AN ECONOMETRIC ANALYSIS OF FISH SEED PRODUCTION BY GOVERNMENT FISHERY STATIONS IN NORTHEAST THAILAND

BY

DOUNGHATAI SRICHAROEN

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ABSTRACT

As one aspect of government policy to alleviate poverty in Northeast Thailand, the role of fishery development and extension in this region has been increasing significantly. However successful policy requires considerable knowledge of fishery technology, and such information has been inadequate. This study was conducted in response to this requirement.

The main objective of this study is to obtain econometric estimates of a fish seed production function for Northeast fishery stations. Two functional forms were assumed for production functions, namely Cobb-Douglas and transcendental logarithmic (translog) functions. The study employed pooled cross section-time series data for eleven fishery stations in the Northeast over a period of three years, 1987-1989.

Econometric results indicated that the transcendental logarithmic model fitted the data better than the Cobb-Douglas model, although an intermediate model (incorporating some but not all second order terms) appeared to provide the best fit. The main factors or inputs determining fish seed production were total weight of female broodstock, fuel (for a water pump), labour, and feed. Furthermore, water condition also affected output. In contrast other inputs such as lime and fertilizer did not significantly affect output. Differences in breeding techniques, location of stations, and the annual time period also had no impact on fish seed production.

The estimated production function exhibited increasing returns-to-scale. First-order conditions for profit maximization and cost minimization were tested using estimates of

the production function. The hypothesis of profit maximization was rejected, whereas the hypothesis of cost minimization was not rejected based on these test results. Assuming cost minimization, a second-order approximation to the dual cost function was calculated using production function estimates and mean data.

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Chapter I

INTRODUCTION

Approximately 19.25 million people or 35 percent of the total population live in Northeast Thailand, which is considered to be the poorest region of the country. Fish is the most important source of animal protein for these people, especially those who live in the rural areas. This is because, when compared to other sources of animal protein, market prices for fish are relatively low. Furthermore, fish can also be obtained by rural people directly from natural water sources such as rivers, swamps, canals, and streams.

A recent study by Khon Kaen University on fish consumption in the Northeast shows that the highest source of animal protein consumption in this region is freshwater fish (about 21.3 kg/head/year). Other major sources of animal protein are chicken (10.5 kg/head/year), pork (7.9 kg/head/year), and beef (6.2 kg/head/year). On the whole the total demand for freshwater fish in this region is approximately 394,981 metric tons per year [13].

The supply of freshwater fish in the Northeast includes fish produced within this region as well as imports from other regions. The total production within the region was approximately 44,237 metric tons (37,190 metric tons from natural water resources, and 7,047 metric tons from aquaculture) in 1987 [7].

Overall there is an excess demand for freshwater fish in the Northeast approximating 350,000 metric tons per year. This excess demand is satisfied by imports from other regions, in particular Central Thailand with higher prices to consumers due to transportation costs and other marketing margins. This situation worsens the poverty problem in this region.

The Department of Fisheries (DOF) under the Royal Thai Government aims to increase fish production in the Northeast to at least a level of self-sufficiency. Policies have been adopted to (1) increase capacity of natural water resources by releasing fish seed, fry and fingerling; and (2) improve water resources management, and provide fish seed and technical knowledge.

In order for the above policies to be implemented, the most important factor obviously is fish seed. At present the DOF has its fishery stations located in every province of Northeast region. The main duty of these stations is to produce fish seed mostly for release into natural water sources, and to provide aquaculture extension. In 1988 these stations produced 61.7 million fish seed, out of which about 73 percent were released in the natural water resources [6].

1.1 Objectives of the Study

In order to increase the fish seed supply in Northeast region, the Department of Fisheries has been improving the productivity of its fishery stations in producing fish seed. However, the improvement has normally focused on the biological techniques, such as stocking density, breeding technique, water control, etc. Little, if any, research has been conducted to improve the productivity of fish seed production.

The overall objective of this study is to estimate by econometric methods the production function for fish seed produced by the government fishery stations in Northeast Thailand. The specific objectives are as follows:

(i) to identify and describe the main factors affecting fish seed produced by the Northeast fishery stations.

(ii) to derive the production function of fish seed produced by the Northeast fishery stations.

(iii) to make recommendations for the improvement of productivity of fish seed production by the Northeast fishery stations.

1.2 Assumptions of the Study

The following assumptions are critical to the econometric model in this study:

(i) due to the unavailability of data for inputs used by each species of fish seed produced, it is assumed that the production processes for each species are identical (or of Gorman Polar form). Therefore, the product of each species can be aggregated consistently into one total product. Information obtained from fisheries' biologists responsible for producing fish seed is consistent with this assumption.

(ii) it is assumed that the aggregate production function for fish seed can be approximated adequately by a transcendental logarithmic (translog) functional form. It is well known that flexible functional forms provide a second order Taylor series approximation to any true functional form [2,4], and the translog is the most popular flexible functional form.

1.3 Organization of the Study

This study is organized as follows. Chapter II gives background information about fisheries in Thailand, especially in the Northeast region. Chapter III briefly summarizes previous econometric studies on fisheries production functions. Chapter IV briefly summarizes the economic theory used in this study, discusses criteria for selecting functional forms for production functions, and presents the Cobb-Douglas, and transcendental logarithmic (translog) functional forms.

Chapter V presents the model specified for this analysis and the method used to analyze data, and describes the data collected for the study. Chapter VI presents econometric results for the study and discusses implications of these results. Chapter VII summarizes and concludes this study. This chapter includes recommendations for the Department of Fisheries, and for further study.

Chapter II

BACKGROUND INFORMATION

2.1 Fish Production in Thailand

Thailand covers a total area of 513,115 square kilometres which can be divided into four distinct regions: the mountainous region in the North, the semi-arid plateau in the Northeast, the Central plain region which is one of the most fertile rice growing areas in the world, and the South peninsula (please see **Figure 2.1**). The climate is tropical and is characterized by high temperatures of 27.6 C (81.7 F) on average, humidity 74.4% [19], and an average volume of 800 billion cubic meters of rainfall per year [23].

The climate described above makes agriculture the main activity of the Thai economy. In 1988, Thailand had a total population of 54.54 million [18], and a per capita income of 20,601 Baht or about US $ 812.98 [17].[1] Most people live in the countryside, and agricultural households account for 55 percent of the total households.

The total value of agricultural products exported in 1989 accounted for approximately 44.65 percent of total exports. The major agricultural products exported in 1989 were fishery products, rice, rubber and rubber products, cassava products, and sugar and products. These accounted for 21.69, 19.72, 13.86, 10.40, and 8.76 percent of the total agricultural exports respectively (**Table 2.1**).

[1] the exchange rate was US $ 1 = 25.34 Bahts in 1988.

