. The identification of the best fish, water and feed management practices among countries and within countries will no doubt be able to improve their respective management systems and performance. This information is of particular importance in a rapidly expanding and changing sector of carp culture in the region.

Higher technical efficiency levels as well as higher yields on semi-intensive/intensive farms than on extensive farms suggest that there is a good potential to enhance productivity through increased intensification of carp culture (i.e. shifting from extensive to semi-intensive/intensive system or intensifying the use of seed, feed and fertilizer). This is also confirmed by highest technical efficiency and highest yield in the semi-intensive/intensive system in India, where the levels of inputs (especially feed, fertilizer and manure) are also highest in the region. However, the realization of higher productivity through increased intensification will not only depend on the timely and adequate availability of these inputs, but also on the development of appropriate policies aiming to minimize negative social and environmental impacts resulting from the increased intensification.

The mean values of potential outputs achievable by individual countries relative to both regional or meta-production country-specific frontiers are presented in Table 11.7. The potential outputs for semi-intensive/intensive farms in Nepal and Bangladesh obtained from the regional or meta-frontier were significantly higher than those obtained from their own frontiers, suggesting that semi-intensive/intensive farms in these countries have the most potential for increasing productivity by catching up with the best technology already available in India and Pakistan. More interestingly, for Nepal the potential output for the semi-intensive/intensive system relative to its own frontier is still less than the actual per-hectare outputs of the other three countries. Thus, Nepal may greatly benefit from the experience and expertise of other countries in developing intensive carp culture, especially from India due to its close geographical proximity. Similarly, Bangladesh could also greatly benefit from India in promoting intensive carp culture. The pattern between the efficiency scores from the meta-production frontier and those from country-specific frontiers is rather mixed for extensive farms, with Nepal and India performing better in terms of their own frontier, while Pakistan and Bangladesh doing better in terms of the meta-production frontier. Despite the presence of substantial inefficiencies among extensive farms in Pakistan also, in view of its highest mean technical efficiency and yield, the rest of the countries may gain from Pakistan’s experience in extensive carp farming.

11.7 Conclusions

This study examines the inter-country differences in technical efficiencies of semi-intensive/intensive and extensive carp pond culture systems among the major carp producing countries in South Asia, namely Nepal, India, Bangladesh and Pakistan. The production data and relevant farm-specific variables collected from the samples of carp producers in these countries are analyzed using a stochastic meta-production frontier, including a model for the technical inefficiency effects. For each country, efficiency scores obtained based on its own production frontier are compared to those obtained from the meta-production frontier.

The results showed significant technical inefficiencies among the sample carp farms in South Asia, which could be explained in terms of various farm-specific variables. Based on the meta-production frontiers the mean technical efficiencies for semi-intensive/intensive and extensive farms in South Asia are estimated to be 0.754 and 0.573, respectively. Among semi-intensive/intensive farms, those from India are most efficient while those from Nepal are least efficient, with those from Bangladesh and Pakistan being in the middle. Among extensive farms, the sample farms from Pakistan and Nepal tended to be technically more efficient than those from the other two countries. These differences in productive performance of carp culture across countries can be attributed to numerous factors, including the adoption of recommended management practices, scale of operation and level of intensification. For example, the adoption of recommended fish, water and feed management practices has positive effect on technical efficiency of pond carp culture, especially for the semi-intensive/intensive system. Among these practices, feed management is found to be most critical for the semi-intensive/intensive system and pond water management is most critical for the extensive system. Among the four countries, the proportion of farms adopting recommended feed management practices is generally highest in India and so is the technical efficiency for the semi-intensive/intensive system.

Based on country-specific production frontiers, the mean technical efficiency for semi-intensive/intensive farms range from 0.726 for Pakistan to 0.857 for Bangladesh, while for extensive farms it vary from 0.389 for Bangladesh to 0.765 for Nepal. Given the data and model specifications, semi-intensive/intensive farms from Nepal and Bangladesh have the most potential for increasing productivity by emulating the 'best-practice' farms in the region. However, based on the results, it is difficult to make a similar observation for extensive farms.

Besides expanding production area, there is substantial potential for increasing the level of carp production in South Asian countries by raising yields per hectare. The results indicated that increased intensification (i.e. using more seed, feed and chemical fertilizer) and improvement in technical efficiency by following regular fish, water and feed management and monitoring activities could raise pond yields. In view of the law of diminishing marginal returns and increased environmental problems associated with more intensive use of inputs, the potential for output growth by increasing the use of inputs cannot continue for ever. Therefore, in the long run, output growth must come from the improvement in technical efficiency.

South Asian countries could also benefit by sharing the expertise and experience among each other within the region as well as other NACA member countries in Asia, especially China where, on average, actual yields are higher than the estimated potential yields for South Asian countries. There may also be a good potential for raising productivity through technological progress, such as development of modern fish farming technologies, improvements in genetic make-up of fish stocks, and development of new fish species. These are some of key areas in which countries could collaborate.

Due to data constraints, this paper is limited to technical efficiency only. Research on other aspects of productive efficiencies, especially allocative and economic efficiencies can be carried out if appropriate data is collected in the future. Furthermore, the present study is based on data from a single production period; a follow up and continuing data collection on a regional or national basis is recommended to examine technical efficiency and hence sustainability of aquaculture over time.

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Appendix 11.1 Sample and data preparation

The carp production survey in South Asia covered different types of carp culture systems, including pond culture, cage/pen culture, and rice-fish culture. Cage/pen as well as rice-fish production systems are excluded from the analyses. Similarly, a sizable proportion of the sample farms had to be dropped due to missing or incomplete data on production, pond and harvest area, and farm type.

Farms growing fresh water prawn (Machrobrachium spp.), mostly in India and Bangladesh, were also excluded from the cost-return and efficiency analyses to make the results comparable across countries. Farms with missing data on stocking and culture period, and labor use were also excluded.

For efficiency analysis, various production indicators, including yield, output/seed ratio, output/labor ratio, labor/pond area ratio were examined for sample observations to in order to check the internal consistency of data. Accordingly, observations associated with implausibly too low or too high values of these indicators were dropped as well. We suspect that some recording or data entry errors are responsible for these extreme observations. Because of these reasons, as indicated in the following table, the sample size varied for different levels of analyses and hence the results presented in this study may be slightly different from those published elsewhere (e.g., ADB/NACA, 1996).

Items analyzed under general information included pond area, adoption of various fish, water and feed management practices, land use prior to aquaculture, water sources to fish ponds, and fish species stocked. Then production value, total cost, and net return were computed. Finally, levels and determinants of technical efficiency were examined by estimating the stochastic production frontier model with technical inefficiency effects.

Total no. of carp farms surveyed		Number of carp pond farms analyzed					
		General information		Cost and returns		Technical efficiency	
		Semi-intensive/ intensive	Extensive	Semi-intensive/ intensive	Extensive	Semi-intensive/ intensive	Extensive
Nepal	495	270	100	257	95	213	73
India	1,004	786	120	733	85	732	85
Bangladesh	626	308	85	289	75	282	70
Pakistan	778	420	240	382	227	378	224
Total	2,904	1,784	545	1,661	482	1,605	452

Chapter 12

Technical efficiency of carp production in Nepal: an application of stochastic frontier production function approach[*]

Khem R. Sharma and PingSun Leung

Abstract
Modern aquaculture is a relatively new activity among Nepalese farmers and a small contributor to the economy. Given the abundance of water resources and fish species, rising demand for fish, and its high profitability, aquaculture has potential for future expansion if it gets appropriate attention from the government. In Nepal, productivity in aquaculture is much lower compared to other countries in the region, which suggests that there is potential for increased fish production through technological progress and improvement in farm-level technical efficiency. However, no formal analysis has yet been conducted to assess the productive performance of Nepalese aquaculture and its potential for future improvement. Against this background, this paper examines the technical efficiency and its determinants for a sample of fish pond farms from the Tarai region of the country using a stochastic production frontier involving a model for technical inefficiency effects. The estimated mean technical efficiency is 0.77, with intensive farms being more efficient than extensive farms. The adoption of regular fish, water, and feed management activities has a strong positive effect on technical efficiency.

12.1 Introduction

Agriculture is the largest contributor to the Nepalese economy, accounting for than 40% of gross domestic product (GDP) and 80% of employment (HMG, 1995). However, the contribution of fisheries sub-sector to the economy is very small. In 1992/93, the fisheries sub-sector, including aquaculture and inland capture fisheries accounted for about 0.7% of total GDP and 1.5% of agricultural GDP (FDD, 1993). Despite its small contribution to GDP, fisheries sub-sector, especially aquaculture has potential for future expansion for several reasons. First, the country is richly endowed with water resources and fish species suitable for aquaculture (Pradhan, 1994). Secondly, pond fish culture is reported to be 2-4 times more profitable than other high value agricultural activities (Baral, 1992), which suggests that aquaculture has potential for raising incomes and hence the socioeconomic conditions of the rural population. Thirdly, the demand for fish for local consumption as well as for export to India has steadily been rising (Rajbanshi, 1995). Finally, aquaculture provides protein-rich food that is socially acceptable to every segment of the population in the country where per capita consumption of animal protein including fish is much lower than in other countries. Besides high priority given to aquaculture development in the eighth five-year plan (1991–1996) the government has to give more attention to aquaculture in future to realize its full growth potential.

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Introduced in the 1950s, the modern or commercial fish culture is a relatively new endeavor to Nepalese farmers. Aquacultural activities are concentrated mainly in the Tarai region of the country. Following the lack of success of integrated fish-rice culture from the high use of pesticides in rice fields, recently efforts have been made to integrate fish with livestock and horticulture. This innovative practice has increased the production of fish, meat, and fruits and vegetables, thereby attracting a large number of farmers to take up aquaculture as their full-time or part-time activity. Furthermore, this has helped farmers reduce production risks and recycle agricultural residues and on-farm resources, making agricultural system environmentally more sustainable.

The Aquaculture Development Projects (Phase I and II), which were implemented during the 1980s, provided government as well as private fisheries development agencies with financial and technical support aiming to improve infrastructure, increase seed production and develop effective markets. These projects also provided farmers with loans for renovating old and constructing new ponds for fish culture. In addition, government also provides some support for inputs (seed, chemicals, fertilizers and machinery) and credit facilities for the farmers involved in aquaculture. As a result, pond yields increased from 0.7 metric tonnes (mt)/ha in 1981 to more than 2 mt/ha in 1997. Similarly, fish production from aquaculture increased from 750 mt to more than 12,000 mt in the same period, an annual increase of ≈ 94% (Anon., 1998). Increase in production has improved the trade of fish and fisheries products, thereby contributing to foreign exchange earnings.

Aquaculture in Nepal mainly features a polyculture system of various carp species. Aquaculture technologies can be classified into three categories, namely pond fish culture, cage fish culture and rice-fish culture. Depending on the use of modern inputs and stocking density, pond fish culture is further divided into three categories˜ extensive, semi-intensive and intensive – with the use of modern inputs and stocking density increasing from extensive to intensive system. The intensive system is generally operated as an integrated enterprise, combining fish with livestock and horticulture. In 1992, cage and fish-rice culture together accounted for less than 1.5% of total fish production from aquaculture (Rajbanshi, 1995).

In 1996/1997 the total fish production in Nepal was 23,200 mt, of which 12,200 mt came from aquaculture and total area under aquaculture was 5,582 ha (CBS, 1997). Given the limited availability of land and related resources the potential for increased production purely by expanding area will soon be limited. Thus, increased production in the long run will have to come mainly through improvement in productivity in aquaculture, i.e. through technological progress and improvement in farm-level technical efficiency. Technical progress relates to the development and adoption of modern technologies, whereas technical efficiency refers to farmer's ability to achieve maximum output from a given amount of resources and the technology available. In a study by the Network of Aquaculture Centers in Asia-Pacific (NACA), the productivity of fish culture in Nepal is found to be much lower than in other NACA member countries. Nepal's poor performance is attributed mainly to the lack of intensification, inadequate genetic improvement of fish stocks, high incidence of diseases and other environment related problems (Anon., 1998). A number of other factors, such as farmer's experience, ownership, scale of operations, access to management practices and other socioeconomic conditions may also have an influence on efficiency.

Except for a few descriptive studies no formal analysis has yet been conducted to examine the production economics of Nepalese aquaculture and its potential for future improvement. Similarly, there is a lack of information on productive gains through increased intensification of fish culture as well as on the effects of farm-specific factors on productivity of culture fish production in Nepal. Against this background, the main objective of this study is to examine the production economics of fish culture, with a particular focus on technical efficiency and its determinants for pond fish culture. Key socio-economic characteristics of sample fish farms, including their farming system, land use and ownership pattern and economic profitability are also highlighted. This information can be very useful in formulating new policies for sustainable fish production in the country.

Since Farrell's (1957) seminal article and subsequent developments of various approaches to efficiency and productivity measurement, frontier techniques have been widely used in determining productive performance in agriculture. However, recent reviews of applications of production frontiers to agriculture show no frontier studies being applied to aquaculture (Coelli, 1995a; Bravo-Ureta and Pinheiro, 1993; Battese, 1992). Production function analyses in aquaculture have been commonly limited to assess the profitability and rate of return of new investment, to estimate economies of scale, to determine optimum intensity of input use and to improve existing management practices (Hatch and Tai, 1997). The lack of frontier studies in fish culture can be attributed primarily to its inherent bio-economic complexity and the consequent difficulty in obtaining appropriate production data, especially data on production inputs. The frontier production approach defines the technical efficiency in terms of a minimum set of inputs needed to produce a given output or maximum output obtainable from a given set of inputs. Thus, production frontiers provide a more appropriate framework for determining efficiency of resource allocation and evaluating potential production achievable from an existing technology than alternative economic methods (namely bio-economic, optimization and 'average' production function models) found in the literature on aquaculture economics and management. Thus, a secondary objective of this study is to demonstrate the applicability of production frontiers to aquaculture.

The stochastic frontier production function (Aigner et al., 1977; Meeusen and van den Broeck, 1977) involving econometric methods and data envelopment analysis (DEA) (Charnes et al., 1978) involving mathematical programming techniques are the most popular methods used in efficiency analyses in agriculture. The main advantage of the stochastic frontier is that it can decompose the deviation from the frontier into its stochastic noise and technical inefficiency components. The need for imposing a particular parametric form for the underlying technology is, perhaps, the main weakness of the stochastic frontier technique. The main advantage of DEA is that it eliminates the need for the parametric assumption of the underlying technology. However, since DEA is deterministic and it attributes all deviations from the frontier to inefficiencies, a frontier estimated by this technique is likely to be sensitive to stochastic noise in the data.

In this paper, production data collected from a sample of carp producers in the Tarai region of Nepal are analyzed using a Cobb-Douglas stochastic frontier production function involving the Battese and Coelli (1995) model for technical inefficiency effects. Seed, labor, fertilizer, feed and other costs are included in the stochastic production frontier. A number of farm-specific factors, including production intensity, farmer's experience, pond ownership, pond size, several management factors and regional differences are included in the technical inefficiency model to determine their influence on technical efficiencies of carp production. The parameters involved in the stochastic production frontier and those in the model for technical inefficiency effects are estimated simultaneously, as opposed to a traditional two-stage procedure where the efficiency indices are estimated first and then regressed on a number of farm-specific explanatory variables to identify factors affecting the efficiency levels. Recently, several authors (Battese and Coelli, 1995; Kumbhakar et al., 1991; Battese et al., 1989) have challenged this second-stage approach by arguing that the farm-specific factors may have a direct influence on productive efficiency and hence they should be included directly in the estimation of production frontier model.

The rest of the paper proceeds with the presentation of the stochastic production frontier model, followed by a description of data, variables and empirical procedures involved in the study. Empirical findings and their implications are presented next. The final section concludes the paper.

12.2 The stochastic production frontier and technical inefficiency model

Following the standard assumption that farmers maximize expected profits (Zellner et al., 1966), a single equation stochastic frontier production function for the cross-sectional data can be defined as:

$$Y_i = f(X_i;\beta)\exp(V_i - U_i) \tag{12.1}$$

where Y_i denotes the production of the i-th sample farm (i = 1, 2, ..., n); X_i is a $(1 \times k)$ vector of functions of input quantities used by the i-th firm; β is a $(k \times 1)$ vector of parameters to be estimated; the V_is are assumed to be independently and identically distributed $N(0, \sigma_v^2)$ random errors, independent of the U_is; and the U_is are non-negative random variables, associated with technical inefficiency in production, which are assumed to be independently distributed and truncations (at zero) of the normal distribution with mean, $Z_i\delta$, and variance, σ_u^2 ($|N(Z_i\delta, \sigma_u^2)|$); Z_i is a (1 x m) vector of firm-specific variables associated with technical inefficiency; and δ is an (m x 1) vector of unknown parameters to be estimated.

Following Battese and Coelli (1995), the technical inefficiency effects, $U_i$in Eqn. 12.1 could be expressed as:

$$U_i = Z_i\delta + W_i \tag{12.2}$$

where W_is are random variables, defined by the truncation of the normal distribution with zero mean and variance, σ_u^2, such that the point of truncation is $-Z_i\delta$, i.e., $W_i \geq -Z_i\delta$. . Besides the firm-specific variables, the Z-variables in Eqn. 12.2 may also include input variables in the stochastic production frontier (12.1), provided that the inefficiency effects are stochastic. If Z-variables also include interactions between firm-specific and input variables, then the Huang and Liu (1994) non-neutral stochastic frontier is obtained.

The technical efficiency of the i-th sample firm, denoted by TE_i, is given as:

$$TE_i = \exp(-U_i) = \frac{Y_i}{f(X_i;\beta)\exp(V_i)} \qquad (12.3)$$

where $f(X_i;\beta)\exp(V_i)$ is the stochastic frontier production. The prediction of technical efficiencies is based on the conditional expectation of expression (12.3), given the model specifications (Battese and Coelli, 1988).

12.3 Data and empirical procedures

12.3.1 Data sources

The data used for this study came from the NACA Aquaculture Sustainability and Environment Survey of carp production in Nepal, conducted during the period of 1994/95. The survey covered a total of 490 aquacultural farms or 3.8% of the total farm population in the country, including 442 carp pond farms from 12 of the 21 districts in the Tarai and 48 carp cage farms in 2 districts from the mid-hills. NACA (1994) provides details for sampling and data collection procedures as well as the instruments employed in the survey. The survey categorized the pond fish operations into semi-intensive/intensive and extensive systems. For the sake of convenience, semi-intensive/intensive systems are referred to as intensive system throughout this chapter..

This paper focuses on pond fish production only. Among the pond farms surveyed, those who had abandoned fish production and those with annual fish production of less than 50 kg were excluded from the analysis. Thus, the number of observations considered to describe the key characteristics of sample farms is 370, including 270 intensive and 100 extensive farms. The analysis of costs and returns was based on 352 farms (257 intensive and 95 extensive) obtained by eliminating some more observations for incomplete or missing data on labor use. Similarly, technical efficiency analysis was based on 286 farms (213 intensive and 73 extensive) after eliminating additional observations with less than 100 kg of annual production and a few potential outliers. For internal consistency of data, various production indicators, including yield, output/seed ratio, output/labor ratio and labor/pond area ratio were examined for each farm in the sample. The observations with implausibly too low or too high values for these indicators were dropped as outliers. We suspect that some recording or data entry errors are responsible for these extreme observations. Therefore, the results presented in this study are more relevant to commercial or market-oriented pond fish farms and are different from those published by NACA (Anon., 1998).

12.3.2 Sample characteristics

Of the 370 farms analyzed, the average farm size was 3.17 ha for intensive farms, 2.88 ha for extensive farms and 3.09 ha for overall sample. Similarly, average pond size was 0.40 ha, 0.45 ha and 0.42 ha, respectively. About 80% of operations had a pond area of less than 0.50 ha and a total farm area of more than 0.50 ha. On an average only 13% of farm area was allocated for aquaculture. The average pond yield of 2,245 kg/ha for semi-intensive/intensive farms was significantly higher than 1,688 kg/ha for extensive farms. Significant regional differences included higher farm size on mid/far western and eastern regions and higher yields on western and central regions.

Aquaculture was the primary activity for only 18% of the farms studied. Similarly, the proportion of farms practicing integrated farming was 24%, of which two-thirds integrated fish with livestock, namely pigs, cattle/buffalo and ducks. The principal land use forms prior to aquaculture were rice farming (71%), public water body (13%) and wetland/swamp (8%). These proportions were similar for both semi-intensive/intensive and extensive farms. Ponds were commonly constructed in loamy (53%) and clayey (34%) soils. The main sources of water for fish ponds were irrigation canal (33%), rainwater (29%) and tubewells (24%). About 15% of farms were lease-operators, with an average lease duration of 5.7 years. Interestingly, although both farm size and pond size were significantly higher for lease-operators than owner-operators, pond yields were similar under the two arrangements.

More than 98% of farms practiced polyculture of several carp species and a few others practiced monoculture, especially of common carp or *Cyprinus carpio*. Cultured species by the majority of sample farms were four exotic Chinese carp – common carp or *Cyprinus carpio (*86%)*,* silver carp or *Hypophthalmichthys molitrix* (79%), grass carp or *Ctenopharyngodon idella* (66%) and big-head carp or *Aristichthys nobilis (60%)* and three indigenous or major carp rohu or *Labeo rohita* (75%), mrigal or *Cirrhinus mrigala* (59%) and catla or *Catla catla* (58%) with Chinese carp being relatively more popular among extensive farms than in semi-intensive/intensive farms. Chinese carp constituted 66% of total stocking in intensive farms as compared to 72% for extensive farms. Similarly, foraging species (grass and common carp) constituted about a third of total stocking, similar for both intensive and extensive fish pond operations. Seed size varied from 0.5 to 8.0 cm in length so the stocking density was normalized to 2.5 cm as described in the output and input variables section below. The normalized seed stocking density of 3.3 pieces/m^2 for intensive farms was significantly higher than 2.5 pieces/m^2 reported on extensive farms, with a sample mean of 3.0 pieces/m^2. Unnormalized stocking rate was respectively 1.8, 0.9 and 1.5 pieces/m^2. On average fish were harvested in 9.5 months when they weighed about 360 g. About 10% of production was used for home consumption.

The proportion of farms using supplementary diets was 75%, of which 97.5% used simple diets mostly of rice bran and other 2.5% used formulated diets. These proportions were quite similar for both intensive and extensive systems. Various fish, water and feed management and monitoring activities practiced by Nepalese carp farms are summarized in Table 12.1. Under fish management activities, multiple stocking and multiple harvesting were the most commonly reported practices, followed by monitoring of carp behavior and manipulation of foraging/filter-feeding seed ratio. Only a small number of farms performed a regular on-farm health analysis. Except for adding chemical and organic fertilizers to improve pond water quality, removing weeds and water level management, the use of other water management and quality monitoring practices was limited to a small number of farms. Similarly, except for supplementary diets, only a small number of farms followed recommended feed management activities. Compared to the extensive system, a relatively higher percentage of intensive farms added inorganic fertilizer to increase water quality, monitored foraging/filter-feeding seed ratio and performed regular health analysis. Among other practices, pond draining and pond drying were reported on 40 and 60% of farms, respectively. Liming was reported on 60% of farms. Less than 10% of farms applied chemical fertilizer and about 25% of them applied organic fertilizer during the pond preparation. Farmers hardly used any chemical for pond treatment.