Figure 2.1: Map of Thailand Showing Northeast and the Other Regions

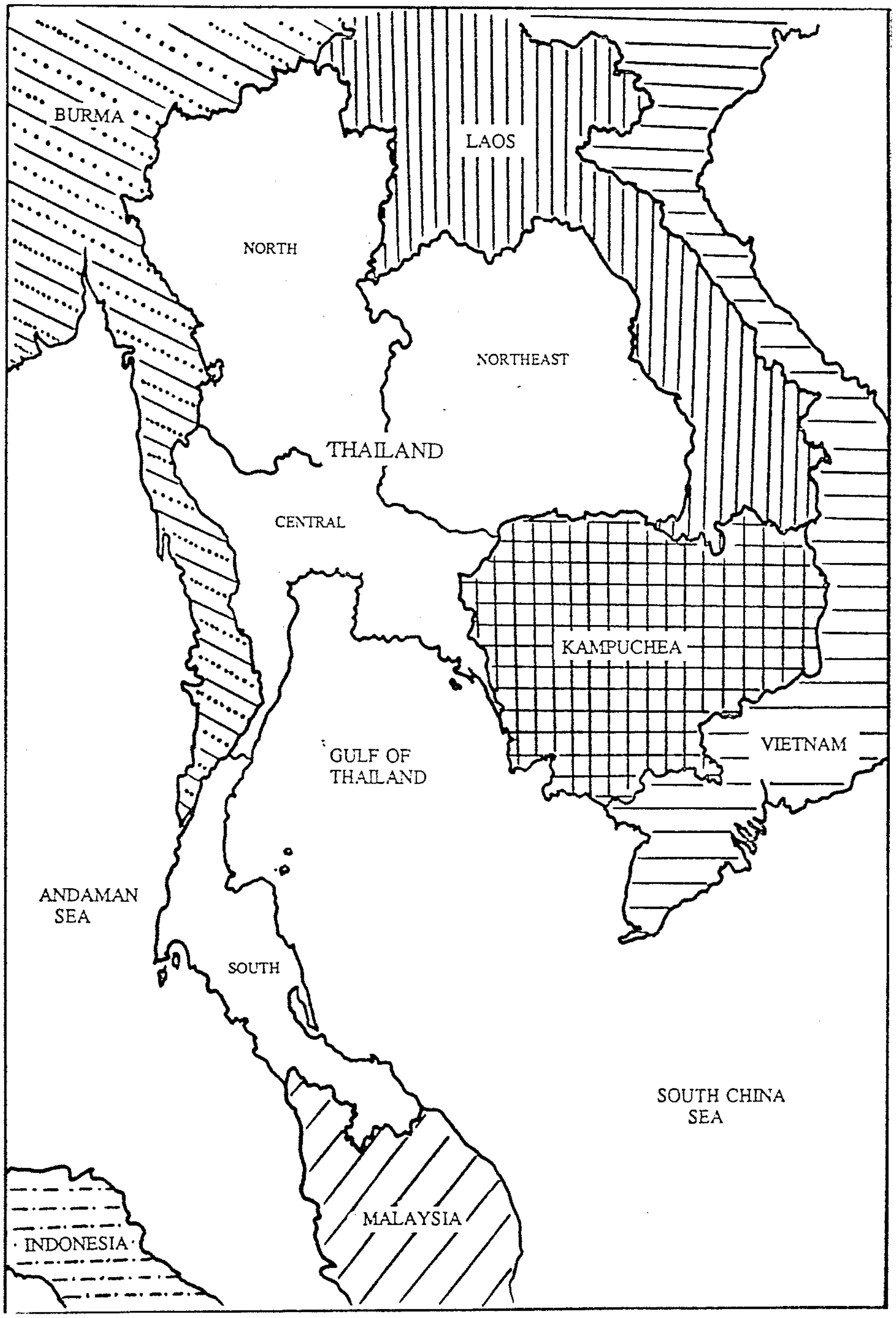


Table 2.1 : Value of Major Agricultural Exported Products, 1987-1989

Unit : million Baht

Products	1987		1988		1989	
	Value	%	Value	%	Value	%
Total	**153,991**	**100**	**194,198**	**100**	**230,537**	**100**
Fishery products	30,221	19.63	41,002	21.11	50,003	21.69
Rice	22,703	14.74	34,676	17.85	45,462	19.72
Rubber and products	23,328	15.15	31,824	16.39	31,953	13.86
Cassava products	20,662	13.42	21,845	11.25	23,975	10.40
Sugar and products	9,349	6.07	10,364	5.34	20,205	8.76
Others	47,728	30.99	54,487	28.06	58,939	25.57

Source : Office of Agricultural Economics, Centre for Agricultural Statistics. *Agricultural Statistics in Brief : Crop Year 1989/90.* Agricultural Statistics No.420, Bangkok, Thailand: Ministry of Agriculture and Co-operatives, 1990, p.56.

In this study, the term "fishery products" refers to both live and processed fish and other aquatic species, such as shrimp, crab, squid, mollusc, and sea weed, etc. These products comprise two main groups (freshwater and marine fishery products). Marine fishery product accounts for more than 90 percent of all fishery products.

Marine fishery products come from two sources. The first source is the coastal aquaculture (such as shrimp culture which has been dramatically increased during the last 10 years), seabass culture, green mussel culture, and sea clam culture. The second source is the capture fishery which is the main source of marine fishery products. The Gulf of Thailand and the Andaman Sea were plentiful sources of fish for Thai marine fishermen in the past. Unfortunately, due to a substantial increase in size of the Thai fishing fleet and the declaration of exclusive economic zones (EEZ) by neighbouring countries, these two sources became overfished.[2] However, as shown in **Table 2.2**, annual marine fishery products has been increasing from 762,187 metric tons in 1967 to 2,067,533 metric tons in 1977, and 2,446,100 metric tons in 1988.

Freshwater fishery products also come from two sources. The first source is freshwater aquaculture, for instance, cage culture, pond culture, ditch culture, and paddy-field culture,[3] and the second source is inland fisheries. The product from freshwater aquaculture has been increasing from 39,367 metric tons in 1978 to 89,782 metric tons in 1987, while the product from inland fisheries is almost stable (in fact there is a slight decrease from 102,129 metric tons in 1978 to 87,360 metric ton in 1987, as shown in **Table 2.3**,and **Table 2.4**).

[2] when a country declares an exclusive economic zone, it means that an area within 200 miles from the coast belongs to that country, and other countries have no right to fish in that area without consent.

[3] Cage culture involves raising fish in a cage, which generally has a wood frame and is surrounded by net (usually nylon). The cage floats in the river near by the owners house. Pond culture involves raising fish in an earth pond normally located in a private area. In horticulture which is normally grown in rows, there are small water ditches dug between each row, and ditch culture involves raising fish in these ditch. Paddy-field culture involves raising fish in paddy-field and harvesting them together with rice.

Table 2.2 : Fisheries Production of Thailand, 1967-1988

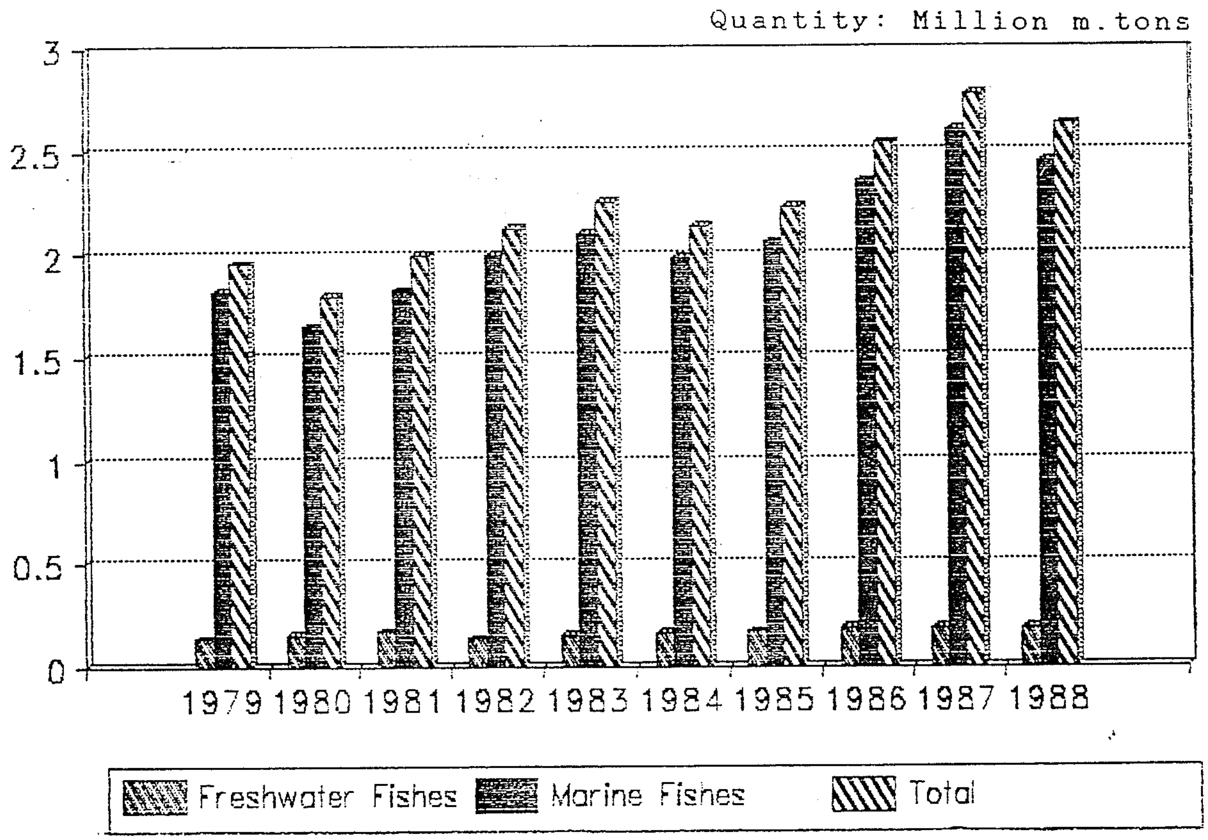
Unit : metric tons

Year	Freshwater Production	Marine Production	Total
1967	85,255	762,187	847,443
1968	85,245	1,004,058	1,089,303
1969	90,439	1,179,595	1,270,034
1970	112,714	1,335,690	1,448,404
1971	116,788	1,470,289	1,587,077
1972	131,383	1,548,157	1,679,540
1973	140,885	1,538,016	1,678,901
1974	158,876	1,351,590	1,510,466
1975	160,692	1,394,608	1,555,300
1976	147,294	1,551,792	1,699,086
1977	122,374	2,067,533	2,189,907
1978	141,496	1,957,735	2,099,281
1979	133,176	1,813,158	1,946,334
1980	143,895	1,647,953	1,791,848
1981	164,581	1,824,444	1,989,025
1982	133,562	1,986,571	2,120,133
1983	155,447	2,099,986	2,255,433
1984	161,819	1,973,019	2,134,838
1985	167,453	2,057,751	2,225,204
1986	187,763	2,352,204	2,539,967
1987	177,142	2,601,929	2,779,071
1988	183,600	2,446,100	2,629,700

Source: Department of Fisheries. *Annual report : 1989*. Bangkok, Thailand: Ministry of Agriculture and Co-operatives, 1991, pp.157-58.

Figure 2.2: Annual Freshwater and Marine Fishes Production,

1979 - 1988.



Source: Office of Agricultural Economics, Centre for Agricultural Statistics. *Agricultural Statistics in Brief : Crop Year 1989/90.* Agricultural Statistics No.420, Bangkok, Thailand: Ministry of Agriculture and Co-operatives, 1990, p.45.

Table 2.3 : Freshwater Production, 1978-1988

Unit : metric tons

Year	Inland Fishery	Freshwater Aquaculture	Total
1978	102,129	39,367	141,496
1979	103,714	29,462	133,176
1980	109,390	34,505	143,895
1981	116,468	48,113	164,581
1982	87,733	45,829	133,562
1983	108,481	46,966	155,447
1984	111,409	50,410	161,819
1985	92,199	75,254	167,453
1986	98,438	89,325	187,763
1987	87,360	89,782	177,142
1988	N.A	N.A	183,600

Source : Department of Fisheries, Fisheries Statistics Sub-Division. *Fisheries Statistics of Thailand 1987*. No.3/1989, Bangkok, Thailand: Ministry of Agriculture and Co-operatives, 1989, p.1.

Table 2.4 : Freshwater Aquaculture by Type of Culture in 1987

	Total	Cage	Pond	Ditch	Paddy-field
No.of fishfarms	71,859	922	61,804	866	8,267
Area of fishfarms (rai)	322,586	66	171,497	2,063	148,960
Production (metric tons)	89,782	936	65,687	1,056	22,103

Source : Department of Fisheries, Fisheries Statistics Sub-Division. *Freshwater Fishfarm Production 1987*. No.7/1989, Bangkok, Thailand: Ministry of Agriculture and Co-operatives, 1989, pp.19-88.

2.2 Fish Production in Northeast Region

The northeast region comprises about one third of the country's total area (**Figure 2.3**). The region consists primarily of wavy highlands with salty and sandy soils which have poor capability of holding water and are generally poor in plant nutrients. This region receives reasonable annual rainfall (approximately 30 percent of the total country's annual rainfall), but unfortunately the pattern of rainfall over the year is extreme. There is generally flooding in the rainy season (June-October) and drought in the dry season (March-May).

There are three main types of water sources for this region. The first type consists of rivers and canals. The rivers include the Chi river (442 km.), Mool river (673 km.), and Mekong river (4,335 km.), which are the three major rivers in this region [20]. Minor rivers include the Kam river, Songkram river, Loei river and Phong river. The second major source of water is reservoirs. Based on a survey by the Department of Fisheries in 1987, there are 834 reservoirs in this region with a total area of 1,186,855.55 rai.[4] The third source of water is natural and man-made swamps. There were 3,795 natural swamps and 1,267 man-made swamps covering a total area of 448,811.84 rai and 70,284.35 rai respectively. The total fishery production from these three groups was 37,190 metric tons in 1987 [8].

Fish farming in this region primarily consists of pond culture and paddy-field culture. There was a total of 28,519 fishfarms in 1987. 24,072 farms employed pond culture, and 4,433 farms employed paddy-field culture. Other farms employed ditch

[4] 1 rai = 1,600 square meters = 0.4 acre = 0.16 hectare.

culture and cage culture. The total output for all farms was 7,047 metric tons of freshwater fish in 1987 (**Table 2.5**).

As presented in the **Table 2.6**, the major freshwater fish produced in this area are Tawes (*Puntius gonionotus*), Nile Tilapia (*Tilapia nilotica*), and Common Carp (*Cyprinus carpio*). These three species account for about 85 percent of the region's total freshwater fish production.

Table 2.5 : Northeast Freshwater Aquaculture by Type of Culture, 1987

	Total	**Cage**	**Pond**	**Ditch**	**Paddy-field**
No. of fishfarms	28,519	3	24,072	11	4,433
Area of fishfarms (rai)	47,725	1	29,727	27	17,970
Production (metric tons)	7,047	5	5,960	1	1,081

Source : Department of Fisheries, Fisheries Statistics Sub-Division. *Freshwater Fishfarm Production 1987*. No.7/1989, Bangkok, Thailand: Ministry of Agriculture and Co-operatives, 1989, pp.21-98.

Figure 2.3: Northeast Region and the Study Area

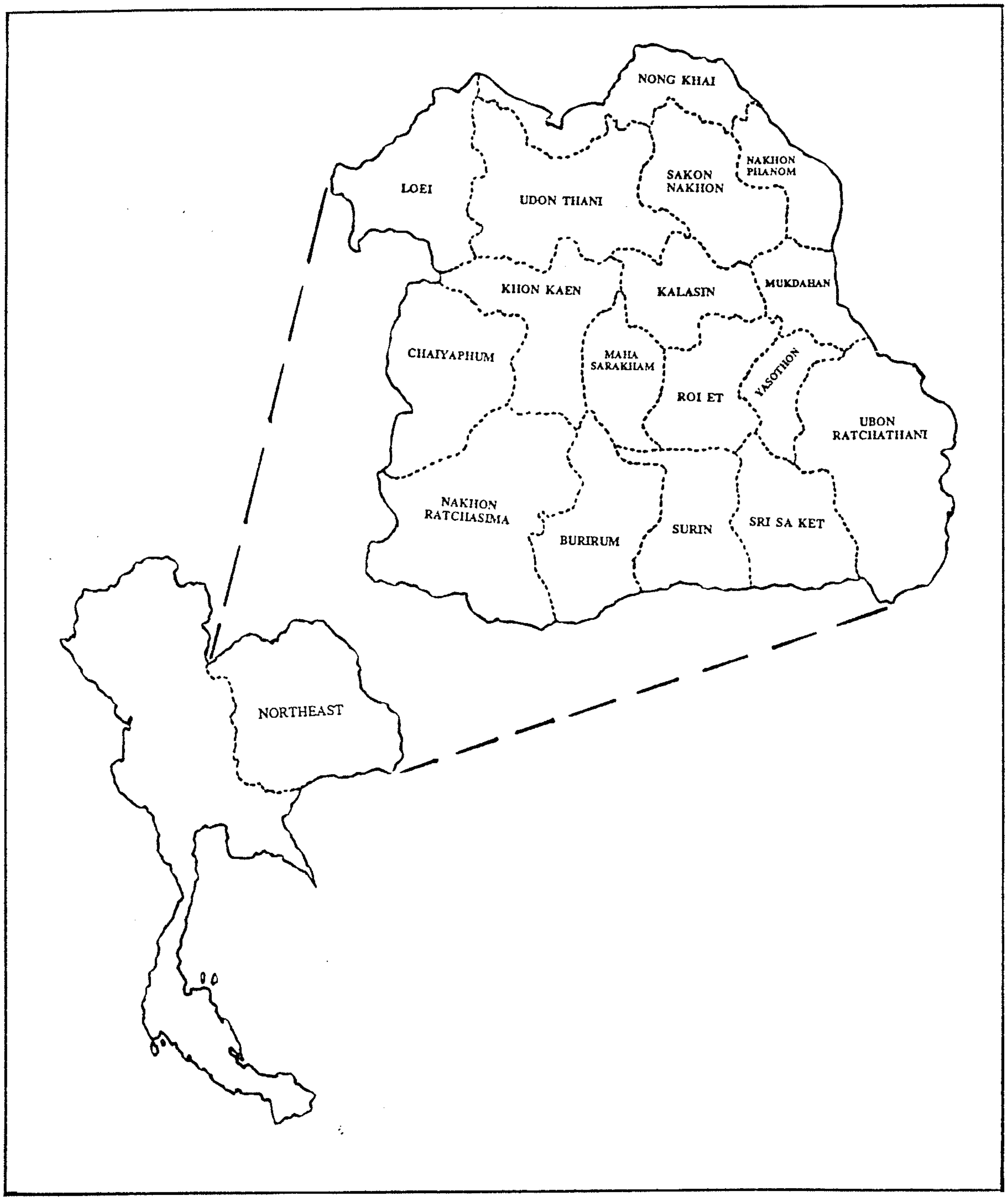


Table 2.6: The Northeast's Total Production of Fishfarms by Species, 1987

Common Name	Scientific Name	Quantity		Value (1,000 Baht)
		m.tons	%	
Total		**7,047.0**	**100**	**181,142.37**
Tawes	*Puntius gonionotus*	2,302.6	33	58,183.02
Nile Tilapia	*Tilapia nilotica*	2,159.1	31	52,845.63
Common Carp	*Cyprinus carpio*	1,550.9	22	39,418.43
Rohu	*Labeo rohita*	254.9	4	6,060.96
Chinese Carp	*Hypohthalmichthys*	215.2	3	5,380.10
Striped Snake Head	*Ophicephalus striatus*	172.7	2	6,424.31
Freshwater Catfish	*Clarias spp.*	112.5	2	4,474.35
Mrigal	*Cirrhina mrigala*	107.5	1	2,620.13
Others	-	171.6	2	5,735.44

Source: Department of Fisheries, Fisheries Statistics Sub-Division. *Freshwater Fishfarm Production 1987*. No.7/1989, Bangkok, Thailand: Ministry of Agriculture and Co-operatives, 1989.

2.3 Demand and Supply of Fish Seed in Northeast Region

Based on a study by Khon Kaen University, the demand for freshwater fish in the Northeast region is approximately 394,981 metric tons a year [13]. When compared to freshwater fish supply within the region, there is about 350,000 metric tons a year of excess demand for freshwater fish. This excess demand must be met by fish imports from other regions (primarily the Central region) and by increases in regional fish production on fishfarms.

In 1986 the total number of fishfarms in the Northeast was 22,332 with an area of 36,484 rai and total production of 5,803 metric tons. In the following year the number of fishfarms increased to 28,519 with an area of 47,725 rai and total production of 7,047 metric tons (**Table 2.7**).

Table 2.7: Comparisons of the Number, Area, and Production of Freshwater Fishfarms in Northeast Region between 1986 and 1987

	1986	**1987**	#▲	%▲
Number of Farm (farms)	22,332	28,519	+6,187	+27.70
Area (rai)	36,484	47,725	+11,241	+30.81
Production (metric tons)	5,803	7,047	+1,244	+21.44

Source: Department of Fisheries, Fisheries Statistics Sub-Division. *Freshwater Fishfarm Production 1987*. No.7/1989, Bangkok, Thailand: Ministry of Agriculture and Co-operatives, 1989.