Table 12.1 Adoption of various management and monitoring practices by Nepalese carp farmers

Management and monitoring practices	Semi-intensive/ intensive (n = 270)	Extensive (n = 100)
Management and monitoring of fish	Percent	
Manipulate filter-feeding/foraging ratio	42.6	34.0
Continuous/multiple stocking	88.5	86.0
Continuous/multiple harvesting	87.4	82.0
Culture yearling in production pond as seed for next crop	21.1	11.0
Daily observation of carp behavior	57.8	51.0
Regular on farm health analysis	13.0	5.0
Management and quality monitoring of pond water		
Mechanical filtration/screening of water inflow	12.6	20.0
Water purification	11.1	6.0
Add chemical fertilizer to increase pond water fertility	48.5	27.0
Add organic fertilizer to increase pond water fertility	53.7	49.0
Remove weeds	44.4	46.0
Water level management during culture	33.0	42.0
pH/alkalinity	1.1	2.0
Dissolved oxygen level	17.0	18.0
Nutrients (N and/or P)	9.3	4.0
Water color and turbidity	9.6	12.0
Check pond sedimentation	1.1	1.0
Feeding and cost management		
Supplementary feeding	75.6	72.0
Feeding enclosure for floating seeds	0.4	1.0
Submerged, but liftable feeding tray	11.1	10.2
Daily check of feeding/left-overs	5.6	3.0
Daily removal of left-overs	0.7	0.0
Regular feed conversion ration calculation	0.7	2.0
Regular production cost analysis	6.3	2.0

The sample farms were affected by a number of problems, such as diseases [mainly epizootic ulcerative syndrome or EUS (39%)], water quantity- and quality-related problems (24%), seed quantity- and quality-related problems (10%), predation and poaching (6%) and lack of experience, technology and credit (6%). On an average, these problems caused a financial loss of NRs 11,387 (US$232), or nearly a third of the total value of production of the affected farms. Less than 3% of the farms encountered social conflicts mostly involving the access to land and water.

Of the 352 fish farms included in financial analysis, the average net margin/farm was NRs 23,610 ($482) or 24% of total value of capital and land. Net margin is total value of production (sales and home use) minus total cost, comprising total variable cost (seed, hired labor, fertilizer, feed and miscellaneous variable costs) and total fixed cost (rent, depreciation, contract cost, interest payments and other general overheads). Thus, net margin is the return to family labor, capital and land used in aquaculture. The financial results were consistent with farmers' perceptions, with more than 80% of the farmers believing aquaculture was either a very or moderately profitable activity. On per hectare terms, net margin was NRs 58,664 ($1,197), with intensive farms being relatively more profitable than extensive farms, but the difference was not statistically significant. Variable costs accounted for about 23% and fixed costs accounted for 16% of the total value of production. Hired labor and feed were the dominant components in variable costs while rent and depreciation were dominant components in fixed costs. On per farm basis net margin was higher on tenant-operated than on owner-operated farms, but it was opposite when net margin is expressed in per hectare terms. Despite some yield differences across the regions net margin/ha was similar geographically.

12.3.4 Output and input variables

For the efficiency analysis, all output and input variables are measured in per hectare terms. The output and input variables involved in the stochastic production frontier for a sample of carp producers in Nepal are described below and their summary statistics are provided in Table 12.2. Also included in Table 12.2 are the summary statistics of farm-specific variables included in the model for technical inefficiency effects, to be described below.

Output (Y) represents the total amount of fish production (in kg/ha). It should be noted that the total quantity of fish production is not an ideal measure for output variable in the production frontier analysis due to the multioutput production structure of fish polyculture involving different fish species. A more appropriate measure would be a geometric mean or quantity index based on revenue shares or prices for different fish species. Unfortunately, information on production, revenue and prices by species to compute the geometric mean or quantity index were not available. Some production frontier studies involving multiple outputs have used total revenue as the output variable. However, there are other problems in using total revenue. First, since total revenue leaves out production that is used for family consumption, it may underestimate output, especially when a substantial portion of fish production is used for family consumption as in Nepal. Secondly, technical inefficiencies can be confounded with allocative inefficiencies resulting from the production of a wrong combination of fish species given their market prices.

Seed (X_1) represents the sum of normalized fish seeds (fries) of different fish species (in no. of pieces/ha). The normalized total seed stocking for each farm was computed as follows:

$$X_1 = \frac{\sum_{j=1}^{8} N_j \cdot L_j^3}{2.5^3} \tag{12.4}$$

where j (1, 2, …, 8) denotes different fish species, namely grass carp, common carp, silver carp, big head carp, rohu, catla, mrigal and miscellaneous species; N_j denotes the number seeds of j-th species; and L_j denotes the seed size of j-th species (in cm).

Thus, all sizes were normalized to 2.5 cm, the most common size of seeds distributed from the government hatcheries.

Seed ratio (X_2) indicates the ratio of the number of foraging seeds to total seeds. Labor (X_3) denotes the total amount of hired (casual and permanent) and family labor used in aquaculture (in person days/ha). Fertilizer (X_4) is the total amount of chemical fertilizers used in fish production (in kg/ha). Feed (X_5) denotes the total dry weight of formulated feed, feed ingredients and green feed used in aquaculture (in kg/ha). One kg of green feed was assumed to be equivalent to 0.2 kg of dry feed (Tan, 1970). Other input (X_6) represents other expenses, including chemicals, water, maintenance, fuel, electricity, and depreciation on pond, housing, and farm machinery involved in fish pond culture (in NRs/ha). In estimating depreciation, the economic life of pond and building structures was assumed to be 20 years and that of farm machinery and equipment to be 15 years.

Besides above inputs, three dummy variables are also included in the stochastic production frontier to account for zero values of fertilizer (X_4), feed (X_5) and other input (X_6) variables for some observations. Without these dummy variables, the estimators for output elasticities of fertilizer, feed and other input obtained from the Cobb-Douglas production function will be biased (Battese, 1996). Following Battese et al. (1996), the marginal products and elasticities of production for other inputs are assumed to be same for farmers using fertilizer, feed and other cost as those not using these inputs. These dummy variables are fertilizer dummy (D_1), feed dummy (D_2) and other input dummy (D_3), each having value 1 if the respective unit was used in aquaculture, 0 otherwise.

12.3.5 Farm-specific variables

In addition to output and input variables described above, a number of relevant farm-specific variables are also included in the analysis to determine important factors influencing technical efficiency in carp production. These variables are described below and summarized in Table 12.2.

- Intensive production dummy (Z_1) has value 1 if the farm adopted semi-intensive or intensive pond culture system and 0 if extensive system.
- Farmer's experience (Z_2) is measured by the number of years the farmer has engaged in carp production.
- Owner operator dummy (Z_3) has value 1 if the farmer is an owner operator and 0 if lease operator.
- Pond area (Z_4) represents the total area of fish pond in ha.

In order to determine the effects of the adoption of various regular management practices on technical efficiency, following fish, water, and feed management indices are also included as explanatory variables in the technical inefficiency model. The activities included under different management indices are listed in Table 12.1.

- Fish management index (Z_5) represents the total number of fish management and monitoring activities followed by the farmer;
- Water management index (Z_6) represents the total number of water management and quality monitoring activities followed by the farmer; and
- Feed management index (Z_7) represents the total number of feed management and monitoring activities followed by the farmer.

Table 12.2 Summary statistics of variables involved in the stochastic production frontier and technical inefficiency model for carp pond culture in Nepal

	Semi-intensive/ intensive (n = 213)		Extensive (n = 73)		All farms (n = 286)	
Variable	Average	SD	Average	SD	Average	SD
Output variable						
Fish production (kg/ha)	2,404	1,175	1,836	898	2,259	1,137
Input variables						
Seed (2.5 pieces/ha)	33,678	27,017	25,881	24,389	31,688	26,549
Forage seed ratio (forage/total)	0.32	0.23	0.37	0.24	0.34	0.23
Labor (person days/ha)	666	618	538	549	634	603
Fertilizer (kg/ha)	185	238	97	213	163	235
Feed (dry kg/ha)	1,797	2,429	1,195	1,694	1,644	2,277
Other input (NRs/ha)	8,452	9,424	8,123	13,804	8,368	10,688
Fertilizer dummy (0 or 1)	0.57	0.50	0.37	0.49	0.52	0.50
Feed dummy (0 or 1)	0.69	0.46	0.64	0.48	0.68	0.47
Other input dummy (0 or 1)	0.89	0.32	0.81	0.40	0.87	0.34
Variables affecting technical inefficiency						
Semi-intensive/intensive (0 or 1)	-	-	-	-	0.74	0.44
Experience (years)	9.77	6.88	9.32	7.53	9.66	7.04
Owner-operated (0 or 1)	0.88	0.33	0.85	0.36	0.87	0.34
Pond area (ha)	0.48	0.67	0.50	0.52	0.49	0.64
Fish management index	2.82	1.13	2.44	0.93	2.72	1.09
Water management index	2.60	1.71	2.42	1.72	2.55	1.71
Feed management index	1.52	0.67	1.48	0.58	1.51	0.65
Central region dummy (0 or 1)	0.38	0.49	0.32	0.47	0.37	0.48
Western region dummy (0 or 1)	0.14	0.34	0.25	0.43	0.16	0.37
Mid/far-western dummy (0 or 1)	0.13	0.34	0.12	0.33	0.13	0.34

n denotes the number of farms used in the analysis of technical efficiency.
SD stands for standard deviation.

Finally, three regional dummies are also included in the technical inefficiency model to capture the effects of regional differences on productive performance of carp culture. The Eastern region is treated as a reference or default region. These regional dummies are as follows:

- Central region dummy (Z_8) has value 1 if the farm is located in the central region, 0 otherwise;
- Western region dummy (Z_9) has value 1 if the farm is located in the western region, 0 otherwise; and
- Mid and far western region dummy (Z_{10}) has value 1 if the farm is located in the mid and far western regions, 0 otherwise.

12.3.6 Empirical model

The stochastic production frontier for the sample fish pond producers is specified as:

$$\mathrm{Ln}Y_i = \beta_0 + \sum_{k=1}^{6} \beta_k \mathrm{Ln}X_{ki} + \beta_7 D_{1i} + \beta_8 D_{2i} + \beta_9 D_{3i} + V_i - U_i \qquad (12.5)$$

where subscript i refers to the i-th farmer in the sample; Ln represents the natural logarithm; Y is output variable and Xs and Ds are input and related variables, defined previously; V_is and U_is are the random variables, also defined previously; and the technical inefficiency effects U_is, are defined by

$$U_i = \delta_0 + \sum_{j=1}^{10} \delta_j Z_{ji} + W_i \qquad (12.6)$$

where Zs are various farm-specific variables, defined earlier and δs are unknown parameters to be estimated.

Initially two Cobb-Douglas stochastic frontiers were estimated separately for semi-intensive/intensive and extensive farms. However, based on the generalized likelihood-ratio test a single production frontier was an adequate representation of the data, given the specification of Cobb-Douglas functional form. The test-statistic was equal to 28.84, which is less than 33.92, the 95% critical value for the χ^2 distribution with 22 degrees of freedom. Note that the intensive dummy is not relevant to the estimation of separate frontiers for semi-intensive/intensive and extensive farms. For the purpose of this study, the Cobb-Douglas form was chosen because of a large number of parameters to be estimated in the translog production frontier, particularly for estimating separate frontiers for the two systems.

The parameters for the stochastic production frontier model (12.5) and those for the technical inefficiency model (12.6) are estimated simultaneously using the maximum-likelihood estimation (MLE) program, FRONTIER 4.1 (Coelli, 1994), which estimates the variance parameters of the likelihood function in terms of $\sigma^2 = \sigma_v^2 + \sigma_u^2$ and $\gamma = \sigma_u^2/\sigma^2$.

It should be noted that the technical inefficiency model (12.6) can only be estimated if the inefficiency effects, U_is, are stochastic and have particular distributional properties (Battese and Coelli, 1995). Therefore, it is of interest to test the null hypotheses that technical inefficiency effects are nonstochastic, $\gamma = 0$; and farm-specific factors do not influence the technical inefficiencies, $\delta_1 = \ldots = \delta_{10} = 0$. Under $\gamma = 0$; the stochastic frontier model reduces to a traditional average response function in which the explanatory variables in the technical inefficiency model are also included in the production function. These and other relevant null hypotheses can be tested using the generalized likelihood-ratio statistic, λ, given by

$$\lambda = -2[\mathrm{Ln}\{L(H_0)\} - \mathrm{Ln}\{L(H_1)\}] \qquad (12.7)$$

where $L(H_0)$ and $L(H_1)$ denote the values of likelihood function under the null (H_0) and alternative (H_1) hypotheses, respectively. If the given null hypothesis is true, λ has approximately χ^2 distribution or mixed χ^2 distribution when the null hypothesis involves $\gamma = 0$ (Coelli, 1995b).

12.4 Results and implications

12.4.1 MLE estimates and tests of hypotheses

The maximum-likelihood estimates of the parameters in the stochastic production frontier model and those in the technical inefficiency model are presented in Table 12.3. Most of the slope coefficients of the stochastic frontier or output elasticities of inputs had expected signs, except for a negative but insignificant estimate for other input. The coefficients associated with seed, labor and fertilizer were highly significant while those for forage seed ratio and feed were not significant. Output elasticity of inputs was the highest for fertilizer (0.142), followed by labor (0.091) and seed (0.077). The composition of foraging vs. filtering species (as measured by the variable forage seed ratio) did not have any effect on per hectare fish production.

Generalized likelihood-ratio tests of various null hypotheses involving the restrictions on the variance parameter, γ, in the stochastic production frontier and the δ-coefficients in the technical inefficiency model are presented in Table 12.4. Both the first and second null hypotheses that technical inefficiency effects are not present and that technical inefficiency effects are not stochastic were rejected. Thus, the traditional average (OLS) function is not an adequate representation of the data involved in the study. The magnitude and significance of the estimate for the variance parameter, γ, also supported the results from the likelihood-ratio tests. The third null hypothesis which specifies that the intercept as well as all the coefficients associated with various farm-specific variables involved in the technical inefficiency model are zero (that the technical inefficiency effects have a half-normal distribution with zero mean) was rejected as well. The less restrictive fourth null hypothesis that all the coefficients of the technical inefficiency model except the intercept are zero (that the technical inefficiency effects have the same truncated-normal distribution with mean equal to δ_0) was also rejected.

Thus, given the model specifications, the results indicate that the farm-specific variables involved in the technical inefficiency model contribute significantly as a group to the explanation of the technical inefficiency effects in carp production although, based on asymptotic t-ratios, slope coefficients were not significant individually. Most variables, such as production intensity, farmer's experience, ownership and various management practices had expected signs. In view of a low validity of asymptotic t-statistic under the maximum likelihood estimation procedure the effects of farm-specific variables on technical efficiency were also tested using the generalized likelihood-ratio tests. Accordingly, as shown by the tests of last two null hypotheses in Table 12.4, production intensity and the degree of adoption of regular management practices had a significant and positive influence on technical efficiency of carp production in Nepal. The superior performance of semi-intensive/intensive farms over extensive farms was also confirmed by ANOVA procedure.

Table 12.3 Maximum-likelihood estimates of stochastic production frontier and technical inefficiency models for carp production in Nepal

	Parameter	Coefficient	Asymptotic t-ratio
Stochastic frontier			
Constant	β_0	6.479	19.485
Ln (Seed)	β_1	0.077	2.839
Ln (Seed ratio)	β_2	0.008	0.764
Ln (Labor)	β_3	0.091	2.970
Ln (Fertilizer)	β_4	0.142	3.581
Ln (Feed)	β_5	0.002	0.062
Ln (Other input)	β_6	-0.040	-1.364
Fertilizer dummy	β_7	-0.677	-3.076
Feed dummy	β_8	0.152	0.645
Other input dummy	β_9	0.304	1.149
Technical inefficiency model			
Constant	δ_0	3.617	2.019
Intensive	δ_1	-1.060	-1.404
Experience	δ_2	-0.016	-0.757
Owner	δ_3	-0.795	-1.251
Pond area	δ_4	0.140	0.601
Fish management index	δ_5	-0.730	-1.593
Water management index	δ_6	-0.015	-0.168
Feed management index	δ_7	-0.786	-1.381
Central region	δ_8	-1.559	-1.179
Western region	δ_9	-0.709	-1.158
Mid and far western	δ_{10}	-0.664	-0.795
Variance parameters			
	σ^2	0.696	1.716
	γ	0.847	9.507
Ln (likelihood)		157.498	
Mean of exp $(\tilde{U}_i)$		0.768	

Table 12.4 Generalized likelihood-ratio tests of hypotheses involving some estimates of the stochastic production frontier

Null hypothesis (H_0)	Log (likelihood)	Test statistic (λ)	Critical value $(\chi^2_{0.95})$	Decision
$\gamma = \delta_0 = \delta_1 = \ldots = \delta_{10} = 0$	-182.70	50.40	20.41*	Reject Ho
[illegible] $\gamma = 0$	-169.24	23.48	5.14*	Reject Ho
$\delta_0 = \delta_1 = \ldots = \delta_{10} = 0$	-179.08	43.16	19.68	Reject Ho
$\delta_1 = \delta_2 = \ldots = \delta_{10} = 0$	-177.60	40.20	18.31	Reject Ho
$\delta_1 = 0$	-161.41	6.82	3.84	Reject Ho
[illegible]	-171.22	27.44	7.82	Reject Ho

*The correct critical values for first and second null hypotheses involving [illegible] are obtained from Table 1 of Kodde and Palm (1986, p. 1246) for 12 and 2 degrees of freedom, respectively.

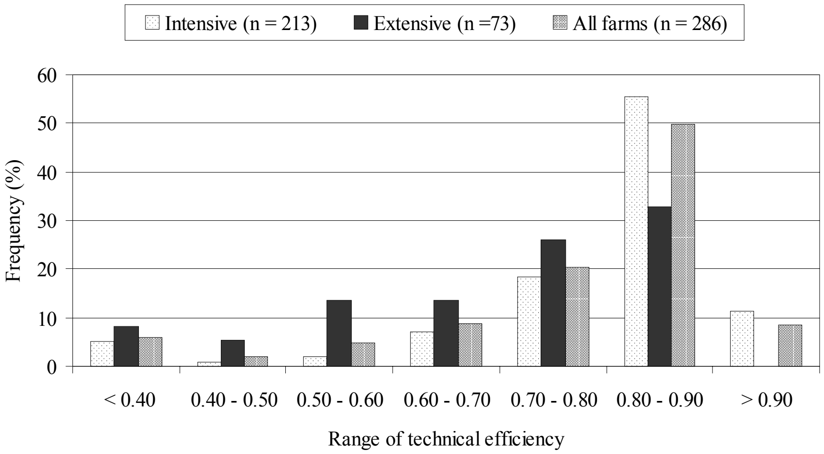

Fig. 12.1 Frequency distribution of technical efficiency estimates for carp producers in Nepal

12.4.2 Technical efficiencies

The estimated technical efficiencies for the overall sample farms ranged from 0.18 to 0.95 with an average efficiency of 0.77. Efficiency scores for intensive farms ranged from 0.22 to 0.95, with a mean efficiency of 0.80 and those for extensive farms varied from 0.18 to 0.90, with a mean score of 0.69. The frequency distributions of the estimated technical efficiencies are depicted in Fig. 12.1. Although the technical efficiencies for both intensive and extensive systems were estimated relative to the same production frontier, the frequency distributions of the estimated scores for the two systems were quite different. For example, more than two-thirds of extensive farms had an efficiency index of less than 0.80 compared to only a third of the intensive farms, but for the efficiency ranges of 0.80 or higher it was other way around.

The estimated mean technical efficiencies for aquaculture were quite similar to those reported on previous frontier studies in Nepalese agriculture. In a recent study by Ali (1996), the mean technical efficiency for a sample of wheat farmers in the Tarai of Western Nepal was estimated to be 0.75. Similarly, in another study by Belbase and Grabowski (1985), the estimated mean technical efficiency for Nepalese farmers was reported to be 0.76.

12.4.3 Policy implications

The results indicate that there is substantial inefficiency in carp production in Nepal, especially among extensive farms. Given the existing technology, the sample aquacultural farms could increase their production by 23% by using their existing resources more efficiently. In other words, carp producers in the sample would be able to increase their average pond yield from 2.3 to 2.8 mt/ha by operating at full efficiency. At full efficiency, intensive farms would be able to increase their production from 2.4 to 2.9 mt/ha and extensive farms from 1.8 to 2.6 mt/ha. However, the predicted frontier production is still less than per hectare production of other NACA member countries. Besides lower production intensity, smaller pond yields in

Nepal can also be attributed to technological gaps, with Nepalese farms operating at a lower production frontier compared to their counterparts in other countries. Thus, Nepal has potential for shifting its production frontier upward in numerous ways, such as increasing farmers' knowledge in modern aquaculture, genetic improvement of fish stocks and control of diseases and other environment related problems. Nepal may greatly benefit from the experience and expertise of other countries in these critical areas.

The results indicates that, given the present state of technology in the country, carp producers have potential for enhancing productivity by increasing input levels, especially seed, fertilizer, and feed. In other words, Nepal has great potential for increasing aquacultural productivity by intensifying carp culture. Farmers would also benefit greatly by following regular fish, water and feed management and monitoring activities. It is imperative that the government should provide continuous support with respect to timely and adequate supply of quality seed and chemical fertilizer, market and infrastructure development, research, training and extension and affordable credit facilities in order to exploit full potential for increased fish production.

12.5 Conclusions

This study examines the production economics of Nepalese aquaculture, mainly focusing on technical efficiency of carp pond culture. The production data and several farm-specific information collected from a sample of carp producers are analyzed using a stochastic production frontier, including a model for the technical inefficiency effects. The paper also highlights farming system, profitability and problems associated with carp production. Output and input variables are measured in per hectare terms. The parameters for the production frontier and those for the technical inefficiency model are estimated simultaneously using a maximum-likelihood estimation technique.

The results showed that there are significant production inefficiencies among the sample carp producers in Nepal. The tests indicate that the farm-specific variables are highly significant in explaining technical inefficiencies for fish farmers, especially production intensity and the adoption of management practices. The mean level of technical efficiency was 0.77, with intensive farms being more efficient than extensive farms. There is potential for higher fish production in Nepal by (1) producing more from the existing resources (i.e. improving technical efficiency); and (2) shifting the production frontier (i.e. technical progress). The results show technical efficiency in carp production can be improved by following regular fish, water and feed management and monitoring activities, and increasing the input levels, especially seed, fertilizer, labor and feed (i.e. intensification). Similarly, some of the ways to increase fish production through technological advancement include development of modern fish farming technologies, improvement in genetic make-up of existing fish species and introduction of improved fish species from other countries. However, the realization of these potentials depends greatly on continuous efforts of the government in ensuring timely and adequate supply of required inputs, technology transfer and development and adequate provision of research, extension, and credit facilities.