The increase in both number and area of fishfarms led to an increase in demand for fish seed, which is the main input for fish farming. Unfortunately there is no data about the demand for fish seed in the Northeast region. However, it can be roughly approximated from the following formula:

$$(2.1) \quad \text{Total fish seed required} = \frac{\text{Total amount of fish produced}}{\text{Survival rate}}$$

Where;

$$\text{Total amount of fish produced} = \frac{\text{Total weight of fish produced}}{\text{Weight/fish at harvesting time}}$$

Total weight of fish produced = Total production

Weight/fish at harvesting time = Harvesting size

Therefore (2.1) can be rewritten as;

$$(2.2) \quad \text{Total fish seed required} = \frac{\text{Total production}}{\text{(Harvesting size)(Survival rate)}}$$

Since the harvesting size and survival rate differ from species to species, the total fish seed required has to be computed by species. Assume that the average harvesting size is 0.4 kg. for Rohu, Chinese Carp, and Mrigal and 0.2 kg. for other species. The survival rate is 70% for every species except Chinese Carp, which has a survival rate of

60% [22]. By using total fish farm production in 1987 from **Table 2.6**, the total fish seed required can be computed from equation (2.2) as shown in **Table 2.8.**

Table 2.8: Total Fish Seed Required for Fish Farming in Northeast Region : 1987

Species	**Total Production** (m.tons) (1)	**Harvesting Size (kg)** (2)	**Survival Rate** (3)	**Total Fish Seed Required(million)** (4)=1000(1)/(2)(3)
Total	**7,047.0**	-	-	**48.48**
Tawes	2,302.6	0.2	0.7	16.45
Nile Tilapia	2,159.1	0.2	0.7	15.42
Common Carp	1,550.9	0.2	0.7	11.08
Rohu	254.9	0.4	0.7	0.91
Chinese Carp	215.2	0.4	0.6	0.90
Mrigal	107.5	0.4	0.7	0.38
Others	456.8	0.2	0.7	3.26

Based on equation (2.2), approximately 48.48 million fish seed were required by Northeast fishfarms in 1987. Given an increase in number and area of fishfarms in this region, it is reasonable to believe that the demand for fish seed is now greater than 48.48 million. Furthermore if the number of fish seed being released into various water sources in order to increase fisheries capability is also considered, the total demand for fish seed in this region will be very much higher than 50 million. For example, if every year the DOF has to release fish seed at the rate of 1,000 per rai into at least 10 percent of the total area of all water sources in the Northeast region (2 million rai), the total amount of fish seed to be released will be about 200 million a year. Therefore, the total demand for fish seed for both fishfarms and water resources management will be approximately 250 million.

On the supply side, there are two groups of fish seed suppliers. The first group is private hatchery farms which consisted of only 41 farms in the Northeast region in 1987 [9]. Although data on fish seed production by these farms is unavailable, the total fish seed supplied by these 41 farms can be calculated from a study by **Tomich** [25]. Tomich found that the average production of fish seed per farm is approximately 2.5 million per year. Therefore total supply of fish seed from 41 hatchery farms in this region may approximate 102.5 million.

The second group of fish seed suppliers is the DOF's fishery stations recently located in every province of the Northeast. These stations produce at least 100 million fish seed per year.

In sum, the total supply of fish seed within the region should be at least 200 million per year (102.5 million from private hatchery farms and 100 million from the DOF's fishery stations).

2.4 Role of the Department of Fisheries in Producing Fish Seed

Fish seed produced by the DOF's fishery stations is normally utilized as follows:

1. release in water bodies for resource management purposes, or, in other words, to increase fisheries capability of public water sources.

2. in fisheries biological research.

3. in aquaculture demonstration and extension.

4. as supply for the fish seed market.

From the previous section, it is apparent that the DOF's fishery stations produce about half of the total fish seed produced in Northeast region, and approximately 70 percent of this is released into water resources. Although the DOF does not want to compete with private nursery fishfarms in the fish seed market, the DOF has to be in the market because sometimes supply from private nursery farms is not adequate to meet the demand.

Chapter III

REVIEW OF RELATED STUDIES

Most studies on fisheries production have focuses on the private sector. Few, if any, studies have been carried out on the government sector. The previous studies on production analysis of private fish farms are summarized in this chapter.

A study by **Panayotou, Wattanutchariya, Isvilanonda, and Tokrisna** [21], *The economics of catfish farming in central Thailand*, focused on the technology and economics of private catfish farms in central Thailand. Data was collected from records of the grow out farms (fish farms that raise fish from fry and fingerling size to marketable size) in two provinces of the central region. A Cobb-Douglas production function was used to determine the input-output relationship in this study. The authors defined output as yield in kg/m^2 of pond area. There were eight inputs included in the model, namely, number of stocked fingerlings/m^2, quantity of trashfish input (kg/m^2), quantity of broken rice input (kg/m^2), quantity of rice bran (kg/m^2), amount of fuel (kg/m^2) (as a proxy variable for water quality), cost of chemical and medication (Baht/m^2), labour in man-days/m^2, and cost of building, machinery and equipment (Baht/m^2).

Furthermore, the authors used dummy variables to test the influences of farm size, farmers' experience, and farm location on output. They classified farm size into three groups; small, medium, and large. The average number of years in catfish farming was used to classify farmers by experience into two groups; above average experience, and less than average experience. Farm location was classified by the two different area of the study.

According to econometric results, eighty percent of the variation in output could be explained by stocking rate, feeding rate of trashfish, and broken rice, fuel for pumping water, chemical and medication applied, size of farm, and experience of the farmer. By summing up the significant coefficient for eight inputs, the authors concluded that increasing returns-to-scale exists for catfish farming in the study area. The authors also recommended whether the level of each input should be increased or decreased, under the assumption of profit maximization, by comparing the value of marginal product with price of the corresponding input. However, they did not determine the optimum level of each input.

Chong, Lizarondo, Holazo, and Smith [3] used grow out private milkfish farms as samples for their study, *Inputs as related to output in milkfish production in the Philippines*. A Cobb-Douglas production function was also applied in order to estimate the input-output relationship of milkfish production. Data was collected by recall and record keeping surveys from 324 farms among seven provinces of the Philippines. There were eleven inputs specified in the model: age of ponds, quantity of fry stocked, quantity of fingerlings stocked, acclimatization time before stocking, hired labour, miscellaneous operating costs, experience of respondent, cost of pesticides, quantity of organic fertilizers, quantity of inorganic fertilizers, and farm size.

The results of their study showed that quantity of fry and fingerlings stocked, miscellaneous operating cost, age of ponds, and fertilizers (both organic and inorganic) were important inputs in explaining output.

Unlike the results from the study by **Panayotou, et al.**, the economies of scale in this study was determined by summing up all coefficients in the model irrespective of whether or not they were statistically significant. Increasing returns-to-scale was found for the national level model which defined input variables on a "per/farm" basis. This study also assumed that farmers are profit maximizers, and determined the optimum level of input by equating the value of marginal product to input price given the geometric mean level of input and output prices.

Tomich 's study [25], *A Review of Private Seedfish Production in Northeast Thailand*, focused on the production of private hatchery farms in the Northeast region of Thailand. Unfortunately, the author did not aim to determine the input-output relationship, instead, he was interested in cost and return from the production process.

However, his results indicated that among inputs used in the process of producing fish seed, feed and labour were the most significant inputs generating operating costs.

One of the objectives of **Purba**'s study [22], "An Economic Study of Fry Production Systems in Northeast Thailand", was the derivation of a production function for private hatchery fish farms in Northeast Thailand. The data used for the analysis was collected from 67 private hatchery farms in eight provinces. The author also employed a Cobb-Douglas functional form to estimate the input-output relationship. His model included six input variables: land, hired labour, manure, fuel and electricity, chemicals, hormone and pituitary gland, and feed. The author also considered differences in farm location by use of a dummy variable for rainfed area and irrigated area.

From the estimated results, three inputs, namely labour, manure, and energy, have significant effect in explaining output. The results further show that output is not influenced by the dummy variable for differences in farm location.

The authors of these studies did not clearly state whether they had tried other functional forms in estimating production functions. However, they gave the reasons for selecting the Cobb-Douglas functional form: its convenient properties [21], its fit with the data as indicated by the F-value and R^2 [3], and it appropriateness when sample size is small [22].

In contrast many recent studies of agricultural production have employed translog functional forms, which are more general than Cobb-Douglas functions. For example, a study by **Lau** and **Yotopoulus** [16], "The Meta-Production Function Approach to Technological Change in World Agriculture", compared results from the estimation of Cobb-Douglas and translog production functions. They employed cross-section data for 43 countries and three years (1960, 1970, and 1980). The authors classified these countries into two groups (developed and less developed countries).

A comparison of econometric estimates for the two specifications demonstrated significant differences in production elasticities for two inputs (land and machinery), whereas estimates for the other inputs (labour, livestock, and fertilizer) were similar in the two cases. The authors concluded that the translog model was more consistent with the limited information available in their study.

In sum, the above fishery production studies all specified the following categories of variable inputs: stocking rate, feed, fuel, fertilizer, and labour. The estimated coefficient of these inputs were statistically significant in at least in two out of the four studies. Translog functional forms should be considered as well as the Cobb-Douglas.

Chapter IV

THEORETICAL FRAMEWORK

This chapter consists of two sections. The first section briefly summarizes the basic economic theory of production used in this analysis. The second section briefly discusses the functional forms that were selected for this study.

4.1 Production Analysis

In the microeconomic theory of the firm, a firm produces commodities by transforming inputs into outputs in accordance with its production function. The production function can be generally written as:

$$(4.1) \qquad Y(y,x) = 0$$

where x is an n-dimensional vector of non-negative inputs, and y is an (m-n)-dimensional vector of non-negative outputs.

In the case of single output (4.1) can be rewritten as:

$$(4.2) \qquad y = f(x)$$

where $f(x)$ is defined to be single valued; that is, for any unique combination of inputs x there corresponds a unique level of output y. In other words, the production function yields the maximum output for an arbitrary input vector [2].

Many implications can be drawn from the estimated production function such as:[5]

(i) **Factor Elasticity (Ei)**, also called "Partial Elasticity of Production". This measures the percentage change in output due to a percentage change in an input while all other inputs are held constant.

$$E_i = \frac{\%\text{ change in } y}{\%\text{ change in } x_i} \tag{4.3}$$

$$= \frac{\partial y / \partial x_i}{y / x_i}$$

$$= \frac{MPPi}{APPi}$$

where y is output, x_i is input i, MPP is the marginal physical product, and APP is the average physical product.

(ii) **Elasticity of Scale** (ε), also called "Total Elasticity of Production" or "Function Coefficient". This measures the percentage change in output as all inputs are varied in proportion. The elasticity of scale can be derived by summing up all the factor elasticity in the function.

[5] the detail of these implications can be found in various economics text books, such as *The Economics of Production* by Beattie and Taylor [1], *Microeconomic Theory : A Mathematical Approach* by Henderson and Quandt [12], *Microeconomic Analysis* by Varian [26].

$$(4.4) \qquad \varepsilon = \Sigma_i E_i \qquad i=1,\ldots\ldots,n$$

The elasticity of scale is a measure of the returns-to-scale of production function. If ε is not constant but depends on the level of inputs, then the returns-to-scale differs from point to point on the production surface. On the other hand, if ε is constant, then the production function is a homogeneous function, or it exhibits constant proportional returns.

If $\varepsilon = 1$, the production function exhibits "constant returns-to-scale" which is one type of a homogeneous function. This implies that output will increase in the same proportion as all inputs.

If $\varepsilon < 1$, the production function exhibits "decreasing returns-to-scale" in which the proportionate increase in output is less than the proportionate increase in all inputs.

If $\varepsilon > 1$, the production function exhibits "increasing returns-to-scale" in which the proportionate increase in output is greater than the proportionate increase in all inputs.

(iii) **Profit Maximization**. The first-order conditions for an interior profit maximum (under perfect competition) are that the value of marginal physical product of each input is equal to its price.

$$(4.5) \qquad VMP_i \equiv p.MPP_i = w_i$$

where VMP_i is the value of marginal physical product of input x_i

p is price of output

MPP_i is the marginal physical product of input x_i

w_i is price of input x_i

(iv) **Cost Minimization**. The first-order conditions for an interior cost minimum are that the marginal rate of technical substitution between each input pair is equal to their price ratio.

$$(4.6) \qquad MRTS_{ij} \quad \equiv \quad (MPP_i)/(MPP_j) \quad = \quad w_i/w_j$$

where $MRTS_{ij}$ is the marginal rate of technical substitution between input x_i and input x_j.

4.2 Functional Forms for Production Functions

Since the true relationship between inputs and output are not known, a difficult task for researchers is how to specify a model that closely approximates the unknown functional form of production process. For this study Cobb-Douglas and translog functional forms are specified.

These two functional forms were selected for three reasons.[6] (a) their simplicity in econometric estimation of production functions and in the derivation of factor elasticities and elasticity of scale, (b) the translog is a flexible functional form, and (c) the Cobb-Douglas is nested within the translog function, and this facilitates statistical discrimination between the two models.

[6] A CES production function was also considered initially in this study, but initial econometric results were unreasonable. Therefore, the CES model was excluded from this study.

(i) **Cobb-Douglas Production Function**. Originally the Cobb-Douglas production function contained only two inputs, capital (K) and labour (L), and it was assumed to be homogeneous of degree 1 in capital and labour, which implied constant returns-to-scale [5].

(4.7) $$y = \alpha K^{\beta} L^{(1-\beta)}$$

Later on the Cobb-Douglas function was generalized to more than two inputs and for all types of the returns-to-scale. The general functional from was changed to be

(4.8) $$y = \alpha x_i^{\beta i} .... x_n^{\beta n}$$

where x_i = input i, β_i is the partial elasticity of input x_i, and $\Sigma\beta_i$ is the returns-to-scale parameter. Production is increasing, constant, or decreasing returns-to-scale if $\Sigma\beta_i$ is greater than, equal to, or less than unity, respectively.

Some characteristics of the Cobb-Douglas production function can be summarized as follow [5]:

- homogeneous of degree $\Sigma\beta_i$ which is the returns-to-scale parameter
- partial elasticity of production for input i is determined by β_i, and is constant
- all input must be used for output to be produced
- there is no finite output maximum at a finite level of input used

- for a given set of parameters, the function can represent only one stage of production.

(ii) **Translog Production Function.** One criterion for selecting the appropriate functional form is that the form should not place prior restrictions on properties of the production function that are of empirical interest. A flexible functional form such as the translog meets this criterion more adequately than the Cobb-Douglas functional form previously discussed. The Cobb-Douglas implies that all elasticities of substitution are equal to one, whereas the translog does not impose such restrictive properties on the production function. More generally the translog provides a second order Taylor series approximation to the unknown true production function (and the Cobb-Douglas only provides a first order approximation) [2,4].

The translog production function is the most popular flexible function form employed in applied research. The general form of the translog production function can be written as:

$$\ln y \quad = \quad \alpha + \Sigma_i \beta_i \ln x_i + \tfrac{1}{2}\Sigma_i \Sigma_j \delta_{ij}(\ln x_i)(\ln x_j) \qquad (4.9)$$

From equation (4.9) it can be seen that one problem with this functional form is that the number of parameters increases exponentially as the number of inputs included in the equation increases. Therefore, as the number of variables increase, this form requires a larger sample size in order to have sufficient degrees of freedom for econometric estimation. Another potential problem with this form is that, because it was derived as a second order Taylor series approximation to a true function, it will best represent the unknown true functional form if the variation in the data set is low. Otherwise a third or higher order Taylor series approximation may be more appropriate, but this would lead to an exponential increase in number of parameters to be estimated.

Chapter V

METHODOLOGY OF THE STUDY

The purpose of this chapter is to develop an econometric model for estimating the production function of fish seed for the Northeast fishery stations. The chapter begins with the econometric model developed for the production function estimation, and definition of the variables included in the model. The second part of this chapter discusses the methods used for the analysis. The last discusses on data collection.

5.1 Models and Variables

In general, the aggregate production function for fish seed can be specified as:

$$Y = f(BS, LI, FU, LB, FD, FR) \qquad (5.1)$$

where

Y	=	number of fish seed produced per square metre of pond area
BS	=	quantity of female broodstock used in breeding process (kg/m^2)
LI	=	quantity of lime applied (bag/m^2)
FU	=	quantity of fuel (diesel) used ($litre/m^2$)
LB	=	labour in $man\text{-}days/m^2$
FD	=	aggregate feed input quantity index (quantities weighted by 1987 feed prices) ($Baht/m^2$)

FR = aggregate fertilizer input quantity index (quantities weighted by 1987 fertilizer prices) (Baht/m^2)

Since both cross-section and time-series data were used in this study, dummy variables for location and time were included in the model.

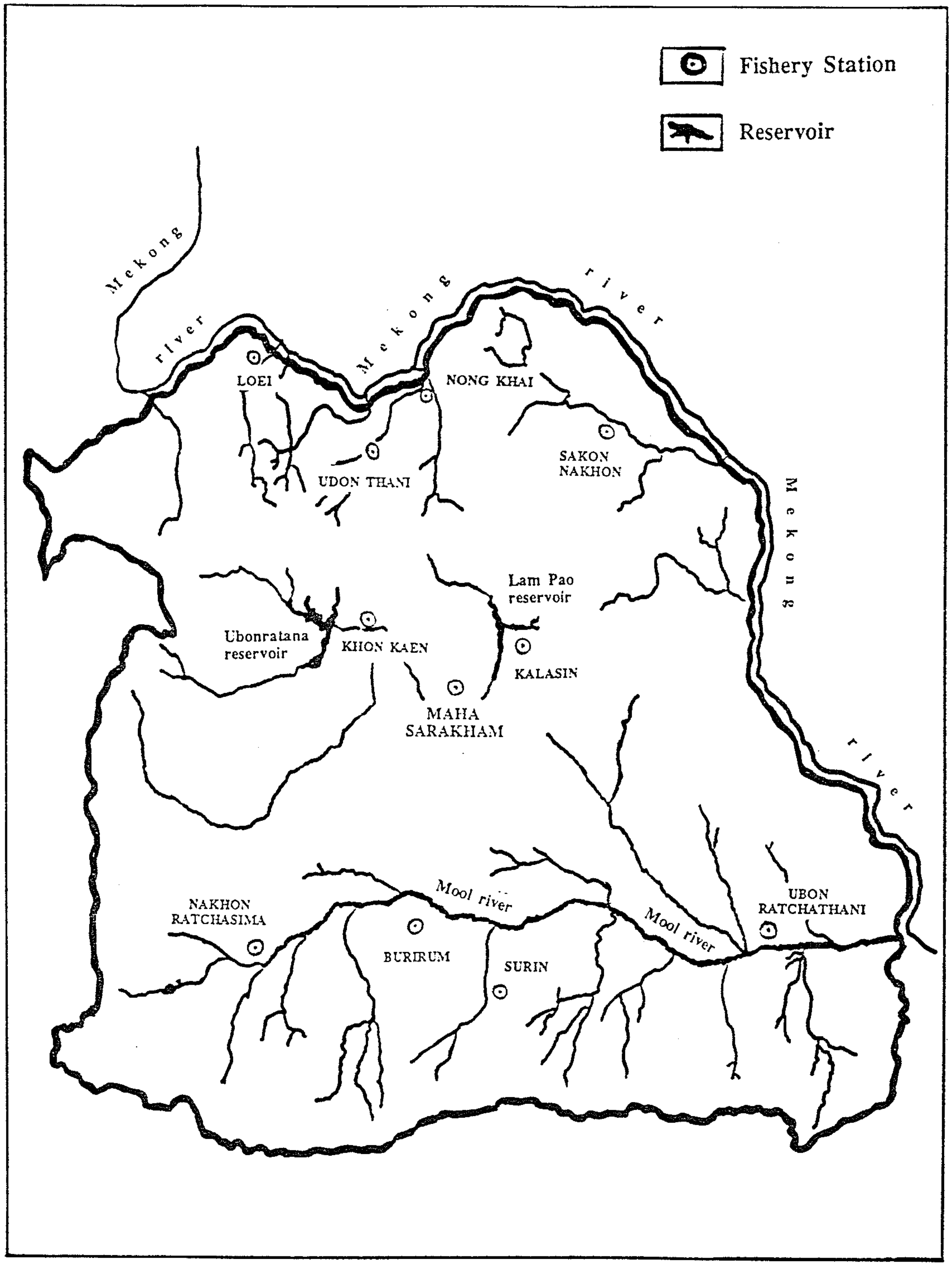
There are 11 different locations of the sample stations (one in each province), but due to the small number of observations it was impossible to assign one dummy variable for each location. Therefore, the 11 northeast provinces were aggregated into 3 groups. The first group was the upper northeast which comprises 4 provinces namely Loei, Udon Thani, Nong Khai, and Sakon Nakhon. The provinces in this group are located along the Mekong river except for Udon Thani which is a bit further inland. The second group was the central northeast consisting of 3 provinces, namely Khon Kaen, Maha Sarakham, and Kalasin. There are two major reservoirs located in this group, Ubonratana reservoir in Khon Kaen, and Lam Pao reservoir in Kalasin. The last group was the lower northeast including Ubon Ratchathani, Surin, Burirum, and Nakhon Ratchasima. The Mool river is the major water source for this group. This river passes through Nakhon Ratchasima, Burirum, Surin, and joins Mekong river at Ubon Ratchathani.