Due to the lack of data, this paper is limited to technical efficiency only. Research on other aspects of productive efficiencies for carp production in Nepal, especially allocative, scale and economic efficiencies can be carried out if appropriate data is collected in the future. In a polyculture system, in view of variations in feeding habits and market values among various fish species, the choice of optimum stocking composition of different fish species is of critical importance both for optimum fish growth and profit maximization. The optimum species composition can readily be determined based on allocative efficiencies. Furthermore, a study on intercountry comparison of productivity involving other carp-growing countries in the region can be highly useful in identifying potential areas for exchange of technical know-how among the countries.

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Chapter 13

Technical efficiency of carp production in Pakistan

Khem R. Sharma

Abstract
The main objective of this study is to examine technical efficiency and its determinants in carp pond culture in Pakistan. A stochastic production frontier involving the model for technical inefficiency effects is applied separately to the samples of semi-intensive/intensive and extensive carp producers. The mean technical efficiencies for semi-intensive/intensive and extensive farms were 0.673 and 0.561, respectively. By operating at full technical efficiency the semi-intensive/intensive farms could, on average, increase their production from 3.0 to 4.5 mt/ha and the extensive farms from 2.6 to 4.6 mt/ha. Much of these efficiency gains would come from the improvement in fish, water and feed monitoring and management. Besides improving technical efficiency, potential also exists for raising carp productivity through increased intensification and technological progress. However, the realization of these potentials will depend on continuous government support for adequate provision of inputs, market and infrastructure, technology transfer and development and extension and credit services to carp farmers.

13.1 Introduction

Aquaculture is a relatively new, but rapidly expanding activity in Pakistan. Despite its small contribution to the national economy, aquaculture has become an increasingly important sector in terms of its potential for increasing domestic supply of fish protein in the country, where average domestic per capita availability of food fish is only 2.4 kilogram per annum, with fish accounting only for 4% of animal protein (FAO/NACA, 1997). Recognizing its potential for contributing to food security and nutrition as well as rural employment and foreign exchange earnings, Pakistan has given a high priority to aquaculture in its development plan. Accordingly, the First Aquaculture Development Project (1981–1986) was implemented aiming to upgrade aquacultural facilities (especially hatchery facilities), promote intensification of aquaculture, develop human resources and promote private sector investment. Similarly, the Second Aquaculture Development Project (1989-1996) was launched to strengthen aquacultural support services and promote carp and trout culture. Because of these efforts, carp production increased from a few hundred metric tonnes (mt) in the 1970s to nearly 24,000 mt in 1995.

Good prospects exist for further output growth in carp production in Pakistan for several reasons. First, carp farming is more profitable compared to most other farming activities. Secondly, the country is believed to have about 2 million ha of freshwater bodies (lakes, reservoirs and rivers) suitable for aquaculture. However, the aquaculture potential of these resources is only slightly utilized at present. For example, in 1995 the total area under aquaculture was only about 14,000 ha. Thirdly, there may be a good potential to enhance productivity through the improvement in technical

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efficiency at the farm level and technological progress at the national as well as regional levels, such as the development of modern technologies and improvement in genetic make-up of fish species.

If aquaculture is to play a vital role in ensuring future fish availability for food security and nutrition in the country, this sector has to develop and expand in an economically viable and environmentally sustainable manner. Among many other factors, increasing efficiency of resource use and productivity at the farm level is one of the prerequisites for sustainable aquaculture (FAO, 1997). Accordingly, measuring technical efficiency at the farm level, identifying important factors associated with efficient production systems and assessing potential for and sources of future improvements are essential for developing sustainable aquaculture. Aquaculture, like many other farming activities, is dependent upon the use of natural resources, such as water, land, seed and feed. As farmers continue to intensify their efforts toward aquaculture, the demand for these resources will rise, leading to increased competition for limited resources and negative environmental consequences, which can be detrimental to the long-term economic viability and sustainability of the production system and environment. Therefore, in the long-run efforts should be made toward output growth through improved technical efficiency, i.e. producing more by utilizing existing resources more efficiently instead of increasing the amount of inputs only.

Against this background, the main objective of this study is to examine the levels and determinants of farm-level technical efficiencies of carp production in Pakistan. The technical efficiency indicates the producer’s ability to achieve maximum output from given quantities of inputs and existing technology. Despite several frontier studies applied to Pakistan agriculture (e.g., Ali and Chaudhry, 1990; Battese et al., 1996; Battese and Broca, 1997), to our knowledge, no study has been conducted concerning the production efficiency in aquaculture. A stochastic frontier production function involving the Battese and Coelli (1995) model for technical inefficiency effects is applied separately to the samples of semi-intensive/intensive and extensive carp farms, interviewed by the Network of Aquaculture Centers in Asia-Pacific (NACA) Aquaculture Sustainability and Environment Survey during 1994/95. The proposed model forms the basis for estimating technical efficiency of sample farms relative to a ‘best-practice’ technology as well as for identifying potential for and sources of future improvements.

13.2 The stochastic production frontier and technical inefficiency model

Farrell’s (1957) seminal article on efficiency measurement led to the development of several approaches to efficiency and productivity analysis. Among these, the stochastic frontier production function (Aigner et al., 1977; Meeusen and van den Broeck, 1977) and data envelopment analysis (DEA) (Charnes et al., 1978) are the two principal methods [see Coelli (1995a) and Coelli et al. (1998) for detailed information on efficiency measurement using the stochastic production frontier and DEA, including their strengths, weaknesses, and estimation procedures]. As noted by Coelli et al. (1998), the stochastic frontier is considered more appropriate than DEA in agricultural applications, especially in developing countries, where the data are likely to be heavily influenced by measurement errors and the effects of weather conditions, diseases, etc. This also applies to the applications of frontier techniques to aquaculture, including carp culture.

Following Aigner et al. (1977) and Meeusen and van den Broeck (1977), a stochastic frontier production function for the cross-sectional data can be defined as follows:

$$\mathrm{Ln}Y_i = f(X_i;\beta) + V_i - U_i \tag{13.1}$$

where Y_i denotes the production of the i-th firm (i = 1, 2, ..., n); X_i is a $(1 \times k)$ vector of functions of input quantities used by the i-th firm; β is a $(k \times 1)$ vector of parameters to be estimated; V_is are independently and identically distributed [iid $N(0, \sigma_v^2)$] random variables, independent of U_is; and U_is are non-negative random variables, associated with technical inefficiency in production, which are assumed to be independently and identically distributed exponential or half-normal variable [$U_i \sim (|N(0, \sigma_u^2)|)$]. Both exponential and half-normal distributions are criticized for arbitrarily restricting the mean of technical inefficiency effects to zero and related consequences for estimated technical efficiency scores. A few researchers have proposed alternative specifications for the technical inefficiency effects, such as the truncated-normal distribution [$U_i \sim$ iid $(|N(\mu, \sigma_u^2)|)$] proposed by Stevenson (1980), the two-parameter gamma distribution proposed by Greene (1990) and the model for technical inefficiency effects proposed by Battese and Coelli (1995). Although there is generally no a priori justification for the choice of any particular distributional forms for the technical inefficiency effects, the generalized truncated-normal distribution has been most frequently used in empirical applications because of its computational simplicity. However, in recent years, the Battese and Coelli (1995) model for the technical inefficiency effects has become more popular because of its computational simplicity as well as its ability to examine the effects of various firm-specific variables on technical efficiency in an econometrically consistent manner, as opposed to a traditional two-step procedure.

According to Battese and Coelli (1995), technical inefficiency effects, U_is in Eqn. 13.1 are assumed to be independently distributed and truncations (at zero) of the normal distribution with mean, $Z_i\delta$, and variance, σ_u^2 [$(|N(Z_i\delta, \sigma_u^2)|)$], where Z_i is a (1 x m) vector of observable firm-specific variables hypothesized to be associated with technical inefficiency, and δ is an (m x 1) vector of unknown parameters to be estimated. Under these assumptions, the technical inefficiency effects, $U_i$scan more formally be expressed as follows:

$$U_i = Z_i\delta + W_i \tag{13.2}$$

where W_is are random variables, defined by the truncations of the normal distribution with mean zero and variance, σ_u^2, such that the point of truncation is $-Z_i\delta$ i.e. $W_i \geq Z_i\delta$. Besides the firm-specific variables, the Z-variables in Eqn. 13.2 may also include input variables in the stochastic production frontier (13.1), provided that the technical inefficiency effects are stochastic. If Z-variables also include interactions between firm-specific factors and input variables, then the Huang and Liu (1994) non-neutral stochastic frontier is obtained.

The technical efficiency of the i-th sample firm, denoted by TE_i, is derived as follows:

$$TE_i = \exp(-U_i) = \exp(-Z_i\delta - W_i) \tag{13.3}$$

The prediction of technical efficiencies is based on the conditional expectation of expression (13.3), given the model specifications (Battese and Coelli, 1988).

13.3 The data

13.3.1 Data sources

The data for this study came from the NACA Aquaculture Sustainability and Environment Survey of carp farms in Pakistan, conducted during the period from November 1994 to July 1995. A sample of 778 farms (~ 15% of the total carp farms in the country) was taken from three provinces (Punjab: 400; Sindh: 220; and Northwest Frontier Province: 158). NACA (1994) provides details for sampling procedures as well as the instrument employed in the survey. Depending upon the levels of inputs (especially, feed, fertilizer and seed) used, the carp farms were roughly divided into two categories, namely semi-intensive/intensive and extensive. Extensive farms applied less inputs, especially feed and chemical fertilizer. Due to a lack of clear-cut distinction between semi-intensive and intensive systems, the survey combined these two into one category. The sample included 492 semi-intensive/intensive farms and 286 extensive farms.

Of the sample farms surveyed, a sizeable number of observations were dropped due to incomplete data. For production economics analysis (i.e. cost and return) farms with no data on culture period (needed to calculate labor use), seed rate and labor use were also dropped. For internal consistency of data, various production indicators, including yield, output/seed ratio, output/labor ratio and labor/pond area ratio, were examined for each farm in the sample. A few more observations with implausibly too-low or too-high values for these indicators were dropped in the efficiency analysis. It is suspected that some recording or data entry errors were responsible for these extreme data points. The total number of farms surveyed as well as those involved in various analyses by level of intensity are presented in Table 13.1.

Table 13.1 Study sample by level of culture intensity

	Semi-intensive/ intensive	Extensive	Total
No. of farms surveyed	492	286	778
No. farms included in various analyses			
General information (farm size, land use, water source, species stocked, and management practices)	420	240	660
Production economics analysis (yield, cost, and return)	382	227	609
Production frontier analysis	378	224	602

13.3.2 Sample characteristics

Of the farms considered to analyze general sample characteristics, the average pond area was 2.68 ha, with extensive farms being somewhat bigger than semi-intensive/intensive farms although the difference was not significant. On average, pond area was biggest in Sindh (6.3 ha), followed by North-west Frontier Province (1.9 ha) and Punjab (0.8 ha). Carp culture was the primary activity for the two-thirds of the sample farms. Similarly, the proportion of farms practicing integrated farming was 26%, the majority of which integrated fish with livestock.

The most dominant form of land use prior to carp farming was low-yielding agricultural land (56%), followed by wetland/swamp areas (17%). Both provinces and culture systems differed significantly with respect to source of water for fish ponds. For example, for semi-intensive/intensive farms the most dominant source of water was tube/shallow wells (60%), while for extensive farms it was irrigation canals (68%). Similarly, tube/shallow wells were the dominant source of water in Punjab and North-west Frontier Province, while in Sindh it was irrigation canals.

Almost all sample farms practiced polyculture of several carp species. Cultured species by the majority of the farms in all three provinces were two indigenous or major carp, namely rohu or *Labeo rohita* (97%) and mrigal or *Cirrhinus mrigala* (93%). Catla or *Catla catla* was reported on almost all farms in Sindh and 69% of farms in Punjab. Among Chinese carp, grass carp or *Ctenopharyngodon idella* was reported on about 75% of farms in Punjab and North-west Frontier Province, while silver carp or *Hypophthalmichthys molitrix* was reported on 75% of farms in Punjab. These proportions were quite similar for both semi-intensive/intensive and extensive systems. In terms of feeding behavior, foraging species (such as grass carp) accounted for about 12% of total stocking, implying the dominance of filtering species in carp polyculture in Pakistan. The stocking rates for semi-intensive/intensive and extensive systems were 0.47 and 0.44 pieces/m^2, respectively.

Except for monitoring of carp behavior, only a small proportion of farms followed recommended fish management and monitoring practices. The sample farms appeared to be doing better with respect to following water quality monitoring practices. The majority of semi-intensive/intensive farms added chemical and organic fertilizers to enhance pond water fertility and monitored pond water level during culture. More than 50% of extensive farms also added organic manure to improve water fertility. Under feed and cost management, about 95% of semi-intensive/intensive farms and only 38% extensive farms applied some supplementary feeds to carp ponds. Only a small number of farms followed other recommended feed and cost management activities (Table 13.2).

Of the sample farms involved in production economic analysis, the average yield for semi-intensive/intensive farms was 3,054 kg/ha compared to 2,631 kg/ha for extensive farms [Extensive farms appeared to be much more productive in Pakistan compared to other countries in Asia. This is attributed to the use of nutrient-rich irrigation water to fill carp ponds and low incidence of diseases and environmental problems in Pakistan. ADB/NACA (1996) provides an analysis of diseases and environmental problems in carp culture in Asia]. This difference was statistically significant. The average value of production/ha was US$ 3,920 (PRs 119,562) for semi-intensive/intensive farms and $3,266 (PRs 99,603) for extensive farms.

Similarly, the average per hectare total production costs excluding the cost of family labor were, respectively, $1,753 (PRs 53,469) and $991 (PRs 30,211). Accordingly, per hectare net margins (i.e. return to family labor and management) for semi-intensive/intensive and extensive farms were $2,167 (PRs 66,092) and $2,275 (PRs 69,392), respectively. Thus, despite a significantly higher value of production on semi-intensive/intensive farms than extensive farms, both systems were found to be more or less equally profitable due to significantly lower production costs in the latter system. Comparing the provinces, Sindh had the highest yield, lowest production costs, and hence was most profitable of the three provinces involved in this study.

Table 13.2 Adoption of various management and monitoring practices by carp farmers in Pakistan

Management and monitoring practices	Semi-intensive/ intensive (n = 420)	Extensive (n = 240)
Management and monitoring of fish	Percent	
Manipulate filter-feeding/foraging ratio	13.8	4.6
Continuous/multiple stocking	21.0	20.4
Continuous/multiple harvesting	15.5	12.9
Culture yearling in production pond as seed for next crop	14.0	6.3
Daily observation of carp behavior	79.0	67.1
Regular on farm health analysis	8.8	13.3
Management and quality monitoring of pond water		
Mechanical filtration/screening of water inflow	30.2	13.8
Water purification	11.2	1.3
Add chemical fertilizer to increase pond water fertility	60.0	34.2
Add organic fertilizer to increase pond water fertility	76.4	52.9
Remove weeds	37.1	35.4
Water level management during culture	62.4	43.3
pH/alkalinity	35.5	23.5
Dissolved oxygen level	11.4	9.2
Nutrients (N and/or P)	5.7	7.1
Water color and turbidity	39.5	45.4
Check pond sedimentation	1.0	1.3
Feeding and cost management		
Supplementary feeding	94.8	38.3
Feeding enclosure for floating feeds	10.2	0.0
Submerged, but liftable feeding tray	8.8	0.0
Daily check of feeding/left-overs	23.6	4.6
Daily removal of left-overs	21.0	1.7
Regular feed conversion ratio calculation	0.5	0.0
Regular production cost analysis	1.0	0.4

Besides output, mean input levels were also generally higher under semi-intensive/intensive system than extensive system. The most notable difference between the two systems was the application of feed to fish ponds. Only a few sample farmers applied feed in extensive system, while almost all of them did so in semi-intensive/intensive system. Labor was the dominant component of production cost, accounting for nearly half of the total variable cost under each production system. Seed accounted for about 10% and 19% of total variable cost of semi-intensive/intensive and extensive farms, respectively. Similarly, feed accounted for 12% and 0.5% of total variable cost, respectively. Contributions of other variable inputs (such as chemicals, water, maintenance, fuel, etc.) were quite similar for the two systems.

13.4 The empirical model

Following the standard assumption that farmers maximize expected profits (Zellner et al., 1966), a single equation Cobb-Douglas stochastic production frontier for semi-intensive/intensive and extensive carp farms in Pakistan is specified as follows:

$$\mathrm{LnY_i} = \beta_0 + \sum_{k=1}^{6} \beta_k \mathrm{LnX_{ki}} + \beta_7 \mathrm{D_{1i}} + \beta_8 \mathrm{D_{2i}} + \beta_9 \mathrm{D_{3i}} + \beta_{10} \mathrm{D_{4i}} + \mathrm{V_i} - \mathrm{U_i} \quad (13.4)$$

where subscript i refers to the i-th farm in the sample; Ln represents the natural logarithm; Y is output variable and Xs and Ds are input and related dummy variables, as defined in Table 13.3 and summarized in Table 13.4; βs are unknown parameters to be estimated; V_is are iid $N(0, \sigma_v^2)$ random variables; U_is are independently distributed ($|N(Z_i\delta, \sigma_u^2)|$) technical inefficiency effects, which are, following Battese and Coelli (1995), further defined as follows:

$$\mathrm{U_i} = \delta_0 + \sum_{m=1}^{8} \delta_m \mathrm{Z_{mi}} + \mathrm{W_i} \quad (13.5)$$

where Zs are various farm-specific variables, as defined in Table 13.3 and summarized in Table 13.4, δs are unknown parameters to be estimated, and W_i is a random variable as defined in Eqn. 13.3. Since the dependent variable in Eqn. 13.5 is defined in terms of technical inefficiency, a farm-specific variable associated with the negative (positive) coefficient will have a positive (negative) impact on technical efficiency. The technical efficiency of the i-th sample farm (TE_i) was estimated in terms of Eqn. 13.3.

Despite its restrictive properties, the Cobb-Douglas form was chosen due to the presence of a large number of zero values for several input variables and hence their cross-product terms to estimate a more flexible translog form. The problem of taking the logarithms of inputs with zero values was avoided by including the dummies for zero valued observations, as indicated in footnote 5, Table 13.3. A common production frontier model for both systems was rejected based on the generalized likelihood test.

Table 13.3 Description of output, input, and farm-specific variables involved in the stochastic production frontier and technical inefficiency model for carp pond culture in Pakistan

Variable	Description
Output (Y)	Aggregated quantity of fish production (in kg/ha)[1]
Input	
Seed (X_1)	Total number of fish seeds or fingerlings stocked (in no. of pieces/ha)[2]
Labor (X_2)	Hired plus family labor used in carp production (in person days/ha)
Chemical fertilizer (X_3)	Amount of chemical fertilizers used in carp culture (in kg/ha)
Organic manure (X_4)	Amount of organic manure used in carp production (in kg/ha)
Feed (X_5)	Total dry weight of formulated feed, feed ingredients, and green feed applied in carp ponds (in kg/ha)[3]
Other input (X_6)	Other inputs (chemicals, water, maintenance, fuel, etc.) and depreciation on fish pond, housing, and machinery used in carp culture (in US$/ha)[4]
Fertilizer dummy (D_1)	Value 1 if chemical fertilizer was used in carp culture, 0 otherwise[5]
Manure dummy (D_2)	Value 1 if organic manure was used in carp culture, 0 otherwise[5]
Feed dummy (D_3)	Value 1 if feed was used in carp culture, 0 otherwise[5]
Other input dummy (D_4)	Value 1 if other input is positive, 0 otherwise[5]
Farm-specific	
Primary activity (Z_1)	Value 1 if carp culture is undertaken as a primary activity, 0 otherwise
Farmer's experience (Z_2)	Number of years the farmer has been engaged in carp production
Pond area (Z_3)	Total area of fish pond in hectares
Fish management index (Z_4)	Total number of fish management and monitoring practices used
Water management index (Z_5)	Total number of water management and quality monitoring practices used
Feed management index (Z_6)	Total number of feed management and monitoring practices used
Punjab dummy (Z_7)	Value 1 if the sample farm is from Punjab, 0 otherwise[6]
Sindh dummy (Z_8)	Value 1 if the sample farm is from Sindh, 0 otherwise[6]

[1] It should be noted that the total quantity of fish production is not an ideal measure of output variable in the production frontier analysis due to the multi-output production structure of fish polyculture. A more appropriate measure would be a geometric mean or quantity index based on revenue shares or prices for different fish species. Unfortunately, information on production, revenue and prices by species to compute the geometric mean or quantity index was not available. Therefore, output variable was defined as a simple aggregate of the outputs of different carp species.

[2] In view of possible variation in seed sizes, it would have been ideal to measure the seed variable in weight (such as kg/ha). However, direct information on seed weight was not available. One way of accounting for size variations would be to convert the number of seeds into weight or to normalize to a standard size using a body length-weight relationship. However, both of these procedures are only approximate and extremely sensitive to slight measurement errors. So, actual number of seeds stocked is used as a measure of seed input.

[3] Following Tan (1970) one kilogram of green feed was assumed to be equivalent to 0.2 kg of dry feed.

[4] In estimating depreciation, the economic life of pond and building structures was assumed to be 20 years and that of farm machinery and equipment to be 15 years.

[5] Without these dummy variables, the estimators for output elasticities of chemical fertilizer, organic manure, feed, and other input obtained from the Cobb-Douglas production function will be biased (Battese, 1996). Given dummy variables (D_j, where $j = 1, 2, 3, 4$), inputs (X_k, where $k = 3, 4, 5, 6$) are more correctly expressed as max (X_k, $1-D_j$). Following Battese et al. (1996), elasticities of production for other inputs are assumed to be the same for farmers using fertilizer, organic manure, feed, and other input as those not using these inputs.

[6] Perhaps, it would be more appropriate to conduct separate frontier analysis for each province instead of using dummy variables. Unfortunately, the available sample size was limited to perform the analysis by province, especially for extensive farms. Northwest Frontier Province was treated as a reference province.

Table 13.4 Summary statistics of variables involved in the stochastic production frontier and technical inefficiency model for carp pond culture in Pakistan

Variable	Semi-intensive/intensive (n = 378) Mean	SD	Extensive (n = 224) Mean	SD
Output (kg/ha)	3,060	1,526	2,639	1,516
Inputs				
Seed (no. of pieces/ha)	4,726	3,995	4,415	2,138
Labor (days/ha)	618	688	506	526
Fertilizer (kg/ha)	512	589	362	539
Manure (kg/ha)	5,021	10,887	5,076	10,104
Feed (kg/ha)	3,751	6,646	69	525
Other input ($/ha)	400	422	234	315
Fertilizer dummy (0 or 1)	0.79	0.41	0.54	0.50
Manure dummy (0 or 1)	0.39	0.49	0.33	0.47
Feed dummy (0 or 1)	0.99	0.09	0.04	0.19
Other input dummy (0 or 1)	0.99	0.11	0.95	0.23
Farm-specific				
Primary activity (0 or 1)	0.61	0.49	0.70	0.46
Experience (years)	4.99	3.86	6.49	4.15
Pond area (ha)	1.98	4.48	2.75	5.78
Fish management index	1.57	0.96	1.27	0.87
Water management index	3.48	1.68	2.79	1.98
Feed management index	1.54	1.32	0.45	0.61
Punjab (0 or 1)	0.48	0.50	0.46	0.50
Sindh (0 or 1)	0.21	0.41	0.48	0.50

n denotes the number of observations involved in estimating the stochastic frontier model
SD stands for standard deviation.

Among farm-specific variables, adopting carp culture as a primary activity is expected to have a positive impact on technical efficiency, as full-time farmers are likely to put more efforts toward carp farming and hence be more efficient than part-time farmers. Experience is generally expected to have a positive effect on production efficiency. Given the lack of empirical knowledge in the effect of farm size on productive performance of carp pond operations, it is difficult to predict total pond area's influence on technical efficiency. The adoption of regular fish, water and feed management practices is expected to have a positive effect on technical efficiency. Comparing yields and production costs across three provinces, farmers from Sindh are expected to be more efficient than those from the other two provinces. Province dummies are expected to pick up differences in water source, species stocked and other environmental factors affecting carp production.

The parameters for the stochastic production frontier model in Eqn. 13.4 and those for the technical inefficiency model in Eqn. 13.5 were estimated simultaneously using the maximum-likelihood estimation (MLE) program, FRONTIER 4.1 (Coelli, 1994), which gives the variance parameters of the likelihood function in terms of $\sigma^2 = \sigma_u^2 + \sigma_v^2$ and $\gamma = \sigma_u^2 / \sigma^2$. In terms of its value and significance, γ is an important parameter in determining the existence of a stochastic frontier; rejection of the null hypothesis, H_0: $\gamma = 0$, implies the existence of a stochastic production frontier. Similarly, $\gamma = 1$ implies that the all deviations from the frontier are due entirely to technical inefficiency (Coelli et al., 1998).

Besides the magnitude and significance of the variance parameter, γ, it is also of interest to examine various null hypotheses, such as technical inefficiency effects are not present, i.e. H_0: $\gamma = \delta_0 = \delta_1 = \ldots = \delta_8 = 0$; technical inefficiency effects follow a standard truncated-normal distribution, suggested by Stevenson (1980), i.e. H_0: $\delta_1 = \ldots = \delta_8 = 0$; and technical inefficiency effects follow a half-normal distribution originally proposed by Aigner et al. (1977), i.e. H_0: $\delta_0 = \delta_1 = \ldots = \delta_8 = 0$. These and other relevant null hypotheses can be tested using the generalized likelihood-ratio statistic, λ, given by

$$\lambda = -2[\mathrm{Ln}\{L(H_0)\} - \mathrm{Ln}\{L(H_1)\}] \tag{13.6}$$

where $L(H_0)$ and $L(H_1)$ denote the values of likelihood function under the null (H_0) and alternative (H_1) hypotheses, respectively [if the given null hypothesis is true, λ has approximately a χ^2 distribution or mixed χ^2 distribution when the null hypothesis involves $\gamma = 0$ (Coelli, 1995b)].

13.5 Results

The maximum-likelihood estimates of the parameters for the stochastic production frontier model and those for the technical inefficiency model for semi-intensive/intensive and extensive carp production systems in Pakistan are presented in Table 13.5. Most of the slope coefficients or output elasticities of inputs for both semi-intensive/intensive and extensive carp production systems were positive, with the exception of the chemical fertilizer coefficient for both farm types and feed coefficient for extensive farms. However, none of these negative coefficients were significant at the 0.05 level. The coefficients associated with labor and seed were highly significant for both farm types, while the coefficient for organic manure was significant for semi-intensive/intensive farms only. For both systems, output elasticity of inputs was highest for seed, followed by labor and organic manure.

Under both systems, the estimated values of variance parameter, γ, were quite high and strongly significant, suggesting that technical inefficiency effects are significant in explaining the levels and variations in carp production in Pakistan. Furthermore, as shown in Table 13.6, the null hypothesis that technical inefficiency effects are not present was also rejected for both systems. Thus, the traditional average (OLS) production function is not an appropriate representation of the sample data. Similarly, the rejection of the second and third null hypotheses suggest that, given the stochastic frontier with the model for technical inefficiency effects (Eqns. 13.4 and 13.5), the standard stochastic error component model is also not appropriate for both half- and truncated-normal distributions of the technical inefficiency effects. Finally, the null hypothesis of the absence of inter-province differences in technical inefficiencies in carp production in Pakistan was also rejected (Table 13.6).

Table 13.5 Maximum-likelihood estimates of stochastic production frontier and technical inefficiency models for carp production in Pakistan

		Semi-intensive/intensive		Extensive system	
	Parameter	Coefficient	T-ratio	Coefficient	T-ratio
Production frontier					
Constant	β_0	4.670	9.26	5.202	5.83
Ln (Seed)	β_1	0.314	6.08	0.343	3.39
Ln (Labor)	β_2	0.129	5.40	0.082	2.26
Ln (Chemical fertilizer)	β_3	-0.050	-1.70	-0.038	-0.65
Ln (Organic manure)	β_4	0.060	2.10	0.063	1.07
Ln (Feed)	β_5	0.023	0.80	-0.133	-1.04
Ln (Other input)	β_6	-0.008	-0.43	-0.003	-0.08
Fertilizer dummy	β_7	0.359	1.99	0.006	0.02
Manure dummy	β_8	-0.492	-1.97	-0.728	-1.31
Feed dummy	β_9	0.031	0.09	0.361	0.39
Other input dummy	β_{10}	0.122	0.75	0.116	0.58
Technical inefficiency model					
Constant	δ_0	1.053	4.59	1.805	3.63
Aquaculture primary activity	δ_1	0.217	1.62	-0.018	-0.06
Experience	δ_2	0.006	0.41	-0.020	-0.68
Pond area	δ_3	0.034	2.36	0.043	2.09
Fish management index	δ_4	-0.080	-1.20	-0.032	-0.27
Water management index	δ_5	-0.208	-3.86	-0.392	-3.54
Feed management index	δ_6	-0.213	-2.35	-0.423	-1.64
Punjab	δ_7	0.331	2.04	0.104	0.24
Sindh	δ_8	-2.547	-3.61	-1.007	-1.97
Variance parameters					
	σ^2	0.359	4.75	0.674	3.60
	γ	0.826	18.09	0.930	30.22
Log (likelihood)		-183.09		-164.28	
Mean of exp –(U_i)		0.673		0.561	

T-ratios are asymptotic t-ratios.

The estimated technical efficiency scores for semi-intensive/intensive farms ranged from 0.091 to 0.941, with a sample mean of 0.673, while those for extensive farms varied from 0.040 to 0.937, with a mean score of 0.561. Thus, the results indicate that semi-intensive/intensive farms are technically more efficient compared to extensive farms, relative to their respective technologies. The frequency distributions of the estimated technical efficiencies for both semi-intensive/intensive and extensive farms are depicted in Fig. 13.1. The frequency distributions for the two systems were quite different. For example, the majority of semi-intensive/intensive farms (~ 52%) had a technical efficiency score of 0.70 and above, while the majority of extensive farms (also ~52%) had an efficiency score of 0.60 and below.

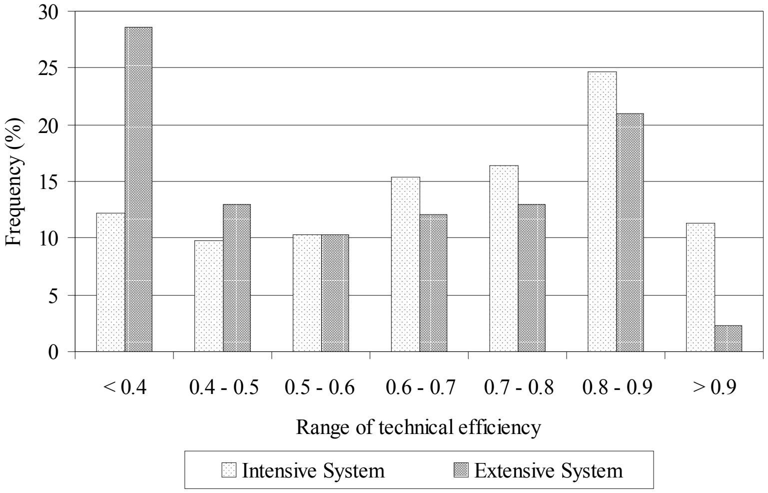

Fig. 13.1 Frequency distribution of technical efficiency estimates for carp producers in Pakistan

Table 13.6 Generalized likelihood-ratio tests of hypotheses involving some estimates of the stochastic production frontier and technical inefficiency models for carp pond culture in Pakistan

Null hypothesis (H_0)	Log (likelihood)	Test statistic (λ)	Critical value ($\chi^2_{0.95}$)	Decision
$\gamma = \delta_0 = \delta_1 = \ldots = \delta_8 = 0$				
Semi-intensive/intensive	-265.03	163.88	17.67	Reject Ho
Extensive	-214.77	100.99	17.67	Reject Ho
$\delta_0 = \delta_1 = \ldots = \delta_8 = 0$				
Semi-intensive/intensive	-247.21	128.25	16.92	Reject Ho
Extensive	-198.75	68.94	16.92	Reject Ho
$\delta_1 = \delta_2 = \ldots = \delta_8 = 0$				
Semi-intensive/intensive	-239.36	112.54	15.51	Reject Ho
Extensive	-197.00	65.45	15.51	Reject Ho
$\delta_7 = \delta_8 = 0$				
Semi-intensive/intensive	-227.01	87.84	5.99	Reject Ho
Extensive	-171.83	15.11	5.99	Reject Ho

The correct critical value for the first and null hypothesis involving □□is obtained from Table 1 of Kodde and Palm (1986, p. 1246) for 10 degrees of freedom.

Given the data and model specifications, the results indicate that the farm-specific variables included in the technical inefficiency model contribute significantly, both as a group and several of them individually, to the explanation of the technical inefficiencies of both semi-intensive/intensive and extensive sample carp farms in Pakistan. Among these variables, as expected the adoption of recommended fish, water and feed management and monitoring practices had a positive impact on technical efficiency, particularly among the semi-intensive/intensive farms. The coefficients associated with the choice of aquaculture as a primary activity as well as experience in carp farming had expected signs on extensive farms and unexpected signs on semi-intensive/intensive farms. However, none of these coefficients were significant. Total pond area had a negative impact on technical efficiency under both systems.

The interprovince differences in technical efficiencies of the sample carp farms were significant, with farmers from Sindh Province being, as expected, technically more efficient than those from the other two provinces, especially those from Northwest Frontier Province. For example, the mean technical efficiency for semi-intensive/intensive farms was 0.881 in Sindh compared to 0.586 for those in Northwest Frontier Province. Similarly, the mean technical efficiency of extensive farms was, respectively, 0.583 and 0.467. Higher technical efficiency in Sindh than in Northwest Frontier Province can partly be attributed to less labor use and higher proportion of farms using nutrient rich irrigation water in the former than in the latter Province.

13.6 Study implications

The results indicate that there are substantial inefficiencies in carp production in Pakistan. Given the available technology and resources, the sample semi-intensive/intensive farms could, on average, improve their production from about 3.0 to 4.5 mt/ha by operating at full technical efficiency levels. Similarly, extensive farms could increase their productivity from about 2.6 to 4.6 mt/ha. These efficiency gains could mainly come from the improvement in the adoption of recommended fish, water and feed management practices. Therefore, further efforts are needed to improve and strengthen the aquacultural extension services. As indicated by positive and significant output elasticity coefficients for seed, both semi-intensive/intensive and extensive farms have substantial potential for increasing carp production by increasing stocking rate.

Higher technical efficiency levels as well as higher yields on semi-intensive/intensive than on extensive farms suggest that there is a good potential to enhance productivity of extensive farms by increasing the level of intensity of carp culture (i.e. shifting from extensive to semi-intensive or intensive system). However, it is also interesting to note that although the actual production of semi-intensive/intensive farms is significantly higher than that of extensive farms, the frontier production (i.e. potential production at full technical efficiency) is higher, but not significantly so, on extensive farms. This indicates that farmers in extensive farms could, in fact, become as productive as those in semi-intensive/intensive system by adopting the technologies of efficient extensive farms in the sample.

Although Sindh Province may have inherent comparative advantage for its superior performance in terms of better access to nutrient-rich irrigation water for fish ponds, the other two provinces still could benefit from its experience and knowledge in carp production. For example, farmers on Sindh primarily stocked Indian carp while their counterparts in other two provinces stocked both Indian and Chinese carp. Numerous factors, such as consumer preferences and environmental conditions may have contributed to the difference in species selection across provinces, but it may still be worth conducting research on the effect of replacing Chinese carp with Indian carp on productivity of carp culture in Punjab and North-west Frontier Province.

Besides the possibility of exchange of experience and expertise among the provinces within the country, there is a good potential for transfer of technologies from the other NACA member countries in the region, such as China and India, especially for the improvement of semi-intensive/intensive systems. For example, semi-intensive/intensive farms on India's Punjab were found to more efficient and hence more productive than their counterparts in Pakistan's Punjab (Sharma and Leung, 1998).

13.7 Conclusions

This study examined technical efficiencies of semi-intensive/intensive and extensive carp producers in Pakistan. The production data and relevant farm-specific variables collected from the samples of semi-intensive/intensive and extensive farms were analyzed separately using a Cobb-Douglas stochastic production frontier, including a model for technical inefficiency effects.

The results showed the presence of significant technical inefficiencies among the sample carp farms in Pakistan, which could be explained in terms of various farm-specific variables, such as adoption of management practices, total pond area and farm location. The adoption of recommended fish, water and feed management practices had a positive impact on technical efficiency. Pond area had a negative influence on the performance of the sample farms both under semi-intensive/intensive and extensive systems.

The mean technical efficiencies for semi-intensive/intensive and extensive farms in Pakistan were estimated to be 0.673 and 0.561, respectively. By operating at full technical efficiency levels the sample semi-intensive/intensive farms could, on average, improve their carp production from 3.0 to 4.5 mt/ha. Similarly, extensive farms could increase their production from about 2.6 to 4.6 mt/ha. Besides increasing technical efficiency, the results showed that carp producers also have potential for increasing production by increasing seed stocking rates. Farmers from Sindh were technically more efficient than those from the other two provinces, especially North-west Frontier Province, suggesting the possibility of exchange of experience in carp culture among the provinces within the country. Pakistan may also benefit from the experience and expertise of other countries in the region, especially in developing semi-intensive/intensive carp culture.

Besides expanding production area, there is substantial potential for increasing the level of carp production in Pakistan also by raising production per unit area. The results indicated that increased intensification and improvement in technical efficiency by following regular fish, water and feed management and monitoring activities could raise productivity. In view of the law of diminishing marginal returns and increased environmental problems associated with more intensive use of inputs, the potential for output growth by increasing the use of inputs will not continue for ever. Therefore, in the long run, output growth must come from the improvement in technical efficiency.

Due to data constraints, this study is limited to analyzing technical efficiency only. Research on other aspects of productive efficiencies, especially allocative and economic efficiencies can be carried out if appropriate data is collected in the future. Furthermore, the present study is based on data from a single production period; a follow up and continuing data collection is recommended to examine technical efficiency and hence sustainability of aquaculture over time.

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Chapter 14

Technical efficiency of carp production in India: a stochastic frontier production function analysis

Khem R. Sharma and PingSun Leung

Abstract
This paper examines the levels and determinants of technical efficiency in carp pond culture in India. The stochastic production frontier technique involving the model for technical inefficiency effects is applied separately to the samples of semi-intensive/intensive and extensive carp producers interviewed during 1994/95. The results showed significant technical inefficiencies in carp production in India, especially among the extensive farms. The mean technical efficiencies for semi-intensive/intensive and extensive sample farms were estimated to be 0.805 and 0.658, respectively. By operating at full technical efficiency levels, the semi-intensive/intensive farms could, on average, increase their production from about 3.4 mt/ha to 4.1 mt/ha. Similarly, the extensive farms could increase their production from 1.3 mt/ha to 1.9 mt/ha. Much of these efficiency gains would come from the improvement in the adoption of recommended fish, water and feed management and monitoring practices. Besides expanding production area, the results indicated several other possibilities of increasing carp production in India by increasing yields per hectare, such as: (1) increased intensification of carp culture (i.e. moving from extensive to semi-intensive or intensive system), (2) improvement in technical efficiency at the farm-level, and (3) technological progress. However, the realization of these potentials will depend on continuous efforts of the government in ensuring adequate supply of inputs, technology transfer and development, and adequate provision of research, extension, and credit services in aquaculture.

14.1 Introduction

Despite being a relatively minor contributor to the overall economy, aquaculture has become an increasingly important sector in India in terms of its potential for contributing to food security and nutrition, employment, foreign exchange earnings and improvements in socio-economic status of rural communities. The modern aquaculture in India started with the establishment of fish farmers' development agencies in the early 1970s. In 1995, the country produced 1.6 million metric tonnes (mt) or 5.8 % of global aquaculture production.

In fact, India is the second largest aquaculture producing country in the world after China. Aquaculture accounts for about one-third of total fishery production and more than two-thirds of inland fish production in the country. In view of limited prospects for significant growth of capture fisheries production and huge potential for output growth of aquaculture, in recent years this sector is being given the highest priority in India's development plan. As a result, during 1984 to 1995, aquaculture production increased by 215.5% against 36.3% for crops and livestock (FAO, 1997, 1998).

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Despite such rapid growth in aquaculture production in recent years, a number of problems still continue to hinder the development of this sector in India. These include inadequate supply of quality fish seed, stagnant fish prices, dependence on traditional practices, lack of cost effective feed, inadequate extension support, limited opportunities for institutional credit and poor infrastructure and marketing facilities (Kumar, 1996). Aquaculture, similar to many other farming activities, is dependent upon the use of natural resources, such as water, land, and seed. As farmers continue to intensify their efforts towards aquaculture, the demand for these resources would rise, leading to increased competition for limited resources and negative environmental impacts. These problems can be detrimental to the long-term economic viability and sustainability of the production system and environment.

Despite these problems to be addressed, India has a huge future growth potential for aquaculture production for several reasons. First, the increasing demand for food fish will require more production from aquaculture as the output growth from capture fisheries is limited.

Secondly, there is potential for increasing productivity, i.e. improvement in technical efficiency at the farm level and technological progress at the national and regional levels such as development of new technologies and genetic improvement of fish stocks.

Thirdly, there is substantial potential for expanding production area. For example, the country has about 2.2 million ha of freshwater ponds/tanks, of which only 0.325 million ha have been developed for aquaculture. Similarly, of the 0.9 million ha of brackish water areas suitable for aquaculture only 70,700 ha have been developed (Kumar, 1996). The country also possesses other vast areas suitable for aquaculture, such as low-lying wetlands, canals, lakes, reservoirs and rivers. Fourthly, the country is endowed with vast and highly diversified fish species, which are well known for their culture potential in Asia. So far, only a few species are cultured commercially. Farming of other species has yet to be realized.

Aquaculture in India is dominated by freshwater fish, including Indian major carp, Chinese carp, and other minor species. These are mainly produced in ponds, often integrated with crops and livestock. Carp do have a number of advantages over other fish species. First, carp can use feeds with moderate protein and fishmeal content. Secondly, they can be reared in ecologically efficient and environmentally benign polyculture systems that make optimum use of the natural productivity of ponds and water bodies where they are stocked. Thirdly, because of a huge and growing consumer base, traditions and relatively low prices, carp have good markets in Asian countries. Finally, carp culture has lower production costs, less input requirements, fewer environmental problems and smaller risks for disease outbreaks compared to shrimp culture (ADB/NACA, 1996).

If aquaculture is to play a vital role in ensuring future fish availability for food security and nutrition of the country’s huge and growing population, this sector has to develop and grow in an economically viable and environmentally sustainable fashion. Among many other factors, increasing the efficiency of resource use and productivity at the farm level is indispensable to sustainable aquaculture (FAO, 1997). Improved water management, better feeding strategies, genetic improvement of stocks and improved health management are some of the ways to enhance productive efficiency at the farm level. Accordingly, measuring technical efficiency at the farm level, identifying important factors associated with the efficient production system and assessing potential for and sources of future improvements are essential for developing sustainable aquaculture. Instead of increasing the use of inputs to increase production, efforts should be made toward output growth through improved technical efficiency, i.e. producing more by utilizing existing inputs more efficiently.

Against this background, the main objective of this study is to examine the levels and determinants of farm-level technical efficiencies of a sample of carp producers in India. Technical efficiency measures the producer's ability to achieve maximum output from a given set of inputs and technology. Despite a large number of efficiency studies being applied to Indian agriculture, to our knowledge, no study has been conducted to examine the production efficiency in carp production. A Cobb-Douglas stochastic frontier production function involving the Battese and Coelli (1995) model for technical inefficiency effects is applied separately to the samples of semi-intensive/intensive and extensive carp pond operations. The proposed model is statistically superior to a traditional two-step procedure in analyzing the effects of various farm-specific factors on production efficiency.

14.2 Materials and methods

14.2.1 Data sources

The data for this study came from the Network of Aquaculture Centers in Asia-Pacific (NACA) Aquaculture Sustainability and Environment Survey of Indian carp farms, conducted during 1994/95. The carp survey was carried out in four states, namely Andhra Pradesh, Punjab, Uttar Pradesh and West Bengal covering a total of 1,004 farms. NACA (1994) provides details for sampling and data collection procedures as well as the instrument employed in the survey. Depending upon the levels of inputs used as well as yields per hectare, the sample carp farms were broadly classified as semi-intensive/intensive and extensive. Extensive farms applied fewer inputs (especially feed, fertilizer and stocking density) and produced smaller yields compared to semi-intensive/intensive ones. Due to a lack of clear-cut distinction between the semi-intensive and intensive systems, these two were combined into one category.

The survey covered different types of carp production systems, including pond culture, cage/pen culture and rice-fish culture. Because of limited observations in the sample, cage/pen as well as rice-fish systems were excluded in this study. A sizable proportion of the sample farms were dropped due to missing or incomplete data on production area, output and farm type. Farms growing fresh water prawn (*Machrobrachium* spp.) were also excluded from the cost-return and efficiency analyses because this study is concerned with carp culture only. Farms with no data on seed stocking, culture period and labor use were also excluded from the cost and return and efficiency analyses. Accordingly, the sample size considered to describe the general characteristics of the survey farms (such as farm size, water source, land use and species stocked) was 906, including 786 semi-intensive/intensive farms and 120 extensive farms. The cost-return and efficiency analyses were based on 732 semi-intensive/intensive and 85 extensive farms. Because of these reasons, some of the results presented in this study may be slightly different from those published elsewhere (e.g., ADB/NACA, 1996).