Two dummy variables, $\mathbf{L_1}$ and $\mathbf{L_2}$, were created to represent the 3 different group of provinces.

L_1 = 1 if the station is located in the upper Northeast, or = 0 otherwise

L_2 = 1 if the station is located in the lower Northeast, or = 0 otherwise.

Figure 5.1: Major Water Sources in Northeast Region



Source: Ruangrai Tokrisna, et al. "Analysis of Fish Marketing and Consumption in Northeast Thailand." Research paper, Bangkok, Thailand: Department of Agricultural Economics, Kasetsart Univ., July 1989, p.8.

Two other dummy variables, $\mathbf{T_1}$ and $\mathbf{T_2}$, were created in order to represent differences in time period.

T_1 = 1 if data was collected from the fiscal year 1987, or = 0 otherwise

T_2 = 1 if data was collected from the fiscal year 1988, or = 0 otherwise.

In general, water quality depends on the level of dissolved oxygen, pH level, water temperature, etc. Water quality is important in fish seed production function since it can affect the maturity of broodstock, the development of fertilized eggs and larvae, etc. Unfortunately, there was no quantitative data on water quality available for this study. On the other hand, it was possible to assess quantitatively whether fisheries had sufficient access to water. This will be referred to as the water condition.

The water condition was classified into 3 levels. The first level occurs when water is below normal condition. For example, water may not be adequate for the production process due to drought, or water may be polluted. The second level occurs when water is in normal condition, i.e. water is adequate for the production process. The third level occurs when water is above normal condition. For example fishery station may be located near a reservoir which can always supply water as requested by the fishery station, or alternatively water may be unusually high in soil nutrients. Therefore, two dummy variables, $\mathbf{W_1}$ and $\mathbf{W_2}$, were created to represent water condition.

W_1 = 1 if water condition is below normal, or = 0 otherwise

W_2 = 1 if water condition is above normal, or = 0 otherwise.

Finally, there were three types of breeding technique used among fishery stations during the period of study: pituitary gland, hormone, and both. Accordingly, dummy variables $\mathbf{BT_1}$ and $\mathbf{BT_2}$ were created where:

BT_1 = 1 if only pituitary gland was used, or = 0 otherwise

BT_2 = 1 if both pituitary gland and hormone were used, or = 0 otherwise.

The general model, equation (5.1), after incorporating these 8 dummy variables can be written as:

$$(5.2) \qquad Y = f(BS, LI, FU, LB, FD, FR, W_1, W_2, BT_1, BT_2, L_1, L_2, T_1, T_2)$$

5.1.1 Cobb-Douglas Model. In the Cobb-Douglas case, equations (5.1) and (5.2) can be written in logarithmic form as:

$$(5.3) \qquad \ln Y = \alpha + \beta_{BS}\ln BS + \beta_{LI}\ln LI + \beta_{FU}\ln FU + \beta_{LB}\ln LB + \beta_{FD}\ln FD + \beta_{FR}\ln FR + e$$

$$(5.4) \qquad \ln Y = \alpha + \beta_{BS}\ln BS + \beta_{LI}\ln LI + \beta_{FU}\ln FU + \beta_{LB}\ln LB + \beta_{FD}\ln FD + \beta_{FR}\ln FR + d_1W_1 + d_2W_2 + d_3BT_1 + d_4BT_2 + d_5L_1 + d_6L_2 + d_7T_1 + d_8T_2 + e$$

where α is a constant term

β_i is the parameter for input x_i; i = BS, LI, FU, LB, FD, and FR

d_i is the parameter for each dummy variable

e is the error term.

Here the disturbance e is assumed to be additive in the logarithmic form.

5.1.2 Translog Model. For the translog functional form, the production function (5.1) and (5.2) can be written as:

(5.5) $$\ln Y = \alpha + \Sigma_i \beta_i \ln x_i + \tfrac{1}{2}\Sigma_i \Sigma_j \delta_{ij}(\ln x_i)(\ln x_j) + e$$

(5-6) $$\ln Y = \alpha + \Sigma_i \beta_i \ln x_i + \tfrac{1}{2}\Sigma_i \Sigma_j \delta_{ij}(\ln x_i)(\ln x_j) + d_1 W_1 + d_2 W_2 + d_3 BT_1 + d_4 BT_2 + d_5 L_1 + d_6 L_2 + d_7 T_1 + d_8 T_2 + e$$

where α is a constant term

β_i is the parameter for input x_i; i = BS, LI, FU, LB, FD, and FR

δ_{ij} is the parameter for input x_i and input x_j; i and j = BS, LI, FU, LB, FD, and FR

d_i is the parameter for each dummy variable

e is the error term.

5.2 Methods of Analysis

The models developed in the previous section were assumed to be single equation models, where output is an endogenous variable and inputs are all exogenous variables.[7] The Ordinary Least Squares (OLS) method was used in order to estimate the Cobb-Douglas

[7] the production function was also estimated by two-stage least squares, assuming that input levels are endogenous and depend on prices of inputs and output. Result are presented in **Appendix E**.

model and the translog model. The *t* distribution was employed to test hypothesis of the significance of individual estimated coefficients. The F distribution was employed to test joint hypotheses. Confidence intervals were constructed for factor elasticities (E), the elasticity of scale (ε), and the first-order conditions of profit maximization and cost minimization.

The computer program used to run the model was **SHAZAM**, which is an econometrics computer program primarily developed by **Kenneth J. White**, Department of Economics, University of British Columbia [27].

5.3 Data Collection

Data used in this study was collected from eleven Northeast fishery stations covering three fiscal years, October 1,1987 - September 31,1989. Most of the data was collected from the station records and annual reports. Interviews of fisheries biologists and staff who are responsible for producing fish seed in each station were also conducted in order to obtain some of the desired information.

Details of data collected are as follows.

5.3.1 Output (Y). Output in this study is defined as the number of total fish seed produced per square metre of earth pond by each fishery station in the period of study. As previously mentioned, there are more than one species of fish seed produced. Output Y, therefore, consists of:

(a) Nile Tilapia (*Tilapia nilotica*) : Y_{tp}

(b) Common Carp (*Cyprinus carpio*) : Y_{cc}

(c) Tawes (*Puntius gonionotus*) : Y_{tw}

(d) Rohu (*Labeo rohita*) : Y_{rh}

(e) Mrigal (*Cirrhina mrigala*) : Y_{mg}

(f) Others : Y_o

In other words, $Y = Y_{tp} + Y_{cc} + Y_{tw} + Y_{rh} + Y_{mg} + Y_o$. Although the data on production of fish seed can be classified by species, data for inputs used by species was not available. Therefore this study cannot determine the fish seed production function by species. Furthermore, during the interviews people responsible for fish seed production stated that each species has the same production process. The product of each species then should be treated as the same product, and can be aggregated into one single product.

5.3.2 Input. Input variables included in this study are:

- **Broodstock (BS)**: broodstock means total weight (kg) of female broodstock used in the breeding process per square metre of earth pond. This was the only input that can be allocated by species.

- **Lime (LI)**: the variable LI was defined as the total quantity of lime used (bag) in the production process per square metre of earth pond. Normally, lime is applied to an earth pond prior to draining water in order to eliminate fish predators and organisms carrying disease.

- **Fuel (FU)**: input FU is defined as the total quantity of diesel used (litre) for water pumps per square metre of earth pond in the production process. This variable was intended as a proxy for the number of water pumps, because data on the number of water pumps was unavailable.

- **Labour (LB)**: labour was measured in man-days per square metre of earth pond.

- **Aggregate Feed Input Quantity Index (FD)**: this variable was defined in terms of 1987 prices by summing up the quantities of feeds used (e.g. rice bran, broken rice, fish meal, bean meal) weighted by their 1987 price.

- **Aggregate Fertilizer Input Quantity Index (FR)**: fertilizers are sometimes applied to the pond in order to increase fish nutrients. This includes both organic and inorganic fertilizers. This variable was defined in terms of 1987 prices by summing up the quantities of fertilizers weighted by their 1987 prices.