14.2.2 Sample characteristics

The average pond area for the sample farms was 2.2 ha, with extensive farms being bigger than semi-intensive/intensive farms. On average, the carp farms from Andhra Pradesh were the largest and those from Uttar Pradesh were the smallest. Aquaculture was the primary activity for the 73% of the farms studied. Similarly, the proportion of farms practicing integrated farming was 24%, of which the majority integrated fish with livestock. The principal forms of land use prior to aquaculture included wetland/swamp (46%), rice farming (28%) and low-yielding agricultural land (10%). The main sources of water to fish ponds included rainwater (41%), tube/shallow wells (34%) and irrigation canals (18%). The most frequently reported form of land ownership was private (56%), followed by leasing (38%). These proportions were similar for both semi-intensive/intensive and extensive farms.

Almost all of the sample farms practiced polyculture of several carp species and a few non-carp species (such as catfish and tilapia). Species cultured by the majority of sample farms included three indigenous carp, such asrohu or *Labeo rohita* (99%), catla or *Catla catla* (99%), and mrigal or *Cirrhinus mrigala* (86%). A sizable proportion of sample farms also cultured Chinese carp, including common carp or *Cyprinus carpio (*49%)*,* silver carp or *Hypophthalmichthys molitrix* (42%), and grass carp or *Ctenopharyngodon idella* (39%). Stocking density was about 1.5 pieces/m^2, similar for the two systems. On average, fish were harvested in 325 days when they weighed about 700 g, with these values being somewhat smaller for extensive farms.

The proportion of farms using supplementary diets was 95% among semi-intensive/intensive and 73% for extensive farms. Various fish, water and feed management and monitoring activities practiced by the sample carp farms are summarized in Table 14.1. Under fish management and monitoring activities, multiple stocking and multiple harvesting were the most frequently reported practices. Only a small proportion of farms performed a regular on-farm health analysis and monitored the stocking ratio of filter-feeding and forage-feeding species. Except for adding chemical and organic fertilizers to improve pond water quality by the majority of semi-intensive/intensive farms, the use of other water management and quality monitoring practices was also limited, especially on extensive farms.

Similarly, except for supplementary diets, only a small number of farms followed recommended feed and cost management activities. The average yields for semi-intensive/intensive and extensive farms were 3,415 kg/ha and 1,267 kg/ha, respectively. The average yields of semi-intensive/intensive farms showed a wide variation, ranging from 2,717 kg/ha in Uttar Pradesh to 4,623 kg/ha in Andhra Pradesh, while those for extensive farms were quite similar across states. The average net margin per farm was estimated to be US$ 2,227 (IRs 69,583) and $672 (IRs 21,006), respectively. Similarly, on per hectare terms, net margins for semi-intensive/intensive and extensive systems were respectively $1,101 (IRs 34,418) and $293 (IRs 9,142), with semi-intensive/intensive farms being significantly more profitable than extensive farms.

Table 14.1 Adoption of various management and monitoring practices by Indian carp farmers

Management and monitoring practices	Semi-intensive/ intensive (n = 786)	Extensive (n = 120)
Fish management and monitoring practices	Percent	
Manipulate filter-feeding/foraging ratio	16.3	25.8
Continuous/multiple stocking	58.8	46.7
Continuous/multiple harvesting	61.2	57.5
Culture yearling in production pond as seed for next crop	17.8	3.3
Daily observation of carp behavior	59.9	22.5
Regular on farm health analysis	21.6	14.2
Water quality Management and monitoring practices		
Mechanical filtration/screening of water inflow	24.6	5.8
Water purification	24.0	27.5
Add chemical fertilizer to increase pond water fertility	76.2	19.2
Add organic fertilizer to increase pond water fertility	83.7	51.7
Remove weeds	26.3	20.8
Water level management during culture	8.3	1.7
pH/alkalinity	43.9	10.0
Dissolved oxygen level	8.3	1.7
Nutrients (N and/or P)	2.2	0.0
Water color and turbidity	39.8	20.0
Check pond sedimentation	19.6	10.8
Feed and cost management practices		
Supplementary feeding	94.7	73.3
Feeding enclosure for floating feeds	26.2	5.0
Submerged, but liftable feeding tray	19.5	14.2
Daily check of feeding/left-over	24.0	1.7
Daily removal of left-over	10.3	0.0
Regular feed conversion ratio calculation	3.6	0.0
Regular production cost analysis	3.4	0.8

14.2.3 The empirical model

Following Aigner et al. (1977) and Meeusen and van den Broeck (1977), the stochastic production frontier for sample carp producers in India can be specified as follows:

$$\mathrm{Ln}Y_i = \beta_0 + \sum_{k=1}^{6} \beta_k \mathrm{Ln}X_{ki} + \beta_7 D_{1i} + \beta_8 D_{2i} + \beta_9 D_{3i} + \beta_{10} D_{4i} + V_i - U_i \qquad (14.1)$$

where subscript i refers to the i-th farm in the sample; Ln represents the natural logarithm; Y is output variable and Xs and Ds are input and related variables, defined in Table 14.2 and summarized in Table 14.3; βs are unknown parameters to be estimated; V_i is an independently and identically distributed $N(0, \sigma_v^2)$ random error;

and the U_i is a non-negative random variable, associated with technical inefficiency in production, which is assumed to be independently and identically distributed and truncations (at zero) of the normal distribution with mean, μ_i, and variance, σ_u^2 ($|N(\mu_i, \sigma_u^2)|$). Following Battese and Coelli (1995), the technical inefficiency distribution parameter, μ_i is defined as:

$$\mu_i = \delta_0 + \sum_{m=1}^{10} \delta_m Z_{mi} \tag{14.2}$$

where Zs are various farm-specific variables, defined in Table 14.2 and summarized in Table 14.3 and δs are unknown parameters to be estimated. Since the dependent variable in Eqn. 14.2 is defined in terms of technical inefficiency, a farm-specific variable associated with the negative (positive) coefficient will have a positive (negative) impact on technical efficiency.

Among farm-specific variables, adopting carp culture as a primary activity is expected to have a positive impact on technical efficiency as full-time farmers are likely to put more efforts toward carp farming and hence be more efficient than part-time farmers. More experienced and owner-operated farms are expected to be more efficient than less experienced and tenant-operated ones. Given the lack of empirical knowledge in the effect of farm size on productive performance of carp pond operations, it is difficult to predict total pond area's influence on technical efficiency. The adoption of regular fish, water and feed management practices is expected to have a positive effect on technical efficiency. State dummies are expected to pick up effects due to differences in water source, species stocked and other environmental factors affecting carp production. The technical efficiency of the i-th sample farm (TE_i) is given as:

$$TE_i = \exp(-U_i) \tag{14.3}$$

The prediction of technical efficiencies is based on the conditional expectation of expression in Eqn. 14.3, given the model specifications (Battese and Coelli, 1988). The parameters for the stochastic production frontier model in Eqn. 14.1 and those for the technical inefficiency model in Eqn. 14.2 were estimated simultaneously using the maximum-likelihood estimation (MLE) program, FRONTIER 4.1 (Coelli, 1994), which estimates the variance parameters of the likelihood function in terms of $\sigma^2 = \sigma_u^2 + \sigma_v^2$ and $\gamma = \sigma_u^2 / \sigma^2$.

Besides the magnitude and significance of the variance parameter, γ, it is also of interest to examine various null hypotheses, such as technical inefficiency effects are not present, i.e. $\gamma = \delta_0 = \delta_1 = \ldots = \delta_{10} = 0$; technical inefficiency effects follow a standard truncated-normal distribution, suggested by Stevenson (1980), i.e. $\delta_1 = \ldots = \delta_{10} = 0$; and technical inefficiency effects follow a half-normal distribution originally proposed by Aigner et al. (1977), i.e. $\delta_0 = \delta_1 = \ldots = \delta_{10} = 0$. These and other relevant null hypotheses can be tested using the generalized likelihood-ratio statistic, λ, given by

$$\lambda = -2[\mathrm{Ln}\{L(H_0)\} - \mathrm{Ln}\{L(H_1)\}] \tag{14.4}$$

where $L(H_0)$ and $L(H_1)$ denote the values of likelihood function under the null (H_0) and alternative (H_1) hypotheses, respectively. If the given null hypothesis is true, λ has approximately χ^2 distribution or mixed χ^2 distribution when the null hypothesis involves $\gamma = 0$ (Coelli, 1995).

14.3 Results

The maximum-likelihood estimates of the parameters for the stochastic production frontier model and those for the technical inefficiency model for semi-intensive/intensive and extensive carp production systems in India are presented in Table 14.4. All slope coefficients or output elasticities of inputs for both semi-intensive/intensive and extensive farms had expected signs. Except for labor, all slope coefficients for the semi-intensive/intensive farms were highly significant ($p \leq 0.01$). For extensive farms, the coefficient of seed was highly significant ($p \leq 0.01$) and that of organic manure was moderately significant ($p \leq 0.10$), while the coefficients associated with rest of the inputs were not significant. Given the low levels of feed and fertilizer use, insignificant coefficients for these inputs for the extensive farms are not unexpected. Comparing the two systems, feed had the highest elasticity for semi-intensive/intensive farms, while seed had the highest elasticity for extensive farms. Interestingly, although the stocking densities were very similar under the two systems output elasticity of seed was estimated to be much higher for extensive farms than semi-intensive/intensive ones.

Under the both systems, the estimated value of variance parameter, γ, was close to 1 and highly significant, suggesting that technical inefficiency effects are significant in explaining the levels and variations in carp production in India. Furthermore, as shown in Table 14.5, the first null hypothesis that technical inefficiency effects are not present in carp production was also rejected for both systems. Thus, the traditional average (OLS) production function is not an appropriate representation of the sample data. Similarly, the rejection of the second and third null hypotheses for both systems suggests that, given the stochastic frontier with the model for technical inefficiency effects (Eqns. 14.1 and 14.2), the standard stochastic error component model is not appropriate for both half-normal and truncated-normal distributions for the technical inefficiency effects. Finally, the null hypothesis of the absence of inter-state differences in technical inefficiencies in carp production was rejected for semi-intensive/intensive farms but not for extensive ones (Table 14.5).

The estimated technical efficiency scores for semi-intensive/intensive farms ranged from 0.146 to 0.959, with a sample mean of 0.805. Similarly, the technical efficiency scores for the extensive farms varied from 0.147 to 0.951, with a mean score of 0.658. Thus, the results indicate that semi-intensive/intensive farms are technically more efficient compared to extensive ones, relative to their respective technologies. The frequency distributions of the technical efficiency estimates are presented in Fig. 14.1. These distributions were quite different for the two systems. For example, the proportions of farms with an efficiency score of less than 0.70 were significantly higher in extensive system than in the semi-intensive/intensive system, while opposite was the case with efficiency score of greater than 0.70.

Table 14.2 Description of output, input, and farm-specific variables involved in the stochastic production frontier and technical inefficiency model for carp pond culture in India

Variables	Description
Output (Y)	Aggregated quantity of fish production (in kg/ha)[1]
Inputs	
Seed (X_1)	Total number of fish seeds or fingerlings stocked (in no. of pieces/ha)[2]
Labor (X_2)	Hired plus family labor used in carp production (in person days/ha)
Chemical fertilizer (X_3)	Amount of chemical fertilizers used in carp culture (in kg/ha)
Organic manure (X_4)	Amount of organic manure used in carp production (in kg/ha)
Feed (X_5)	Total dry weight of formulated feed, feed ingredients, and green feed applied in carp ponds (in kg/ha)[3]
Other input (X_6)	Other inputs (chemicals, water, maintenance, fuel, etc.) and depreciation on fish pond, housing, and machinery used in carp culture (in US$/ha)[4]
Fertilizer dummy (D_1)	Value 1 if chemical fertilizer was used in carp culture, 0 otherwise[5]
Manure dummy (D_2)	Value 1 if organic manure was used in carp culture, 0 otherwise[5]
Feed dummy (D_3)	Value 1 if feed was used in carp culture, 0 otherwise[5]
Other input dummy (D_4)	Value 1 if other input is positive, 0 otherwise[5]
Farm-specific	
Primary activity (Z_1)	Value 1 if carp culture is undertaken as a primary activity, 0 otherwise
Farmer's experience (Z_2)	Number of years the farmer has been engaged in carp production
Owner-operated (Z_3)	Value 1 if the farm is owner-operated, 0 otherwise
Pond area (Z_4)	Total area of fish pond in hectares
Fish management index (Z_5)	Total number of fish management and monitoring practices used
Water management index (Z_6)	Total number of water management and monitoring practices used
Feed management index (Z_7)	Total number of feed management and monitoring practices used
Andhra Pradesh (Z_8)	Value 1 if the sample farm is from Andhra Pradesh, 0 otherwise[6]
West Bengal (Z_9)	Value 1 if the sample farm is from West Bengal, 0 otherwise[6]
Punjab (Z_{10})	Value 1 if the sample farm is from Punjab, 0 otherwise[6]

[1] It should be noted that the total quantity of fish production is not an ideal measure of output variable in the production frontier analysis due to the multi-output production structure of fish polyculture. A more appropriate measure would be a geometric mean or quantity index based on revenue shares or prices for different fish species. Unfortunately, information on production, revenue and prices by species to compute the geometric mean or quantity index was not available.

[2] In view of possible variation in seed sizes, it would have been ideal to measure the seed variable in weight (such as kg/ha). However, direct information on seed weight was not available. One way of accounting for size variations would be to convert the number of seeds into weight or to normalize to a standard size using a body length-weight relationship. However, both of these procedures are only approximate and extremely sensitive to slight measurement errors. So, actual number of seeds stocked is used as a measure of seed input.

[3] Following Tan (1970) one kilogram of green feed was assumed to be equivalent to 0.2 kg of dry feed.

[4] In estimating depreciation, the economic life of pond and building structures was assumed to be 20 years and that of farm machinery and equipment to be 15 years.

[5] As shown by Battese (1996), without these dummy variables, the estimators for output elasticities of fertilizer, organic manure, feed, and other input obtained from the Cobb-Douglas production function will be biased. With these dummies, the k-th input can be more correctly expressed as max $(1-D_k, X_k)$, for $k > 2$. Following Battese et al. (1996), elasticities of production for other inputs are assumed to be same for farmers using fertilizer, organic manure, feed, and other input as those not using these inputs.

[6] It would be more appropriate to conduct separate frontier analysis for each province. Unfortunately, the sample size was limited for separate analyses, especially for extensive farms. However, the combined approach used in this paper allows for the inter-state comparison of efficiency levels. Uttar Pradesh was treated as the reference province.

Table 14.3 Summary statistics of variables involved in the stochastic production frontier and technical inefficiency models for carp pond culture in India

	Semi-intensive/intensive (n = 732)		Extensive (n = 85)	
Variable	Mean	Standard deviation	Mean	Standard deviation
Output (kg/ha)	3,415	1,492	1,267	552
Inputs				
Seed (no. of pieces/ha)	14,978	14,656	16,023	17,251
Labor (days/ha)	349	416	399	511
Fertilizer (kg/ha)	606	973	131	433
Manure (kg/ha)	9,174	14,341	4,143	5,611
Feed (kg/ha)	4,654	6,076	645	654
Other input ($/ha)	222	202	118	174
Fertilizer dummy (0 or 1)	0.75	0.43	0.31	0.46
Manure dummy (0 or 1)	0.83	0.38	0.62	0.49
Feed dummy (0 or 1)	0.88	0.33	0.72	0.45
Other input dummy (0 or 1)	0.91	0.29	0.84	0.37
Farm-specific				
Primary activity (0 or 1)	0.75	0.43	0.61	0.49
Experience (years)	5.87	4.19	6.01	4.73
Owner-operated (0 or 1)	0.59	0.49	0.44	0.50
Pond area (ha)	2.00	2.61	2.35	5.35
Fish management index	2.38	1.21	1.89	1.42
Water management index	3.96	1.89	2.07	1.82
Feed management index	1.87	1.07	1.05	0.69
Andhra Pradesh (0 or 1)	0.27	0.45	0.25	0.43
West Bengal (0 or 1)	0.30	0.46	0.44	0.50
Punjab (0 or 1)	0.15	0.36	-	-

Note that the sample did not have extensive farms in Punjab.

Given the data and model specifications, the results indicate that the farm-specific variables included in the technical inefficiency model contribute significantly, both as a group and several of them individually, to the explanation of the technical inefficiencies among the sample carp producers. Among these variables, except for fish management practice for extensive farms, the adoption of recommended fish, water and feed management practices had expected positive impact on technical efficiency. These impacts were particularly notable on semi-intensive/intensive farms. As expected, the choice of aquaculture as a primary activity had a positive effect on technical efficiency, but it was significant at the 0.10 level on extensive farms only. Similarly, the experience showed a moderate positive effect on performance of the semi-intensive/intensive farms only. The coefficients for pond area and ownership were rather mixed, but none of these were significant at the 0.10 level.

Table 14.4 Maximum-likelihood estimates of stochastic production frontier and technical inefficiency models for carp production in India

	Parameter	Semi-intensive/intensive		Extensive	
		Coefficient	T-ratio	Coefficient	T-ratio
Stochastic production frontier					
Constant	β_0	7.336	36.50	5.990	10.18
Seed (X_1)	β_1	0.080	4.08	0.159	2.89
Labor (X_2)	β_2	0.001	0.05	0.040	0.84
Chemical fertilizer (X_3)	β_3	0.119	7.75	0.060	1.19
Organic manure (X_4)	β_4	0.038	2.89	0.098	1.69
Feed (X_5)	β_5	0.148	13.46	0.092	1.44
Other input (X_6)	β_6	0.040	3.61	0.026	0.94
Fertilizer dummy (D_1)	β_7	-0.695	-7.07	-0.132	-0.44
Manure dummy (D_2)	β_8	-0.289	-2.34	-0.751	-1.53
Feed dummy (D_3)	β_9	-1.081	-11.55	-0.714	-1.75
Other input dummy (D_4)	β_{10}	-0.196	-2.52	-0.318	-1.96
Technical inefficiency model					
Constant	δ_0	0.511	2.86	1.221	3.55
Primary activity (Z_1)	δ_1	-0.056	-0.84	-0.613	-1.91
Experience (Z_2)	δ_2	-0.018	-1.67	0.020	0.77
Owner-operated (Z_3)	δ_3	0.096	1.02	-0.307	-0.84
Pond area (Z_4)	δ_4	0.021	0.75	-0.015	-0.81
Fish management index (Z_5)	δ_5	-0.017	-0.53	0.253	2.25
Water management index (Z_6)	δ_6	-0.166	-2.78	-0.092	-0.95
Feed management index (Z_7)	δ_7	-0.410	-2.86	-0.697	-2.25
Andhra Pradesh (Z_8)	δ_8	-1.923	-2.41	-0.582	-1.30
West Bengal (Z_9)	δ_9	0.145	1.32	-0.399	-1.04
Punjab (Z_{10})	δ_{10}	0.184	1.10	-	-
Variance parameters					
	σ^2	0.401	3.44	0.273	2.54
	γ	0.871	23.28	0.916	13.05
Log (likelihood)		-165.75		-26.47	
Mean of exp $(\tilde{U}_i)$		0.805		0.658	

T-ratios are asymptotic t-ratios.

Table 14.5 Generalized likelihood-ratio tests of hypotheses involving some estimates of the stochastic production frontier and technical inefficiency models

Null hypothesis (H_0)	Log (likelihood)	Test statistic (λ)	Critical value ($\chi^2_{0.95}$)	Decision
Semi-intensive/intensive				
$\gamma = \delta_0 = \delta_1 = ... = \delta_{10} = 0^a$	-221.05	110.61	20.41	Reject Ho
$\delta_0 = \delta_1 = ... = \delta_{10} = 0$	-208.35	85.20	19.68	Reject Ho
$\delta_1 = ... = \delta_{10} = 0$	-199.29	67.09	18.31	Reject Ho
$\delta_8 = \delta_9 = \delta_{10} = 0$	-175.84	20.18	7.82	Reject Ho
Extensive				
$\gamma = \delta_0 = \delta_1 = ... = \delta_9 = 0^a$	-46.56	40.18	19.05	Reject Ho
$\delta_0 = \delta_1 = ... = \delta_9 = 0$	-39.55	26.16	18.31	Reject Ho
$\delta_1 = ... = \delta_9 = 0$	-39.34	25.74	16.92	Reject Ho
$\delta_8 = \delta_9 = 0$	-28.79	4.63	5.99	Accept Ho

[a] The correct critical value for the first hypothesis involving $\gamma = 0$ is obtained from Table 1 of Kodde and Palm (1986 p. 1246) for 12 degrees of freedom for intensive system and 11 degrees of freedom for extensive system.

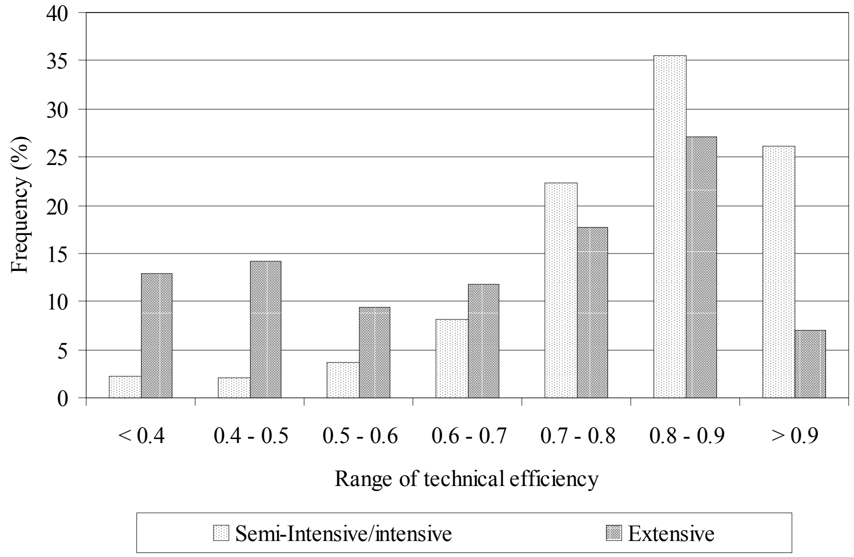

Fig. 14. 1 Frequency distributions of technical efficiency indexes for semi-intensive/intensive and extensive carp farms

For semi-intensive/intensive farms, the state-specific factors, represented by state dummies, had a significant impact on technical efficiencies, with sample farms from Andhra Pradesh being technically more efficient than those from the other three states. Among extensive farms, those from Andhra Pradesh and West Bengal tended to be more efficient than those from Uttar Pradesh. However, these differences were not significant. The mean efficiency levels by system and by state are presented in Table 14.6. Also presented in the table are potential output levels achievable by operating at the full technical efficiency levels.

Table 14.6 Average technical efficiencies and actual and potential output levels by province

	Number of farms	Technical efficiency	Actual output (kg/ha)	Potential output (kg/ha)
Semi-intensive/intensive				
Andhra Pradesh	200	0.907	4,623	5,038
Uttar Pradesh	201	0.755	2,717	3,519
West Bengal	220	0.767	2,916	3,722
Punjab	111	0.790	3,490	4,305
All	732	0.805	3,415	4,114
Extensive				
Andhra Pradesh	21	0.683	1,110	1,580
Uttar Pradesh	27	0.605	1,240	1,994
West Bengal	37	0.684	1,376	1,990
All	85	0.658	1,267	1,890

Discussion

The results showed significant technical inefficiencies among sample carp producers in India, which could be explained in terms of various farm-specific as well as state-specific variables. The mean technical efficiencies for semi-intensive/intensive and extensive farms were estimated to be 0.805 and0.658, respectively. These estimates compared fairly well with the mean technical efficiency estimates reported by several other frontier applications to Indian agriculture. For example, Datt and Joshi (1992) reported a mean technical efficiency of 0.66 in rice production in Uttar Pradesh. Using the farm-level data from 1975 to 1985, Battese and Coelli (1996) estimated the mean technical efficiencies of the farmers in Aurepalle, Kanjara, and Shirapur villages of Andhra Pradesh to be 0.747, 0.738, and 0.711, respectively. Likewise, based on the farm-level data, the mean technical efficiency for a sample of jute growers from West Bengal was reported to be 0.86 (Bhattacharya et al., 1996).

Semi-intensive/intensive producers from Andhra Pradesh were technically more efficient than those from the other three states. Estimated technical efficiency scores for extensive farms were quite similar across states. By operating at full technical efficiency levels, semi-intensive/intensive farms could, on average, increase their production from about 3.41 mt/ha to 4.1 mt/ha. Likewise, extensive farms could increase their productivity from 1.31 mt/ha to 1.91 mt/ha. Most of these gains would come from the improvement in the adoption of recommended fish, water and feed management and monitoring practices. Therefore, further efforts are needed to improve and strengthen the aquacultural extension services in the country.

Higher yields as well as higher technical efficiency levels on semi-intensive/intensive farms than extensive farms suggest that there is substantial potential for extensive producers to improve productivity by intensifying the carp culture (i.e. moving from extensive to semi-intensive or intensive system or using more seed, fertilizer and feed). However, the realization of this potential depends on the timely and adequate availability of these inputs as well as the design of appropriate policies for mitigating potential negative environmental impacts resulting from the increased input use.

Comparing actual and frontier production levels across states it is interesting to note that, for semi-intensive/intensive producers, the frontier outputs in Uttar Pradesh, West Bengal and Punjab are, on average, less than the actual per hectare production in Andhra Pradesh. Thus, the former three states may gain from the experience and expertise of the latter in improving productivity in semi-intensive/intensive carp culture. Similarly, the estimated frontier production for semi-intensive/intensive farms in India is still less than the actual per hectare production of other NACA member countries, especially China and Indonesia (ADB/NACA, 1996). This suggests that India also has room to improve productivity also by shifting its production frontier through technological progress, such as the transfer and development of new technologies and genetic improvements of fish stocks.

Besides expanding area, the results suggest substantial potential for increasing carp production in India by raising yields per hectare by increased culture intensification (i.e. using more seed, feed and fertilizer) and the improvement in technical efficiency (i.e. following regular fish, water and feed management and monitoring activities). In view of the law of diminishing marginal returns and increased environmental problems associated with more intensive use of inputs, the potential for output growth by increased intensification will be exhausted soon. Therefore, in the long run, output growth must come from improvement in technical efficiency.

The results also suggest potential for increasing productivity through the exchange of expertise and experience among the states within India as well as other NACA member countries in Asia, especially China. There is also a good potential for raising productivity through technological progress, such as development of modern technologies, improvements in genetic make-up of fish stocks and development of new fish species. However, the realization of these potentials depends greatly on continuous government efforts in ensuring timely and adequate supply of required inputs, technology transfer and development and adequate provision of research, extension and credit facilities.

Due to data constraints, this paper is limited to technical efficiency only. Research on other aspects of productive efficiencies, especially allocative and economic efficiencies can be carried out if appropriate data are collected in the future. In a polyculture system, in view of varied feeding habits and different prices among various fish species, the choice of optimum stocking composition of different fish species is of critical importance both for optimum fish growth and profit maximization. The optimum species composition can be determined in terms of allocative efficiencies. Furthermore, the present study is based on data from a single production period; follow up and continuing data collection are recommended to examine technical efficiency and hence sustainability of carp production over time.

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Chapter 15

Technical efficiency of carp pond culture in Peninsula Malaysia: an application of stochastic production frontier and technical inefficiency model

Mitsuo Iinuma, Khem R. Sharma and PingSun Leung

Abstract
Carp pond culture is an important contributor to the aquaculture industry in Peninsula Malaysia. However, carp production has decreased since the advent of new aquaculture development policies, and carp pond farms are concerned with improving productivity to sustain growing fish demand while staying profitable. In this paper, stochastic production frontier analysis is conducted in conjunction with a technical inefficiency model to examine the productive performance and its determinants in carp pond culture in Peninsula Malaysia. The mean technical efficiency for sample carp farms is estimated to be 0.42 indicating a great potential for increasing carp production in Peninsula Malaysia through improved efficiency. Seed ratio has a significant effect on fish production; therefore, the proper choice of species composition is important to improving productivity in carp polyculture. Because the intensive/semi-intensive system is found to be technically more efficient than the extensive system, efforts should be made to promote the intensive/semi-intensive carp culture.

15.1 Introduction

Since the seminal article of Farrell (1957) and subsequent developments of various techniques for efficiency and productivity measurement, frontier production function models have been widely used in determining productive performance in agriculture. However, except for a few studies (e.g., Gunaratne and Leung, 1996; Gunaratne and Leung, 1997; Sharma and Leung, 1998; Sharma et al., 1998;), their application to aquaculture has been very limited. The frontier production approach defines the technical efficiency in terms of a minimum set of inputs needed to produce a given output or maximum output obtainable from a given set of inputs.

The parametric stochastic frontier production function (Meeusen and van den Broeck, 1977: Aigner et al., 1977) involving econometric methods and non-parametric data envelopment analysis (DEA) (Charnes et al., 1978) involving mathematical programming techniques are the two most popular methods found in the literature. The main advantage of the stochastic frontier is that it can decompose the deviation from the frontier into stochastic noise and technical inefficiency in production. The need for imposing a particular parametric form for the underlying technology is the main weakness of this technique. The main advantage of DEA is that it eliminates the

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need for the parametric assumption of the underlying technology. However, since DEA is deterministic and it attributes all deviations from the frontier to inefficiencies, a frontier estimated by this technique is believed to be sensitive to stochastic noise in the data.

The majority of studies on production economics of fish culture have used 'average' or traditional production function approaches. Panayotou et al. (1982) and Nerrie et al. (1990) applied average Cobb-Douglas production function to catfish pond farming in Thailand and United States, respectively. Likewise, Jackson (1983) and Chong et al. (1982) also applied average Cobb-Douglas production function to milkfish pond farming in Indonesia and the Philippines, respectively. Recently, average Cobb-Douglas form was applied to tilapia, milkfish and eel pond farming in Taiwan (Hsiao, 1994).

Besides ignoring the presence of technical inefficiencies in production, previous studies have also ignored the multi-product feature of fish polyculture except for the multi-product analysis of polyculture of milkfish, shrimp and clam in Taiwan (Wann, 1994). Recognizing the multi-output production structure, Sharma et al. (1999) have derived technically and economically optimal combination of different fish species for carp polyculture farms in China using the non-parametric DEA technique.

In Peninsula Malaysia, freshwater fish culture, especially carp pond culture, has been a traditional practice since the early 1900s. Until the mid-1980s, carp pond culture dominated freshwater fish culture production. Because carp pond culture is practiced in small scale (0.2 to 1 ha) and managed mostly as extensive or semi-intensive system, the productivity of carp pond culture in Peninsula Malaysia is generally low (Liong et al., 1988). Recently, the government has strengthened its extension efforts to promote more intensive production systems.

However, carp production in freshwater ponds has gradually declined since the federal government launched a new policy for aquaculture development in the mid-1980s (Ubaidillah, 1985). The decline of carp production is attributed to the replacement of the traditional carp pond culture with that of other fish species, such as tilapia, catfish or freshwater prawn under the new aquaculture policy and to shift in consumer preferences from carps to other fish species. However, in terms of total freshwater fish production, carp pond culture is still prominent in Peninsula Malaysia. Therefore, the improvement in carp culture production is indispensable for the increase of freshwater fish production in the future.

In this study, stochastic production frontier with a technical inefficiency model is applied to estimate technical efficiency of carp pond culture in Peninsula Malaysia. Through the estimated model and technical efficiency estimates, some policy implications are suggested to promote carp production in Peninsula Malaysia.

15.2 Stochastic production frontier and technical inefficiency model

The stochastic frontier production function for cross-sectional data is specified as:

$$Y_i = f(X_i ; \beta) \exp(V_i - U_i) \tag{15.1}$$

where Y_i denotes the production for the i-th farm ($i = 1, 2, \ldots, n$); X_i is a $1 \times k$ vector of value of known functions of inputs of production and other explanatory variables associated with the i-th farm; β is a $k \times 1$ vector of unknown parameters to be estimated; the V_is are random variables which are assumed to be independently and identically distributed $N(0, \sigma_v^2)$, and independent of the U_is; and the U_is are non-negative random variables associated with technical inefficiency in production and are assumed to be independently distributed as truncations of the $N(Z_i\delta, \sigma_u^2)$ distribution. Following Battese and Coelli (1995), U_is can be represented as:

$$U_i = Z_i\delta + W_i \tag{15.2}$$

where Z_i is a $1 \times p$ vector of variables which may influence efficiency of a farm; δ is a $p \times 1$ vector of parameters to be estimated; and W_is are the random variables defined by the truncation of the normal distribution with mean 0 and variance σ_u^2, such that the point of truncation is $-Z_i\delta$, i.e. $W_i \geq -Z_i\delta$. These assumptions are consistent with U_i being a non-negative truncation of the $N(Z_i\delta, \sigma_u^2)$ distribution (Battese and Coelli, 1995).

The maximum likelihood estimation procedure is proposed for the simultaneous estimation of the parameters of the stochastic frontier model in Eqn. 15.1 and those for the technical inefficiency model in Eqn. 15.2. The likelihood function and its partial derivatives with respect to the parameters of the model are presented in Battese and Coelli (1993).

The technical efficiency of production for the *i*-th farm is defined as:

$$TE_i = \exp(-U_i) = \frac{Y_i}{f(X_i;\beta)\exp(V_i)} \tag{15.3}$$

The prediction of the technical efficiencies is based on conditional expectation of expression in Eqn. 15.3, given the model assumptions.

15.3 Data and variables

15.3.1 Data sources

The data for this study came from the field study of carp pond farms in Peninsula Malaysia for the Regional Study on Aquaculture Sustainability and the Environment conducted by Network of Aquaculture Centers in Asian-Pacific (NACA) and Asian Development Bank (ADB) (NACA/ADB, 1994; NACA/ADB, 1995). The NACA/ADB survey covered five states, namely Kedah, Perak, Selangor, Negari Sembilan and Pahang in Peninsula Malaysia.

Only 135 carp pond farms were randomly selected and interviewed to collect economic and management data for carp production. The sample farms were classified into two culture systems, namely intensive/semi-intensive and extensive culture. Farms with incomplete production data were deselected from this study, resulting in a database of 94 farms, comprising 52 intensive/semi-intensive farms and 42 extensive farms.

15.3.2 Sample characteristics

Of the 94 farms analyzed, the average grow-out pond area is 0.34 ha for all sample farms; 0.33 ha for intensive/semi-intensive farms and 0.36 ha for extensive farms. About 88% of operations have a pond area of less than 0.50 ha. Thus, as noted by Senoo et al. (1991), the overall operation size of carp pond culture in Peninsula Malaysia is relatively small. The average fish production is 2,548 kg/ha for all sample farms. The average production of intensive/semi-intensive farms is 3,831 kg/ha and that for extensive farms is 960 kg/ha.

About 78% of sample carp farms practice fish culture as primary activity. Similarly, about 24% of sample farms integrate fish farming with other agricultural activities. The principal land uses prior to carp culture are wetland/swamp (48%), rice farming (35%) and low-yield/unsuitable agriculture land (13%). The dominant soil types for sample carp ponds are clay (76%), loam (11%), peat/organic rich soil (10%) and sandy (3%). The main source of water for fish ponds is freshwater spring (59%), followed by spring (19%), river (7%), irrigation canal (5%) and rainwater (4%). About 15% of farms are tenant-operated using leased lands, public lands or cooperative lands.

All sample farms practice polyculture of several freshwater finfish species. Grass carp (*Ctenopharyngodon idellus*) is cultured on 85% of sample farms, followed by Javanese carp or *Puntius gonionotus* (77%), big-head carp or *Aristichthys nobilis* (64%), common carp or *Cyprinus carpio* (40%) and river carp or *Leptobarbus hoevenii* (20%). Silver carp (*Hypophthalmichtys molitrix*) and rohu (*Labeo rohita*) are also cultured. Beside these carp species, tilapia (*Oreochromis niloticus* or *O. mossambicus*) is cultured on 65% of the sample carp farms.

All sample farms regularly use several types of supplementary feeds for carp pond culture. Simple diets are used by all and formulated diets are used by 76% of sample farms. In terms of simple diets, 91% of sample farms use plant materials, followed by food processing waste (63%), bran and oil cakes (28%) and fishmeal (2%). In terms of formulated diets, the locally produced commercial pelleted feed is most popular.

Liming for pond preparation is reported on 86% of sample carp farms. About 74% of farms apply fertilizer for pond preparation and water treatment, mostly organic fertilizers. Farmers rarely use inorganic fertilizer and hardly use any chemicals for pond treatment.

15.3.3 Output and input variables

All output and input variables used for this study are expressed on a per hectare basis. Because the pond area of sampled carp farms varies from 0.11 to 1.3 ha, it is necessary to eliminate the pond area effect on output and input variables in the production frontier. The output and input variables involved in the stochastic production frontier for the sample carp farms in Peninsula Malaysia are described below and their summary statistics are provided in Table 15.1. The detailed mathematical derivations of these variables can be found in Iinuma (1998).

Output (Y) refers to total quantity of fish harvested during the 1994 production year, measured in kilograms per hectare. It should be noted that the total quantity of fish production is not an ideal measure for output variable in the production frontier analysis due to the multi-output production structure of fish polyculture. A more appropriate measure would be a geometric mean or quantity index based on revenue shares or prices for different fish species. Unfortunately, data on production, revenue and prices by species were not available.

Table 15.1 Summary statistics for variables involved in the stochastic production frontier and technical inefficiency model for carp pond culture in Peninsula Malaysia

Variable	Average	Standard deviation	Minimum	Maximum
Output				
Fish production (kg/ha)	2,548	2,459	280	12,286
Inputs				
Seed (pieces/ha)	34,090	37,852	1,229	167,982
Seed ratio (forage/filter)	4.033	6.797	0.066	50
Feed (dry-weight kg/ha)	5,953	6,824	380	30,469
Feed ratio (dry/green)	3.818	4.274	0.025	20
Labor (persondays/ha)	619	400	24	1,983
Other inputs (MR/ha)	767	994	11	7,478
Farm-specific				
Intensive culture (0 or 1)	0.553	0.500	0	1
Intensive culture (0 or 1)	0.851	0.358	0	1
Primary activity (0 or 1)	0.777	0.419	0	1
Pond area (ha)	0.344	0.251	0.11	1.3
Pond age (years)	10.0	5.2	2.0	30.0

Other inputs (X_6) represent other variable inputs (chemicals, water, maintenance, fertilizer, etc.) and overhead costs (farm rent, insurance, interest, etc.), measured in MR (Malaysian Ringgit)/ha.

Seed (X_1) represents the quantities of total fish seed (fry) released into ponds, pieces per hectare, standardized to 2.5 cm. Because of the variation in seed size among different fish species and among different farms, total number of fish seed used is not a good measure of seed variable. Therefore, various seed sizes are normalized to 2.5 cm.

Seed ratio (X_2) indicates the ratio between the seed of 'forage feeding' fish and 'filter feeding' fish species. In this study, 'filter feeding' species comprise those mainly feeding on plankton and macrophytes at the surface layer and 'forage feeding' species comprise those mainly feeding on benthos and macrophytes at the bottom layer of the pond. Based on Ong (1988) and Opuszynski and Shireman (1995), bighead carp, sliver carp, rohu, river carp and tilapia are categorized as 'filter feeding' species, while grass carp, common carp and Javanese carp are categorized as 'forage feeding' species.

Feed (X_3) represents the total dry weight of feed, measured in kilograms per hectare. Three feed types, namely dry formulated feed (commercial pelleted feed), dry feed ingredients (bran, oil cake, etc.) and green feed (collected green weed) are included in the NACA/ADB survey. For simplicity, these different feed types are converted into dry weight equivalents and aggregated to form a single feed variable. The water content of green feed is assumed to be 80%, the average value of water content calculated based on Tan (1970). Thus, the weight of green feed is simply converted into dry weight by multiplying it by 0.2.

Feed ratio (X_4) represents the ratio between the total dry feed (dry formulated feed and dry feed ingredients) and the total green feed in dry weight equivalent.

Labor (X_5) represents the total quantity of family and hired labor used in carp farming, measured in person-days per hectare.

15.3.4 Operational and farm-specific variables

In addition to output and input variables described above, a number of relevant operational and farm-specific variables, Z_p, are also included in the analysis in order to determine their influence on technical efficiency for carp pond culture. These variables are described below and summarized in Table 15.1.

Intensive culture dummy (Z_1) has a value of 1, if the carp pond farm follows semi-intensive or intensive culture system, 0 if the farm adopts extensive system.

Ownership dummy (Z_2) has a value of 1, if the farm is owner-operated, 0 if the farm is tenant-operated.

Primary activity dummy (Z_3) has a value of 1, if carp pond culture is the primary activity for the operator, 0 otherwise.

Pond area (Z_4) represents the grow-out pond area (hectare) used for carp culture.

Pond age (Z_5) represents the years for which a farmer has engaged in carp farming at the current site as of 1994.

15.4 Empirical model

This study uses the Cobb-Douglas functional form to estimate the stochastic production frontier for carp pond culture in Peninsula Malaysia as:

$$\mathrm{Ln}Y_i = \beta_0 + \sum_{k=1}^{6} \beta_k \ln X_{ki} + V_i - U_i \tag{15.4}$$

where subscript i refer to the i-th farm in the sample; Ln represents the natural logarithm; Y represents output and Xs are input variables defined earlier; βs are parameters to be estimated; V_is and U_is are random variables defined earlier. Maximum likelihood estimation of Eqn. 15.4 provides the estimators for βs and variance parameters, $\sigma^2 = \sigma_v^2 + \sigma_u^2$ and $\gamma = \sigma_u^2/\sigma^2$.

Following Battese and Coelli (1995), it is further assumed that the technical inefficiency distribution parameter, U_i is a function of various operational and farm-specific variables hypothesized to influence technical inefficiencies as:

$$U_i = \delta_0 + \sum_{p=1}^{5} \delta_p Z_{pi} + W_i \tag{15.5}$$

where Zs are various operational and farm-specific variables, defined earlier; δs are unknown parameters to be estimated; and W_is are also defined earlier.

It should be noted that the technical inefficiency model in Eqn. 15.5 can only be estimated if the technical inefficiency effects, U_is, are stochastic and have particular distributional properties (Coelli and Battese, 1996). Therefore, it is of interest to test the null hypothesis that the technical inefficiency effects are absent, $\gamma = \delta_0 = \delta_1 = ... = \delta_5 = 0$; that technical inefficiency effects are nonstochastic, $\gamma = 0$; and that farm-specific factors do not influence the inefficiencies, $\delta_1 = ... = \delta_5 = 0$. Under $\gamma = 0$; the stochastic frontier model reduces to a traditional average function in which the explanatory variables in the technical inefficiency model are included in the production function. These and related null hypotheses can be tested using the generalized likelihood-ratio statistic, λ, given by:

$$\lambda = 2[\mathrm{Ln}\{L(H_1)\} - \mathrm{Ln}\{L(H_0)\}] \qquad (15.6)$$

where $L(H_0)$ and $L(H_1)$ denote the values of likelihood function under the null (H_0) and alternative (H_1) hypotheses, respectively. If the given null hypothesis is true, λ has approximately χ^2-distribution or mixed χ^2-distribution when the null hypothesis involves $\gamma = 0$ (Coelli, 1995).

Given the model specifications, the technical efficiency index for the i-th farm in the sample (TE_i), defined as the ratio of observed output to the corresponding frontier output, is given by:

$$TE_i = \exp(-U_i) \qquad (15.7)$$

The prediction of technical efficiencies is based on the conditional expectation of expression in Eqn. 15.7, given the values of $V_i - U_i$ evaluated at the maximum likelihood estimates of the parameters of the stochastic frontier model (Battese and Coelli, 1988). The frontier production for the i-th farm can be computed as the actual production divided by the technical efficiency estimate.

The parameters of the stochastic production frontier model in Eqn. 15.4 and those of the technical inefficiency model in Eqn. 15.5 are estimated simultaneously by maximum likelihood (ML) estimation method, using the computer program, FRONTIER version 4.1 (Coelli, 1994).

15.5 Results

15.5.1 ML estimates and test of hypotheses

Table 15-2 shows the maximum likelihood (ML) estimates of parameters of the stochastic production frontier model and those for the technical inefficiency model. Except for feed ratio (X_4), the β-coefficients associated with input variables (X_k) are estimated to be positive and significant. It means that seed, seed ratio, feed, labor and other inputs included in the production frontier have a significant influence on fish production in carp pond culture in Peninsula Malaysia. The β-coefficient (input elasticity) is the highest for seed ratio (0.184), followed by feed (0.168), labor (0.159), seed (0.075) and other inputs (0.071). The results indicate that the relative importance of 'forage feeding' vs. 'filter feeding' species has a highly significant effect on the level of carp production.

The γ--parameter associated with the variances in the stochastic production frontier is estimated to be close to 1 (Table 15.2). Although the γ-parameter can not be interpreted as the proportion of the total variance explained by technical inefficiency effects, the result indicates that technical inefficiency effects do make a significant contribution to the level and variation of carp production in Malaysia.

Generalized likelihood-ratio tests of various null hypotheses involving the restrictions on the variance parameter, γ, in the stochastic production frontier and δ-coefficients in the technical inefficiency model are presented in Table 15.3. Both null hypotheses that the technical inefficiency effects are not present and that inefficiency effects are not stochastic are rejected. Thus, the traditional average production function is not an adequate representation of carp production data used in this study. This is also confirmed by the estimated value of the variance parameter, γ, which is highly significant.

The third null hypothesis that the constant term and all the coefficients associated with various farm-specific variables in the technical inefficiency model are zero (that the technical inefficiency effects have a traditional half-normal distribution with zero mean) is rejected. The less restrictive fourth null hypothesis that all the parameters of the technical inefficiency model except the constant term are zero (that the technical inefficiency effects have the same truncated-normal distribution with mean equal to δ_0) is also rejected. Given the specifications of the stochastic production frontier model, defined by Eqns. 15.4 and 15.5, the likelihood-ratio tests indicate that technical inefficiency effects are significant in explaining the variation in productive performance of the sample carp farmers in Peninsula Malaysia.