5.3.3 Price. Prices of variables included in this study are as follows:

- **Output Price (p)**: output price was constant at 0.10 Baht per unit of fish seed. This is the price that fishery stations use for selling fish seed to farmers.

- **Input Prices (w)**: for each observation, price of each input was determined from the total cost of input and the amount of the corresponding input used. For the aggregate feed input quantity index, price was then assumed to be equal to 1 Baht in 1987, and for the other two years, prices of this input were calculated from dividing actual value of feed input in each year by the aggregate feed input quantity index in the corresponding year. The same procedure was used in the determination of price of the aggregate fertilizer input quantity index.[8]

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[8] details of the determination of the aggregate feed input quantity index, the aggregate fertilizer input quantity index, and their prices are presented in **Appendix A**.

5.4 Normalization of Data

Based on preliminary regression results (not reported here), it was not clear that pond area was a significant input in fish seed production. A possible explanation for this is that pond area may serve as a physical medium of fish seed production that does not influence production at the margin over a broad range of input combinations, and managers may always choose to operate fisheries within this range. When the coefficient of pond area was significant in these initial regressions, its marginal product was estimated as negative rather than as positive (suggesting that pond area was serving as a proxy for omitted variables).

As a result, it was decided to normalize outputs and inputs by pond size and otherwise exclude this input from specified production functions (this practice is also followed, without explanation, in other empirical studies of fish production). This transformation is strictly correct only if production is constant returns to scale in pond area and other inputs (pond area may be either significant or insignificant in production over observed ranges of inputs); but at least this transformation provides a consistent treatment of pond area under this assumption irrespective of whether pond size influences output at the margin. Moreover pond area was statistically insignificant as an additional separate variable in models where output and inputs are normalized on pond area, which suggests either constant returns to scale in production using pond area and other inputs, or that pond area is insignificant in production over observed ranges of inputs. Constant returns to scale in pond area and other inputs appears to be contradicted by our estimates below of increasing returns to scale in other inputs.

If pond area does influence production over observed combinations of inputs and there are increasing returns to scale in production, then the calculations of returns to scale reported in this study are likely to underestimate returns to scale (when pond size as well as other inputs is treated as a variable input).

Chapter VI

RESULTS AND INTERPRETATION

The first section of this chapter reports econometric results for Cobb-Douglas and translog production functions. A comparison of these results is presented in the second section of this chapter. In the last section, one of the estimated models was selected to represent the production function for fish seed produced by the Northeast fishery stations, and implications of estimates for this production function are discussed.

6.1 The Estimated Production Function

The econometric results for production function specified in the previous chapter were presented in this section.

6.1.1 Cobb-Douglas Model

The Cobb-Douglas production function written in logarithmic form is:

$$\ln Y = \alpha + \beta_{BS}\ln BS + \beta_{LI}\ln LI + \beta_{FU}\ln FU + \beta_{LB}\ln LB + \beta_{FD}\ln FD + \beta_{FR}\ln FR + e \quad (6.1)$$

Estimates of equation (6.1) suggested that output was significantly influenced by only 2 inputs, namely broodstock (BS) and labour (LB). The other inputs lime (LI), fuel (FU), feed (FD), and fertilizers (FR) were not statistically significant (**Table 6.1**).

The 8 dummy variables representing water condition (W_1 and W_2), breeding technique (BT_1 and BT_2), location (L_1 and L_2), and time period (T_1 and T_2) were added to the model in order to test their effects on the output level. Therefore, the Cobb-Douglas model, also in logarithmic form, was:

$$(6.2) \qquad \ln Y = \alpha + \beta_{BS}\ln BS + \beta_{LI}\ln LI + \beta_{FU}\ln FU + \beta_{LB}\ln LB + \beta_{FD}\ln FD + \beta_{FR}\ln FR + d_1W_1 + d_2W_2 + d_3BT_1 + d_4BT_2 + d_5L_1 + d_6L_2 + d_7T_1 + d_8T_2 + e$$

Estimates of equation (6.2) suggested 4 significant inputs: broodstock (BS), fuel (FU), labour (LB), and feed (FD). For the dummy variables, only the coefficient of W_2 (water condition above normal) was statistically significant.

The adjusted R^2 increased from 0.9372 in equation (6.1) to 0.9726 in equation (6.2). It was decided to keep all dummy variables in the model, while inputs lime (LI) and fertilizers (FR) were removed. These 2 inputs were removed because neither of them was statistically significant in either estimation, and the hypothesis that the coefficients of both inputs are equal to zero ($\beta_{LI} = \beta_{FR} = 0$) was also accepted (the calculated F-value = 0.83, while the F-value at 95 % confidence level with 2 and 18 degrees of freedom = 3.52). Hence the model was respecified as:

$$(6.3) \qquad \ln Y = \alpha + \beta_{BS}\ln BS + \beta_{FU}\ln FU + \beta_{LB}\ln LB + \beta_{FD}\ln FD + d_1W_1 + d_2W_2 + d_3BT_1 + d_4BT_2 + d_5L_1 + d_6L_2 + d_7T_1 + d_8T_2 + e$$

Estimates of equation (6.3) indicated that coefficients of all remaining inputs were statistically significant. However, for the dummy variables, only W_2 was significant. The joint F-test that the coefficients for BT_1, BT_2, L_1 L_2, T_1 and T_2 are all equal zero was accepted (the calculated F-value = 1.22, while the F-value at 95% confidence level with 6 and 20 degrees of freedom = 2.60). Therefore, the model was respecified and was re-estimated again with 4 input variables and 2 dummy variables representing water conditions (W_1 and W_2).

$$(6.4) \qquad \ln Y = \alpha + \beta_{BS}\ln BS + \beta_{FU}\ln FU + \beta_{LB}\ln LB + \beta_{FD}\ln FD + d_1W_1 + d_2W_2 + e$$

Estimates of equation (6.4) (**Table 6.1**) showed that all coefficients were statistically significant, and adjusted $R^2 = 0.9717$. The estimate of this final Cobb-Douglas production function is:

$$(6.4.a) \qquad \ln Y = 8.3983 + 0.38406\ln BS + 0.10757\ln FU + 0.72687\ln LB + 0.23668\ln FD - 0.14948W_1 + 0.33758W_2$$

Given this final estimate of the Cobb-Douglas, the factor elasticity (Ei) was derived from the formula $E_i = \beta_i$. Therefore, the elasticities of each input included in the equation (6.4) are:

$$(6.5)\quad \begin{aligned} E_{BS} &= \beta_{BS} = 0.38406 \\ E_{FU} &= \beta_{FU} = 0.10757 \\ E_{LB} &= \beta_{LB} = 0.72678 \\ E_{FD} &= \beta_{FD} = 0.23668 \end{aligned}$$

and the elasticity of scale (ε), which is the summation of Ei, is 1.45509. An elasticity of scale greater than one implies that the Cobb-Douglas production function, equation (6.4), exhibits increasing returns-to-scale.

Table 6.1: The Estimated Cobb-Douglas Production Function [a]

Variables	Equation (6.1)	Equation (6.2)	Equation (6.3)	Equation (6.4)
Constant	9.1856** (0.40869)	8.5472** (0.31305)	8.4812** (0.29240)	8.3983** (0.25120)
lnBS	0.45007** (0.08491)	0.37857** (0.06675)	0.38849** (0.06558)	0.38406** (0.05876)
lnLI	0.02159 (0.01364)	0.00359 (0.00998)	-	-
lnFU	0.11830 (0.07848)	0.14799** (0.05756)	0.12336** (0.04854)	0.10757* (0.04592)
lnLB	0.78611** (0.12993)	0.72500** (0.09235)	0.73852** (0.07751)	0.72678** (0.07805)
lnFD	0.03635 (0.11176)	0.21867** (0.08396)	0.26203** (0.07081)	0.23668** (0.06721)
lnFR	0.00463 (0.01147)	0.01091 (0.00876)	-	-
W_1	-	-0.04463 (0.10818)	-0.03397 (0.10658)	-0.14948* (0.07809)
W_2	-	0.38593** (0.10797)	0.37601** (0.10651)	0.33758** (0.08156)
BT_1	-	-0.12999 (0.10899)	-0.14341 (0.10653)	-
BT_2	-	-0.02110 (0.10323)	-0.05711 (0.09843)	-
L_1	-	0.03193 (0.09791)	0.00989 (0.09382)	-
L_2	-	-0.11372 (0.1098)	-0.13458 (0.10463)	-
T_1	-	0.12460 (0.08954)	0.13855 (0.08655)	-
T_2	-	0.11859 (0.08900)	0.09229 (0.08282)	-
$\bar{R}^2$	0.9372	0.9726	0.9731	0.9717
S	0.24449	0.16146	0.16009	0.16421
SSE	1.55420	0.46924	0.51260	0.70108
MSE	0.05977	0.02607	0.02563	0.02696

a Numbers in parentheses are standard error of estimated coefficients
* Statistically significant at the 95% confidence level
** Statistically significant at the 99% confidence level
\- Inclusion of the variable in the regression was not attempted

6.1.2 Translog Model

The general form of the translog production function with only six input variables can be written as:

$$(6.6)\quad \ln Y = \alpha + \Sigma_i \beta_i \ln x_i + \tfrac{1}{2}\Sigma_i \Sigma_j \delta_{ij}(\ln x_i)(\ln x_j) + e$$

$$i = BS,LI,FU,LB,FD,FR$$

$$j = BS,LI,FU,LB,FD,FR$$

This model was first estimated by including only six input variables, and then two pairs of dummy variables were added (with 6 input variables and 33 observations, only 4 dummy variables can be incorporated into the translog model at a time). For the model with only 6 input variables, all coefficient (excluding the intercept) were statistically insignificant. When the dummy variables were included, only 2 coefficients of input variables were significant.