Table 15.2 Parameter estimates of stochastic production frontier and technical inefficiency models

Variable	Parameter	Coefficient	Standard error
Stochastic production frontier			
Constant	β_0	4.943***	0.401
Ln (Seed)	β_1	0.075*	0.039
Ln (Seed ratio)	β_2	0.184***	0.019
Ln (Feed)	β_3	0.168***	0.024
Ln (Feed ratio)	β_4	0.006	0.023
Ln (Labor)	β_5	0.159*	0.082
Ln (Other inputs)	β_6	0.071***	0.016
Technical inefficiency model			
Constant	δ_0	0.787***	0.291
Intensive culture dummy	δ_1	– 0.838***	0.111
Ownership dummy	δ_2	0.699***	0.262
Primary activity dummy	δ_3	– 0.193	0.145
Pond area	δ_4	– 0.325	0.324
Pond age	δ_5	0.034***	0.011
Variance parameters			
	γ	0.999993***	0.000003
	σ^2	0.200***	0.047
Log(likelihood)		– 41.143	
Mean of exp($-U_i$)		0.418	

*** Significant at the 0.01 level, ** significant at the 0.05 level, and * significant at the 0.10 level.

Table 15.3 Generalized-likelihood ratio tests of hypotheses of parameters of the stochastic production frontier and technical inefficiency models for carp pond culture in Peninsula Malaysia

Null hypothesis	Log- likelihood value	Test statistic value (λ)	Critical value ($\chi^2_{0.95}$)	Decision
$H_0 : \gamma = \delta_0 = ... = \delta_5 = 0$	– 87.924	93.562	11.911	Reject H_0
$H_0 : \gamma = 0$	– 44.003	5.720	5.138	Reject H_0
$H_0 : \delta_0 = \delta_1 = ... = \delta_5 = 0$	– 87.640	92.994	12.591	Reject H_0
$H_0 : \delta_1 = ... = \delta_5 = 0$	– 80.907	79.528	11.071	Reject H_0

The correct critical values for the first and second hypothesis involving $\gamma = 0$ are obtained from Table 1 of Kodde and Palm (1986, p.1246) with degrees of freedom equal to 6 and 2, respectively.

The results for the technical inefficiency model are presented in Table 15.2. The □-coefficient of intensive/semi-intensive culture dummy is estimated to be significantly negative, indicating that the intensive/semi-intensive culture system is technically more efficient than the extensive culture system. The □-coefficient of the ownership dummy is estimated to be significantly positive, which indicates that tenant-operated farms are technically more efficient than owner-operated ones. The □-coefficient of the primary activity dummy is estimated to be negative; however, it is statistically insignificant. The □-coefficient of pond area is estimated to be negative, indicating that the large operations are technically more efficient than smaller ones. However, this difference is not statistically significant. The □-coefficient of pond age is estimated to be significantly positive. It shows that carp farms operating newer ponds are technically more efficient than those operating older ponds.

15.5.2 Technical efficiency

Fig. 15.1 depicts the frequency distribution of the estimated technical efficiency scores for the sample carp producers in Peninsula Malaysia. The estimated technical efficiencies range from 0.07 to 0.99, with a mean efficiency level of 0.42. For about 70% of the sample carp farms, the estimated technical efficiency score is 0.50 or below.

Senoo et al. (1991) noted that carp pond farmers generally carry out extensive culture system in small operation in Peninsula Malaysia, and Ang (1990) indicated that carp polyculture is generally conducted under the semi-intensive system in Malaysia. The proportion of intensive carp pond farms is quite low in Peninsula Malaysia. In other words, in Peninsula Malaysia, there exists great potential for increasing carp production through improvements in technical efficiency.

Fig. 15.2 compares the frequency distributions of technical efficiency scores between the intensive/semi-intensive and extensive farms. These results indicate that the distributions of the technical efficiency indices are very different for the two culture systems. The technical efficiencies of extensive culture farms range between 0.07 and 0.55, while those for intensive/semi-intensive farms range between 0.21 and 0.99. The average technical efficiency indices for intensive/semi-intensive and extensive culture farms are estimated to be 0.57 and 0.24, respectively (Table 15.4). Thus, on average, the estimated technical efficiency for intensive/semi-intensive farms is more than twice that for extensive culture farms. However, the mean technical efficiency for intensive/semi-intensive farms is also not high.

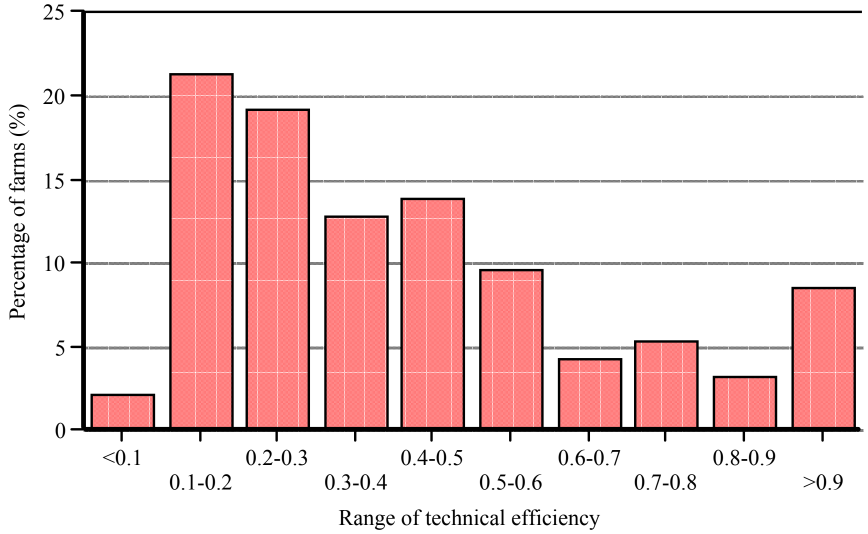

Fig. 15.1 Frequency distribution of technical efficiency for carp pond culture in Peninsula Malaysia

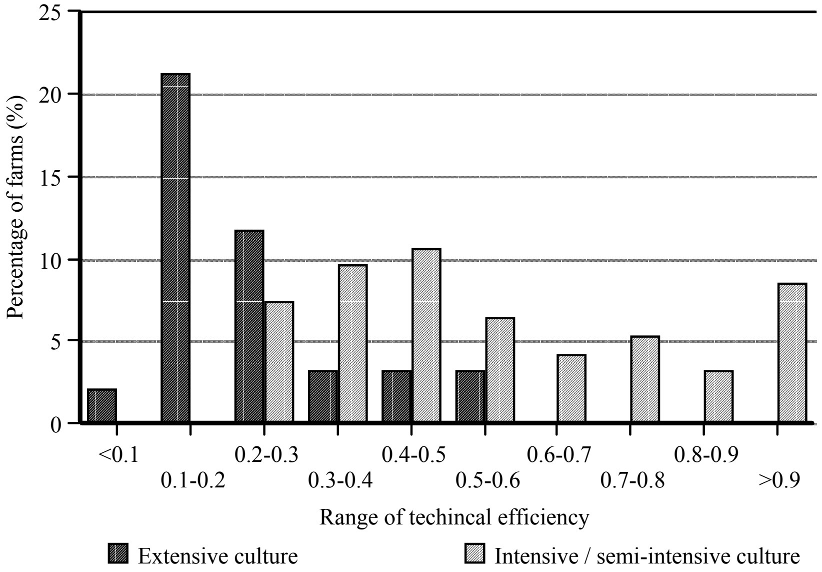

Fig. 15.2 Frequency distribution of technical efficiency for carp pond culture in Peninsula Malaysia by culture system

15.6 Discussion and policy implications

Because the present study is based on only 94 carp pond farms from 5 of 11 states in Peninsula Malaysia, it is difficult to suggest significant policy measures based on this study. However, the findings reveal some useful characteristics of carp pond culture in Peninsula Malaysia. The mean technical efficiency for the sample carp farms is estimated to be about 0.42, which suggests that there exists substantial potential for increasing fish production in Peninsula Malaysia through improved technical efficiency of carp pond culture. The results show that the sample carp farms, on average, could increase their per-hectare fish production from 2.5 to 5.7 mt/ha (or 125%) if all farms were able to operate at full technical efficiency (Table 15.4).

Table 15.4 Average technical efficiency, fish production, and revenue by culture system

	Intensive/semi-intensive	Extensive	All farms
Number of farms	52	42	94
Average technical efficiency	0.565 (0.248)	0.236 (0.123)	0.418 (0.260)
Average fish production (kg/ha)			
Actual production	3,831 (2,679)	960 (337)	2,548 (2,459)
Frontier production	6,599 (2,195)	4,657 (2,117)	5,732 (2,358)
Difference (%)	72	385	125
Average revenue (MR/ha)			
Actual revenue	16,393 (11,972)	4,135 (1,629)	10,916 (10,831)
Frontier revenue	28,054 (10,228)	20,395 (10,183)	24,632 (10,850)
Difference (%)	71	393	126

Figures in parentheses denote standard deviations.

Since the technical efficiency for intensive/semi-intensive system is significantly higher than that for extensive system, the government extension efforts should be directed toward promoting intensive/semi-intensive culture system. Fong and Cook (1996) indicated that the rate of return to capital for the intensive system is higher than for the extensive system of carp pond culture in Peninsula Malaysia. Furthermore, they also stressed the importance of extension services to promote the intensive carp culture in Peninsula Malaysia. Table 15.4 shows the mean levels of actual and frontier production and revenue levels by culture system. Based on these results, on average, intensive/semi-intensive farms can increase their productivity from 3.8 to 6.6 mt/ha (or 72%) and extensive farms from 1.0 to 4.6 mt/ha (or 385%) by operating at full technical efficiency.

Enlarging pond area also has some potential to improve the level of technical efficiency of carp pond farming. Most carp pond farms in Peninsula Malaysia operate small pond areas. Ang (1990) stressed the need for commercializing carp pond culture. Thus, expanding pond area can promote the commercialization of carp pond production. The pond age has a negative impact on technical efficiency in carp pond culture. This finding is consistent with the fact that maintaining the pond quality is important to improve the level of technical efficiency of carp pond farming. The extension workers should educate carp farmers about the importance of regular pond management and treatment practice. Most carp pond farms in Peninsula Malaysia are owner-operated. It is found that tenant-operated farms tend to be more efficient than owner-operated farms. Because the tenant-operated farms have higher production cost due to rental payments compared to owner-operated farms, they have to earn extra revenue to compensate for additional cost. Perhaps, the tenant-operated farms put more effort in carp production and are more efficient compared to the owner-operated farms.

The seed ratio is found to be an important factor influencing fish production in polyculture system. The result indicates that when the ratio of 'forage feeding' to 'filter feeding' species increases, the total fish production also increases. This is consistent with other biological studies (Sahu and Jana; 1996; Milstein et al., 1988). Extension workers should educate farmers about the importance of choice of species composition to enhance productivity in carp pond culture.

The feed input is found to be a significant contributor to fish production in carp pond culture. However, the ratio of dry feed to green feed does not show a significant influence on the productive performance for carp farming. However, according to Law et al. (1983) and Mazid et al. (1997), dry supplemental feed is nutritionally better for fish growth than green feed. Therefore, feed management is also critical to higher productivity in carp pond culture in Peninsula Malaysia.

15.7 Conclusions

A stochastic production frontier is estimated in order to assess the level and determinants of technical efficiency for a sample of carp pond farms in Peninsula Malaysia. The carp production data and other relevant information in the NACA/ADB survey (NACA/ADB, 1994) are analyzed by estimating a Cobb-Douglas stochastic production frontier involving a model for technical inefficiency effects. The production frontier involves six input variables, including seed, seed ratio, feed, feed ratio, labor and other inputs. Similarly, the technical inefficiency model includes five farm-specific variables, namely culture intensity, ownership, carp farming as a primary activity, pond area and pond age.

The mean technical efficiency for the sample carp farms, estimated by the stochastic production frontier, is quite low (0.42). This indicates that there is great potential for increasing carp production in Peninsula Malaysia by improving technical efficiency. At full technical efficiency, on average, the sample carp farms could increase the per-hectare fish production by 125% compared to the actual production.

All β-coefficients in the stochastic production frontier are estimated to be positive and significant, except for the coefficient for feed ratio. The results indicate that these inputs make a positive and significant contribution to fish production in carp pond culture in Peninsula Malaysia. The coefficient of seed ratio further indicates that managing the seed composition between forage and filter feeding species is important to promote productivity in carp polyculture.

The results from the technical inefficiency model indicate that the various farm-specific factors mentioned above contribute significantly to the level of and variations in technical inefficiency of carp pond culture in Peninsula Malaysia. On average, the intensive/semi-intensive culture system is found to be technically more efficient than the extensive system. Contrary to expectations, tenant-operated farms tend to have a higher level of technical efficiency than owner-operated ones. The pursuit of carp culture as primary activity and total pond area are positively related to technical efficiency, but their effects are insignificant. Pond age shows negative and significant impact on technical efficiency.

In this study, only 94 carp pond farms were used to estimate the stochastic production frontier. To improve the statistical reliability of results, the sample size should be increased. If the sample size is large, then alternative functional forms of the production frontier can be considered and production frontiers can be estimated separately for extensive, semi-intensive and intensive systems.

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Chapter 16

Economic efficiency and optimum stocking densities in fish polyculture: an application of data envelopment analysis (DEA) to Chinese fish farms

Khem R. Sharma, Pingsun Leung, Hailiang Chen and Aaron Peterson

Abstract
Polyculture is commonly practiced in pond aquaculture where several fish species are reared together, creating a multi-output production structure. This study applied a nonparametric data envelopment analysis (DEA) technique for multiple outputs to: (1) measure economic or 'revenue' efficiency and its technical and allocative components for a sample of Chinese polyculture fish farms; and (2) derive the optimum stocking densities for different fish species. The mean economic efficiency was estimated to be 0.74. Technical inefficiencies accounted for most of the production inefficiencies in Chinese fish farms. On average, farmers should increase grass carp and decrease black carp stocking rates. Smaller farms and those from the developed regions were found to be relatively more technically and economically efficient.

16.1 Introduction

The primary goal of rational pond management is to utilize existing conditions in the ponds to produce fish to maximize economic returns to farmers. Polyculture utilizes the concept that a mixed stock of selected fish species, with complementary or minimal competing feeding habits and different ecological requirements, can exploit the resources of the different ecological niches in a pond efficiently, thereby resulting in maximum fish production for given input quantities. Selecting proper species alone, however, is not adequate. The assumption that different fish species will not compete remains true only within the limits of a certain density of stocking, food supply and environmental conditions of a pond. Furthermore, the species-mix that maximizes economic returns to farmers depends on market prices of the different fish species. The determination of an optimum combination of differing species remains a primary problem. Its solution requires extensive experimentation and in-depth understanding of the pond ecosystem and biological interaction among fish species as well as economic factors. Stocking rates of different fish species should be such that the total revenue or profit is maximized for given fish prices and technological constraints. In practice, stocking rates are determined based mainly on ecological features of fish species, often ignoring their technical and economic interrelationships.

This study demonstrates an appropriate approach to determining the technically and economically optimum species-mix using data envelopment analysis (DEA)

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technique. In addition, it provides the estimates for technical, allocative and economic efficiency measures of a sample of Chinese fish farms. This information is very useful to assess the potential for and sources of improvements in production as well as economic return of fish polyculture.

DEA is a nonparametric production frontier approach that can measure the efficiency of a firm relative to the production possibility or input requirement set. Under the output-based approach, performance is judged by the ability to produce the maximum output(s) achievable from a given set of inputs (technical efficiency) or to maximize revenue given output prices and input quantities ('revenue' or overall economic efficiency) (Färe et al., 1994). Under the input-based approach, performance is measured in terms of maximum feasible reductions in input quantities (technical efficiency) or total cost given input prices and output(s) ('cost' or overall economic efficiency). In each case, the ratio of economic and technical efficiencies provides a measure of allocative efficiency. Under the output-based approach, allocative efficiency reflects the ability of the firm to produce optimum combination of different outputs, while under the input-based approach it reflects the ability to use inputs in optimum proportion.

Most DEA applications to efficiency measurements in the literature are the input-based type. The few published applications of output-based efficiency have primarily focused on technical, scale and congestion efficiencies (Färe et al., 1994, pp. 125-127). The use of output-based approaches to estimate all three measures of Farrell (1957) technical, allocative and economic efficiencies is limited in the literature, perhaps due to lack of availability of suitable multiple-output datasets (Färe et al., 1994). To our knowledge, this is the only study using DEA to empirically estimate all three measures of Farrell (1957) technical, allocative and economic efficiencies.

Since Farrell's (1957) seminal article and subsequent developments of various approaches to efficiency and productivity measurement, frontier techniques have been widely used in determining productive performance in agriculture and various other industries. Except for a few studies (Sharma and Leung, 1998; Gunaratne and Leung, 1996, 1997), applications of production frontiers to aquaculture are, however, quite limited. Production function analyses in aquaculture are usually limited to assessing the profitability and rate of return of new investments, estimating economies of scale, determining optimum intensity of input use and improving existing management practices (Hatch and Tai, 1997). Fish polyculture with its multi-output feature provides a promising setting for applications of the output-based efficiency measurement technique, especially DEA.

The most notable feature of DEA is that it generates a single input/output index to characterize efficiency of a firm or decision-making unit (DMU) producing multiple outputs from a set of inputs (Charnes et al., 1978). For a sample of DMUs, DEA not only identifies the efficient units from the inefficient ones, but it also computes the efficient input and output levels for inefficient units in terms of linear combinations of input and output levels of efficient units. For polyculture fish farms, this information can be used to calculate optimum output combinations as well as the corresponding stocking densities of different fish species.

Despite its ability to analyze multi-inputs and multi-outputs production technologies, DEA technique has some limitations. Because DEA is deterministic and attributes all the deviations from the frontier to inefficiencies, the efficiency measures estimated by this technique are believed to be sensitive to measurement errors or other noise in the data. Contrary to popular belief, Sharma et al. (1998) have found DEA to be more robust compared to the parametric, stochastic production frontier approach. Because of its inherent dimensionality constraint, efficiency measures obtained from DEA may also be sensitive to alteration in sample size as well as the number of input and output variables, especially when the number of DMUs is small relative to a total number of input and output variables. As noted by Coelli et al. (1998), the addition of an extra input or output in a DEA model cannot result in a decrease in the technical efficiency scores. However, when the number of DMUs is large relative to the number of input and output variables, as in the present study, the addition or removal of one or two variables will perhaps not result in significant changes in DEA results. Moreover, in practice this problem is often minimized by carefully selecting the input and output variables based on theory, experience and empirical evidence. Once a set of input and output variables are fixed, the removal of an existing variable or the addition of an extra variable is, to the best of our knowledge, not a standard practice in DEA, although it is commonly done in econometric technique to test certain hypotheses.

16.2 Background of the study

Fisheries production, which is one of China's most dynamic economic sectors, has experienced rapid development since the implementation of economic reforms, particularly the production contract responsibility system in the late 1970s. Leung et al. (1993) examine the impacts of the production contract responsibility system on freshwater fisheries production in China.

The total output of aquatic products increased from 4.65 million metric tonnes (mt) in 1978 to 21.46 million mt in 1994, growing at an annual rate of 22.6%. Similarly, the total aquaculture production increased from 1.21 million mt to 11.35 million mt (an annual increase of 52.3%) and the share of aquaculture in total aquatic production increased from 26% to 53% between the two periods. In 1993, freshwater fisheries or inland aquaculture accounted for about two-thirds of total aquaculture production, of which about three-fourths came from pond culture. In China, fish pond culture is dominated by various species of Chinese carps, including grass carp, silver carp, bighead carp, common carp, crucian carp, black carp and local breams, which accounted for more than 85% of total freshwater fisheries production in 1993 (Wang and Yi, 1995).

Above statistics suggest that the future of aquaculture production in China will depend quite heavily on performance and growth in pond polyculture. By analyzing the farm-level technical, allocative and economic efficiencies, this study examines the performance of Chinese fish culture and its potential for future improvement.

16.3 DEA model for fish polyculture system

Consider the situation with n fish farms or decision making units (DMUs), each producing s different types of fish species using m inputs, one of which is the total amount of seed (fingerling) stocked. Note that the seed is expressed as the total seed of all fish species instead of each species individually. Defining the seed input for each species involves two problems. First, this increases the number of constraints which will in turn increase the efficiency scores of the sample farms as frontier becomes tighter when the number of constraints becomes large. Second, this requires one-to-one correspondence between actual stocking and production levels of each species, which is inappropriate, especially when some farmers are inefficient simply by stocking or not stocking certain species. Thus, in this analysis, the total amount of fingerlings stocked is regarded as carrying capacity of the pond which can be allocated to different species in accordance with their production levels at full efficiency.

The i-th DMU uses X_{ki} units of the k-th input in the production of Y_{ri} units of the r-th fish species. A separate linear programming (LP) problem is solved for each of the n DMUs in the sample. The output-based technical efficiency for the i-th DMU can be obtained by solving the following LP problem:

$$\max_{\phi_i,\ \lambda_j} \phi_i \tag{16.1}$$

st.:

$$\phi_i X_{ri} - \sum_{j=1}^{n} \lambda_j Y_{rj} \le 0 \qquad \text{r = 1, …, s fish species,}$$

$$X_{1i} - \sum_{j=1}^{n} \lambda_j X_{1j} \ge 0 \qquad \text{seed or fry stocked,}$$

$$X_{ki} - \sum_{j=1}^{n} \lambda_j X_{kj} \ge 0 \qquad \text{k = 2, …, m other inputs,}$$

$$\lambda_j \ge 0 \qquad \text{j = 1, …, n DMUs,}$$

where ϕ_i is the proportional increase in outputs possible and λ_j is the weight or intensity variable used to derive all possible linear combinations of the sample observations. When the value of ϕ_i in Eqn. 16.1 is 1, $\lambda_i = 1$, and $\lambda_j = 0$ for $j \neq i$, the i-th DMU lies on the frontier and is technically efficient. For the inefficient units, $\phi_i > 1$, $\lambda_i = 0$, and $\lambda_j \neq 0$ for $j \neq i$. The output-based technical efficiency index of the i-th DMU (TE_i) can be computed as follows:

$$TE_i = \frac{1}{\phi_i} \tag{16.2}$$

The measurement of output-based technical efficiency is depicted graphically in Fig. 16.1 for a simplified situation with 5 observations (A, …, E) producing two fish species (Y_1 and Y_2) from a given set of inputs. Observations B, C, D and E lie on the production possibility frontier and hence are technically efficient, while observation A lies below the frontier and is inefficient. In other words, the farmer located at point A has a potential to increase the production levels of both species to point $\phi_A A$ in the production possibility frontier. The potential production levels for observation A are obtained by a linear combination of technically efficient observations B and C.

The measure of output-based economic or 'revenue' efficiency can be obtained by solving the revenue maximizing DEA model and then relating the actual revenue to maximum revenue as follows:

$$\underset{Y_{ri}^{*},\lambda_j}{\text{Max}} \sum_{r=1}^{s} P_{ri} Y_{ri}^{*} \tag{16.3}$$

st.:

$$Y_{ri}^{*} - \sum_{j=1}^{n} \lambda_j Y_{rj} \leq 0 \qquad \text{r = 1, …, s fish species,}$$

$$X_{1i} - \sum_{j=1}^{n} \lambda_j X_{1j} \geq 0 \qquad \text{seed or fry stocked,}$$

$$X_{ki} - \sum_{j=1}^{n} \lambda_j X_{kj} \geq 0 \qquad \text{k = 2, …, m other inputs,}$$

$$\lambda_j \geq 0 \qquad \text{j = 1, …, n DMUs,}$$

where y_{ri}^{*} is the revenue maximizing or economically efficient production of the r-th species of the i-th DMU and P_{ri} is the observed price received by the i-th DMU for the r-th species. The economic or 'revenue' efficiency index for the i-th DMU (EE_i) is then computed as:

$$EE_i = \frac{\sum_{r=1}^{s} P_{ri} Y_{ri}}{\sum_{r=1}^{s} P_{ri} Y_{ri}^{*}} \tag{16.4}$$

which is the ratio of actual revenue to maximum or potential revenue. Any difference between the actual and potential revenue is attributed to either of two sources: technical inefficiency (producing too few outputs of one or more species given input quantities) and allocative inefficiency (producing non-optimal combination of fish given prices). Following Farrell (1957) and Färe et al. (1994), the output-based allocative efficiency index for the i-th DMU (AE_i) can be derived using Eqns. 16.2 and 16.4 as:

$$AE_i = EE_i / TE_i \tag{16.5}$$

Graphically, the distance AF represents economic or 'revenue' inefficiency for observation A (Fig. 16.1) and the ratio of OA/OF gives the measure of economic efficiency, which can be decomposed into allocative and technical components. The distance between points $\phi_A A$ and F is allocative inefficiency, created by a revenue loss from the incorrect choice of output levels of two species given their prices. The ratio of $O\phi_A A/OF$ gives the measure of allocative efficiency. Only observation D is economically efficient (Fig. 1) and hence both technically and allocatively efficient.

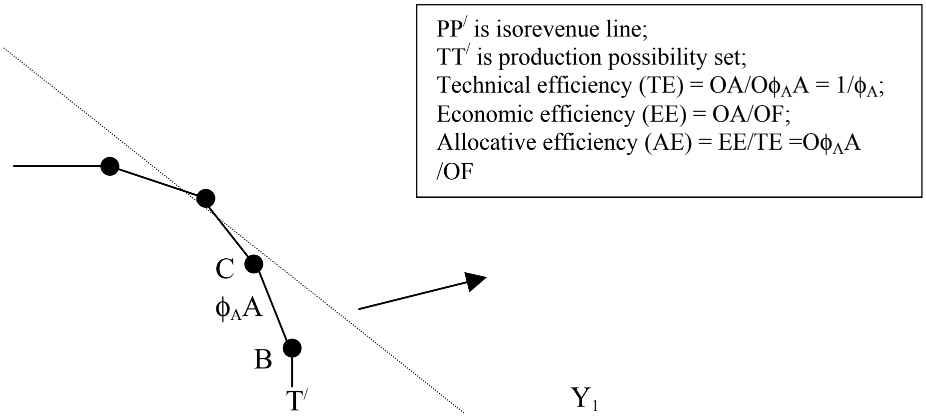

Fig. 16.1 The output-based technical, allocative and economic efficiency measures

The projected or frontier production of the r-th species of the i-th DMU ($\hat{Y}_{ri}$) is given by:

$$\hat{Y}_{ri} = \sum_{j=1}^{n} \lambda_j Y_{rj} = \phi_i Y_{ri} \qquad r = 1, \ldots, s \text{ fish species} \tag{16.6}$$

For calculating the technically efficient productions of the i-th farm, the intensity variables are the solutions of the optimization problem described in Eqn. 16.1. For calculating the economically efficient productions, they come from Eqn. 16.3.
Similarly, the technically and economically optimum level of total seed (fry) to be stocked in the pond of the i-th farm (X^*_{1i}) can be derived as follows:

$$X^*_{1i} = \sum_{j}^{n} \lambda_j X_{1j} \tag{16.7}$$

with intensity variables taken from Eqns. 16.1 and 16.3, respectively.

Note that the total seed stocked in the pond (X_1) is the sum of seed stocked for individual species. Mathematically it can be written as:

$$X_{1j} = \sum_{r=1}^{s} S_{rj} \qquad r = 1, \ldots, s \text{ fish species} \tag{16.8}$$

where S_{rj} denotes the amount of seed stocked of the r-th species on the j-th farm. Combining Eqns. 16.7 and 16.8 we get :

$$X^*_{1i} = \sum_{j}^{n} \lambda_j S_{1j} + \sum_{j}^{n} \lambda_j S_{2j} + \Lambda + \sum_{j}^{n} \lambda_j S_{sj} = S^*_{1i} + S^*_{2i} + \Lambda + S^*_{si} = \sum_{r=1}^{s} S^*_{ri} \tag{16.9}$$

where S^*_{ri} denotes the optimum amount of seed to be stocked of the r-th species by the i-th farm. The total optimum seed of all species is derived first, and then the optimum seed for each species is calculated from a linear combination of stockings of that species on efficient farms such that the sum of optimum amount of seeds for individual species equals the total efficient seed input computed from the model. Furthermore, the estimated optimum stocking densities are consistent with the frontier production levels for each species, also obtained from a linear combination of production levels of that species on efficient farms.

16.4 The data and the variables

16.4.1 The data

The data for this study came from a research project ‘bioeconomic model of Chinese integrated fish farming,’ conducted jointly by the Freshwater Fisheries Research Center in Wuxi, China, International Development Research Center of Canada (IDRC), and the Network of Aquaculture Centers in Asia-Pacific (NACA) in 1984/1985. The project covered eight provinces: Anhui, Heilongjiang, Jiangxi, Shandong, Hunan, Jiangsu, Zhejiang and Hubei, which are the major carp producing provinces in China. The study selected a sample of 117 fish farms in these eight provinces. Farms were not randomly selected due to the lack of information on the total number of fish farms in each province. Proportionately more farms were selected from those provinces where total fish production was greatest. Available information indicated, however, that a fairly representative sample was obtained for all provinces surveyed except for Hubei province, where the survey was restricted to two government-owned ‘model’ farms. Omitting these two farms in Hubei province, the total number of farms analyzed was 115.

A one-page questionnaire was administered to collect information on stocking and output of various fish species, feed, labor, and other inputs for one production year. The questionnaires were delivered to the selected farms at the end of 1984 and collected at the beginning of 1986. Technicians who worked on farms recorded all information for the project. The project researchers visited farms at the important production periods such as stocking and harvest times and verified collected information. Chen et al. (1995) provide further details on data collection and characteristics of sample farms.

To our knowledge this data set is the only comprehensive data available for polyculture fish farms, although they were collected several years ago. Additionally, most of the adjustments caused by the production contract system were thought to have been completed by 1984/85, and that no major changes in fish farming took place thereafter. This view is supported by the production data collected from a sample of fish farms in Jiangsu and Hubei provinces by NACA in 1994/95. For example, the average farm size in 1994/95 was 12.7 ha compared to 10.8 ha in 1984/85. Similarly, the average pond yields were 7190 and 6881 kg/ha, respectively. Although overall stocking rate has slightly increased in recent years, the stocking compositions of different species have been quite similar for the two periods.

16.4.2 The variables

Fish polyculture typically involves the production of several fish species or outputs using several inputs, including seed or fingerlings, feed, manure and fertilizers, labor, land and capital services. For the purpose of this study, based on their feeding habits, fish outputs are aggregated to following four ecological categories, all measured in kilogram per hectare as follows:

Y_1 carnivores black carp (*Mylopharyngodon piceus*);

Y_2 herbivores grass carp (*Ctenopharyngodon idella*);

Y_3 filter-feeders - silver carp (*Hypophthalmichthys molitrix*) and bighead carp (*H. nobolis*); and

Y_4 and omnivores or 'other species' - common carp (*Cyprinus carpio*), crucian carp (*Carassius auratus*), Chinese beam (*Megalobrama amblycephala*), tilapia and miscellaneous species not included in other categories.

Similarly, the inputs involved in fish polyculture are also aggregated into four categories, all expressed on annual basis, as follows:

Seed (X_1) represents the total amount of seeds (fry) of all species released to the pond, measured in kg/ha;

Feed (X_2) denotes the total dry weight of feed, measured in ton/ha with green feed quantity converted to dry weight equivalent by multiplying it by 0.2 (Tan, 1970);

Labor (X_3) represents the total expenses for family and hired labor used in fish farming, measured in yuan/ha (because number of hours worked per year was not available); and

Other costs (X_4) represent the total expenses on manure, fertilizers and fuel, health expenses and depreciation costs, measured in yuan/ha.

Output prices needed to calculate overall economic or 'revenue' efficiency are represented by P_r ($r = 1, \ldots, 4$) and measured in yuan/kg. Summary statistics for outputs, inputs, and output prices are presented in Table 16.1.

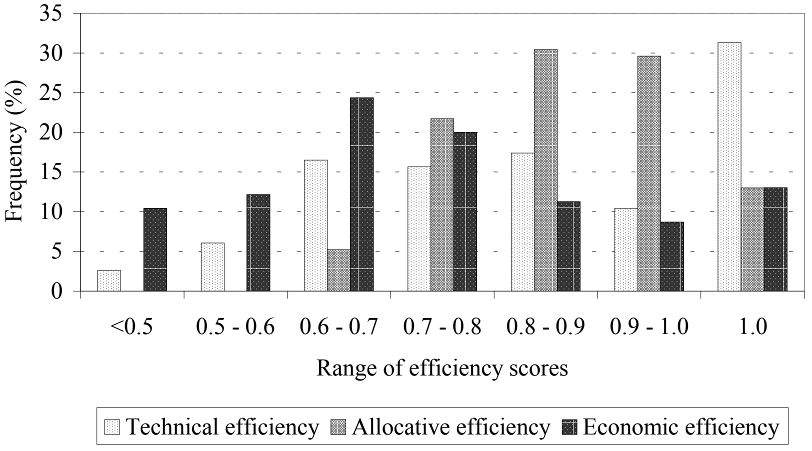

Fig. 16.2 Frequency distributions of technical, allocative and economic efficiency measures for Chinese fish farms

It would be interesting to identify the various farm-specific factors, such as farm size, experience, age and level of education of farmers, and the adoption of improved management practices that may significantly influence the efficiency levels of the sample fish farms. Unfortunately, except for pond size there exists no information on such variables for the farms involved in the study. To analyze the effects of pond size on efficiency, the sample fish farms are grouped into three size categories: small (< 5 ha), medium (5 – 10 ha) and large (> 10 ha).

Table 16.1 Summary statistics of outputs, inputs and output prices for Chinese fish farms

	Mean	Standard deviation	Minimum	Maximum
Outputs (kg/ha)				
Black carp	178.7	486.3	0.0	3,421.4
Grass carp	1,936.4	1,049.0	210.3	5,115.4
Filter-feeder	3,194.4	1,182.5	982.1	6,436.2
Other carp	1,571.2	1,113.7	55.2	6,829.8
Inputs				
Seed (kg/ha)	968.5	583.0	121.8	2,519.3
Feed (ton/ha)	21.3	14.6	2.5	82.1
Labor (yuan/ha)	3,409.8	2,842.0	420.0	14,531.4
Other costs (yuan/ha)	3,091.5	2,163.8	312.5	11,030.0
Output prices (yuan/kg)				
Black carp	4.11	1.21	0.35	9.00
Grass carp	3.28	0.64	0.85	4.99
Filter-feeder	1.80	0.36	1.08	2.77
Other species	2.91	0.66	1.64	6.36

Farmers' performance also depends on various socio-economic factors, notably the level of local development and provision of infrastructure, which in turn affect the farmer's access to inputs, availability of modern technologies, and level of farmer's education and technical know-how.

To examine the effects of socio-economic conditions on efficiency levels, depending upon the level of development, provision of infrastructure, and income levels the sample provinces are divided into two development levels: low (Anhui, Heilongjiang, Jiangxi, Shandong and Hunan) and high (Jiangsu and Zhejiang). Farmers in Jiangsu and Zhejiang have better access to infrastructure, inputs and modern fish farming technologies and a higher education level and hence are likely to be more efficient than those from the other provinces. As noted by Chen et al. (1995), the higher per capita incomes found in developed provinces (such as Jiangsu and Zhejiang) create larger market demands for fish, which in turn promote more intensive, efficient pond culture. On the other hand, limited fish demand in low-income provinces acts as a constraint on production.

16.5 Results and implications

The DEA model for computing technical efficiency (Eqn. 16.1) was solved using DEAP 2.1 (Coelli, 1996) and that for economic or 'revenue' efficiency (Eqn. 16.3) was solved using a general linear programming package, LINGO (1995) as the procedure for calculating 'revenue' efficiency is not available in DEAP 2.1.

16.5.1 Technical, allocative and economic efficiencies

The estimated technical efficiency scores for the sample of Chinese fish farms vary from 0.39 to 1.0, with a sample average of 0.83. Allocative efficiency measures range from 0.66 to 1.0, with an average of 0.87. Similarly, the 'revenue' or economic efficiency indices vary from 0.33 to 1.0, with a mean of 0.74. Of the 115 farms involved in the study, 36 (or 31%) are found to be technically efficient and 15 (or 13%) are allocatively and economically efficient. Frequency distributions of the estimated efficiency scores are depicted in Fig. 16.2. The majority of sample farms have allocative efficiency index within the range of 0.8 – 0.9 and economic efficiency index within the range of 0.6 – 0.7.

As shown by analysis of variance results in Table 16.2, both smaller farm size and higher level of development tend to improve technical and economic efficiencies, but interestingly not allocative efficiency. The small farms (< 0.5 ha) are technically and economically more efficient than the large ones (> 10 ha). Although this finding contradicts a popular belief that larger farms are able to capture economies of size and operate at higher efficiency levels than smaller ones, the negative relationship between farm size and efficiency in Chinese fish farms is, however, not unexplainable. Because their pond area is limited, small farms are likely to put more efforts into maintaining their fishponds, feeding, and monitoring of fish health and hence tend to be more efficient. The farmer's ability to follow these regular activities decreases with farm size. Perhaps, the loss created from such management inefficiencies outweighs the gain from the economies of scale on large farms. As expected, farmers from the developed provinces are technically and economically more efficient than those from the under-developed areas.

16.5.2 Optimum stocking and input levels

The technically and economically optimum stocking and input levels are computed for both efficient and inefficient farms. These results are summarized in Table 16.3. On average, farmers have to decrease the stockings of black carp and other species and increase the stocking of grass carp. The decrease in stocking of black carp is unexpected considering its market value, which is the highest of all four species, but not surprising given the fact that only 5 out of 15 efficient farms produced black carp, that also in small quantities. The low optimum stocking of black carp could be attributed to high cost of snail, the major feed ingredient used for that species. Thus the high market value of black carp may be due to its low production level and high production cost.

Table 16.2 Effects of farm size and development level on technical, allocative, and economic efficiency levels among Chinese fish farms

	Technical efficiency	Allocative efficiency	Economic efficiency
Farm size			
< 5 ha (n = 31)	0.898^{a}	0.888^{a}	0.798^{a}
5 – 10 ha (n = 36)	0.834^{a,b}	0.866^{a}	0.724^{a,b}
> 10 ha (n = 48)	0.790^{b}	0.857^{a}	0.681^{b}
F-statistics	4.45**	1.01	4.47**
Development level			
Low (n = 55)	0.792	0.859	0.688
High (n = 60)	0.871	0.876	0.761
F-statistics	7.26***	0.88	5.21**

Different superscripts indicate that the pair-wise differences between different farm sizes for each of the three efficiency indices are significant at the 0.05 level.
F-statistics are tests of null hypotheses that efficiency is unaffected by farm size or development level.
n Represents the number of observations.
** Significant at the 0.05 level and *** significant at the 0.01 level.

Table 16.3 Actual and technically and economically optimum stocking and input levels for Chinese fish farms

	Technical efficiency			Economic efficiency		
	Efficient Farms (n = 36)	Inefficient farms (n = 79)		Efficient farms (n = 15)	Inefficient farms (n = 100)	
	Actual/ optimum	Actual	**Optimum**	Actual/ optimum	Actual	**Optimum**
Seed (kg/ha)						
Black carp	120.4	24.5	28.3	9.6	61.2	0.5
Grass carp	316.1	380.5	325.4	378.9	345.2	412.0
Filter-feeder	375.3	337.9	418.8	353.0	361.4	360.1
Other species	218.2	197.6	142.9	202.2	204.4	186.1
Total	1,030.0	940.5	915.4	943.7	972.2	958.8
Other inputs						
Feed (ton/ha)	18.8	22.4	21.3	15.8	22.1	21.4
Labor (yuan/ha)	2,718.3	3,724.9	2,507.8	1,988.9	3,622.9	2,488.5
Other costs (yuan/ha)	2,854.9	3,199.3	2,864.7	2,675.9	3,153.8	2,883.7

By comparing the total actual and total optimum stocking rates, on average, the sample farmers are fairly efficient in terms of the total amount of seed being stocked in the pond, but they are inefficient in terms of the choice of optimum composition of different species. Among other inputs, on average the sample farms are most efficient in using feed and least efficient in utilizing labor.

Table 16.4 provides the average deviations from the optimum production and stocking levels of different species for the sample farms that are economically inefficient. Except for black carp the majority of inefficient farms are producing less of every species compared to optimum levels. Similarly, the majority of inefficient farms have under-stocked the seeds of grass carp and filter-feeders and over-stocked black carp.

Table 16.4 Average deviations below (-) and above (+) the ecnomically optimum production and stocking levels of each species for economically inefficient farms (n = 100)

	Production (kg/ha)		Stocking (kg/ha)	
Species	Below-optimal	Above-optimal	Below-optimal	Above-optimal
Black carp	-4.6 (18)	320.5 (62)	-0.6 (15)	93.5 (65)
Grass carp	-1,148.2 (66)	462.4 (34)	-125.3 (55)	156.1 (45)
Filter-feeder	-2,375.4 (88)	684.9 (12)	-171.0 (61)	96.2 (39)
Other species	-1,804.5 (89)	376.8 (11)	-92.5 (49)	124.6 (51)

Figures in parentheses denote the numbers of inefficient farms in each cateogory. Note that values for black carp do not sum to 100 as some inefficient farms do not produce that species.

16.5.3 Policy implications

By operating at full efficiency the sample farmers would substantially increase output or revenue, reduce cost, and raise profitability of fish production. These results are presented in Table 16.5. Accordingly, on average the sample farmers would increase their production by more than 3,450 kg/ha and revenue by 7,773 yuan/ha, which are respectively 50% and 45% of actual or observed values. In addition, the sample farmers would be able to save about 11% of their production costs by operating at full efficiency levels. These cost savings result from the elimination of excess inputs (input slacks) in production. As a result of an increase in revenue and decrease in cost, by operating at full efficiency the sample fish farmers, on average, would be able to increase their per hectare profit by as much as 218%.

Table 16.5 Average potential increases in output and profit levels for Chinese fish farms (n = 115)

		Potential increases at full efficiency			
	Actual	Technical	Allocative	Total	Percent
Output (kg/ha)	6,881	1,957	1,500	3,457	50.2
Revenue (yuan/ha)	17,416	7,157	616	7,773	44.6
Cost (yuan/ha)	13,166	-1,263	-216	-1,479	-11.2
Profit* (yuan/ha)	4,250	8,420	832	9,252	217.7

*Profit equals revenue minus cost.

The incremental output at full economic or ‘revenue’ efficiency comes almost equally from improvements in both technical and allocative efficiencies, while total efficiency gains for revenue, cost, and profit come mainly from the improvement in technical efficiency. For example, the contribution of allocative efficiency to increased output at full economic or ‘revenue’ efficiency is 43%, while the corresponding value for increased revenue is just 8%. This is due to the decline of share of high value black carp in total output at full economic efficiency compared to that for total output at full technical efficiency. The results suggest that improvement in technical efficiency is key to economic success of Chinese fish farms.

In view of rapid growth and the changes in the institutional arrangement of fisheries production in recent years, the inverse relationship between farm size and efficiency levels provides some useful insights into the future performance and sustainability of pond fish culture in China. Comparing the 1984/85 data and the 1994/95 NACA Aquaculture Sustainability and Environment Survey data, it is found that the proportion of small farms (< 5 ha) has increased, while that of medium (5 – 10 ha) and large (> 10 ha) farms has decreased significantly in recent years. However, the average farm size has not changed much. This indicates that, compared to the 1980s, most of the farms are getting smaller, while a few large ones are getting larger in the 1990s. Thus, the mean efficiency levels may have gone up in recent years, but there still may exist some potential for improvement. However, this need to be verified formally by conducting a similar study based on the recent data. The results also indicate that provision of infrastructure, adequate inputs and modern fish farming techniques is crucial to improve the productive performance of pond fish culture in China.

16.6 Conclusions

Output-based DEA, a nonparametric efficiency measurement technique was used to derive technical, allocative, and economic or ‘revenue’ efficiency measures and to compute optimal stocking densities of different fish species in Chinese fish polyculture. The multi-output multi-input production structure for fish polyculture is defined in terms of four output categories (black carp, grass carp, filter-feeders and other species) and four input categories (seed, feed, labor and other costs).

The mean technical, allocative, and economic efficiencies for the sample fish farms are estimated to be 0.83, 0.87, and 0.74, respectively. Of 115 farms included in the analysis, 36 were technically and 15 were allocatively and economically efficient. The results indicate that smaller farms and those from the developed provinces are technically and economically more efficient than larger ones and those from the underdeveloped provinces. The results indicate that, on average, farmers should increase the stocking of grass carp and decrease that of black carp. By operating at full efficiency, the farmers would be able to increase production from 6,881 to 10,338 kg/ha and profit from 4,250 to 13,501 yuan/ha.

It is interesting to note that, based on the 1984/85 data used in the present study, technical inefficiency in Chinese fish farms practicing polyculture accounted for most of the economic inefficiency. In other words, Chinese fish farms, on the average, had adjusted quite well to the prices of the different fish species in the market in selecting the proper species combination. However, there could be room for the improvement in the species combination from a technical or economic point of view. This is in contrary to the general belief that most Chinese fish farms are technically efficient with respect to the proper choice of species combination and inefficiency would most likely be stemmed from the difficulty in adjusting to the market prices of the different species after the open-market policy. Although it would be difficult to extend such conclusion to the present situation in Chinese fish farms, available information seems to suggest that present situation is quite similar to the mid-eighties, particularly that market reforms were already well underway during that time.

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