The translog model was adjusted by removing inputs lime (LI) and fertilizers (FR) from the model, and adding all 8 dummy variables into the model. The resulting translog production function was:

$$(6.7)\quad \ln Y = \alpha + \beta_{BS}\ln BS + \beta_{FU}\ln FU + \beta_{LB}\ln LB + \beta_{FD}\ln FD + \delta_{BSBS}(\ln BS)^2 + \delta_{FUFU}(\ln FU)^2 + \delta_{LBLB}(\ln LB)^2 + \delta_{FDFD}(\ln FD)^2 + \delta_{BSFU}\ln BS\ln FU + \delta_{BSLB}\ln BS\ln LB + \delta_{BSFD}\ln BS\ln FD + \delta_{FULB}\ln FU\ln LB + \delta_{FUFD}\ln FU\ln FD + \delta_{LBFD}\ln LB\ln FD + d_1W_1 + d_2W_2 + d_3BT_1 + d_4BT_2 + d_5L_1 + d_6L_2 + d_7T_1 + d_8T_2 + e$$

Lime (LI) and fertilizers (FR) were excluded from the model for two reasons. First, these two inputs were insignificant in the simpler Cobb-Douglas model. Second, the joint hypothesis that these two inputs are insignificant in the translog model (6.6) was not rejected (the calculated F-value for this restriction was 4.40, while the critical F-value at 95% confidence level with 13 and 3 degrees of freedom was 8.79).

The estimated coefficients of equation (6.7) were insignificant except for W_2 and the intercept. Accordingly three hypotheses were tested. The first hypothesis was that this translog production function (6.7) can be reduced to a Cobb-Douglas, i.e. all second-order coefficients equal zero, $\delta_{ij} = 0$, (all i,j). Therefore, the restricted model can be written as:

$$(6.8) \quad \ln Y = \alpha + \beta_{BS}\ln BS + \beta_{FU}\ln FU + \beta_{LB}\ln LB + \beta_{FD}\ln FD + d_1W_1 + d_2W_2 + d_3BT_1 + d_4BT_2 + d_5L_1 + d_6L_2 + d_7T_1 + d_8T_2 + e$$

The second hypothesis was that all second-order cross coefficients equal zero, i.e. $\delta_{ij} = 0$ for all $i \neq j$. The restricted model for this hypothesis can then be written as:

$$(6.9) \quad \ln Y = \alpha + \beta_{BS}\ln BS + \beta_{FU}\ln FU + \beta_{LB}\ln LB + \beta_{FD}\ln FD + \delta_{BSBS}(\ln BS)^2 + \delta_{FUFU}(\ln FU)^2 + \delta_{LBLB}(\ln LB)^2 + \delta_{FDFD}(\ln FD)^2 + d_1W_1 + d_2W_2 + d_3BT_1 + d_4BT_2 + d_5L_1 + d_6L_2 + d_7T_1 + d_8T_2 + e$$

The third hypothesis was that all the second-order own coefficients are equal to zero, i.e. δ_{ii} = o for all i. The restricted model for this hypothesis is:

$$(6.10)\quad \ln Y = \alpha + \beta_{BS}\ln BS + \beta_{FU}\ln FU + \beta_{LB}\ln LB + \beta_{FD}\ln FD + \delta_{BSFU}\ln BS\ln FU + \delta_{BSLB}\ln BS\ln LB + \delta_{BSFD}\ln BS\ln FD + \delta_{FULB}\ln FU\ln LB + \delta_{FUFD}\ln FU\ln FD + \delta_{LBFD}\ln LB\ln FD + d_1W_1 + d_2W_2 + d_3BT_1 + d_4BT_2 + d_5L_1 + d_6L_2 + d_7T_1 + d_8T_2 + e$$

An F-test was employed to test whether or not any of these hypothesis can be accepted. The F-value for each restricted model was calculated from:

$$(6.11)\quad \text{F-value} = \frac{(SSE_R - SSE_u)/r}{SSE_U/(n-k-1)}$$

where SSE_R is the sum of squared errors from the restricted model, equation (6.8), (6.9), and (6.10); SSE_U is the sum of squared errors from the unrestricted model, equation (6.7); r is the number of restriction imposed, for example r=4 for the restricted equation (6.10) since there are 4 coefficients restricted to be zero; and n-k-1 is the degrees of freedom for the unrestricted equation.

The estimates of equations (6.7), (6.8), (6.9), and (6.10) are shown in **Table 6.2**, and the calculated F-value and the critical F-value at a 95% confidence level are shown in **Table 6.3**. From the F-test, the first hypothesis was barely accepted, and the other two hypotheses were accepted (or more precisely, not rejected). These results suggest that the translog model, equation (6.7), should be reduced to be the Cobb-Douglas model. However, it is obvious from estimates of equation (6.9) and equation (6.10) that a different conclusion is more appropriate: the coefficient for $(\ln BS)^2$ in equation (6.9), and the coefficient for lnFUlnLB in equation (6.10) were statistically significant at a 99% confidence level.

Consequently, 3 other models were defined by incorporating $(\ln BS)^2$, lnFUlnLB, and both, respectively, into equation (6.8) as follows:

$$(6.12)\quad \ln Y = \alpha + \beta_{BS}\ln BS + \beta_{FU}\ln FU + \beta_{LB}\ln LB + \beta_{FD}\ln FD + \delta_{BSBS}(\ln BS)2 + d_1W_1 + d_2W_2 + d_3BT_1 + d_4BT_2 + d_5L_1 + d_6L_2 + d_7T_1 + d_8T_2 + e$$

$$(6.13)\quad \ln Y = \alpha + \beta_{BS}\ln BS + \beta_{FU}\ln FU + \beta_{LB}\ln LB + \beta_{FD}\ln FD + \delta_{FULB}\ln FU\ln LB + d_1W_1 + d_2W_2 + d_3BT_1 + d_4BT_2 + d_5L_1 + d_6L_2 + d_7T_1 + d_8T_2 + e$$

Table 6.2: The Estimated Translog Production Function, Equation (6.7)-(6.10)[a]

Variables	Equation (6.7)	Equation (6.8)	Equation (6.9)	Equation (6.10)
Constant	8.8500** (2.6730)	8.4812** (0.29240)	5.0203** (1.1863)	9.5939** (1.2054)
lnBS	-0.77149 (1.1930)	0.38849** (0.06558)	-2.1264** (0.79766)	-0.36182 (0.48839)
lnFU	0.71192 (0.63190)	0.12336* (0.04854)	0.98682* (0.53451)	0.86204* (0.44531)
lnLB	2.2828 (1.5902)	0.73852** (0.07751)	0.74722 (0.79028)	1.9739** (0.73537)
lnFD	-0.47955 (1.0233)	0.26203** (0.07081)	0.24034 (0.14849)	-0.58050 (0.36638)
$(\ln BS)^2$	0.15505 (0.24824)	-	-0.32733** (0.10169)	-
$(\ln FU)^2$	0.12833 (0.13767)	-	0.13810 (0.07872)	-
$(\ln LB)^2$	0.39417 (0.55793)	-	-0.02013 (0.16366)	-
$(\ln FD)^2$	-0.00610 (0.17885)	-	-0.03357 (0.08069)	-
lnBSlnFU	-0.39326 (0.26521)	-	-	-0.21134 (0.10234)
lnBSlnLB	-0.49916 (0.54525)	-	-	-0.09074 (0.16982)
lnBSlnFD	-0.11710 (0.16916)	-	-	-0.17803 (0.12272)
lnFUlnLB	0.51638 (0.35515)	-	-	0.59805** (0.17301)
lnFUlnFD	0.04653 (0.16768)	-	-	0.01232 (0.12575)
lnLBlnFD	-0.17898 (0.35254)	-	-	-0.09196 (0.19700)
W_1	0.08465 (0.19500)	-0.03397 (0.10658)	-0.04432 (0.15278)	-0.03382 (0.12271)
W_2	0.47978* (0.25359)	0.37601** (0.10651)	0.41203** (0.12370)	0.36752** (0.09998)
BT_1	-0.12857 (0.12196)	-0.14341 (0.10653)	-0.00701 (0.10706)	-0.09809 (0.08879)
BT_2	0.00917 (0.10340)	-0.05711 (0.09843)	0.06014 (0.10302)	0.02378 (0.07994)
L_1	0.14507 (0.19801)	0.00989 (0.09382)	0.26411 (0.12148)	0.01668 (0.08427)
L_2	0.29628 (0.29723)	-0.13458 (0.10463)	0.25834 (0.25267)	0.17516 (0.20689)
T_1	0.08046 (0.08826)	0.13855 (0.08655)	0.04357 (0.08939)	0.10114 (0.06826)
T_2	0.07293 (0.08537)	0.09229 (0.08282)	0.00637 (0.08151)	0.08105 (0.06249)
$\bar{R}^2$	0.9841	0.9731	0.9809	0.9871
S	0.12310	0.16009	0.13495	0.11073
SSE	0.15154	0.51260	0.29139	0.17164
MSE	0.01515	0.02563	0.01821	0.01226

[a] Numbers in parentheses are standard errors of the estimated coefficients, - Inclusion of the variable in regression was not attempted

[*] Statistically significant at the 95% confidence level, [**] Statistically significant at the 99% confidence level

Table 6.3: Comparison of the Calculated F-value and the Critical F-value

Hypothesis	Calculated F-value	Value of $F_{0.05}$	Degrees of freedom
1. $\delta_{ij} = 0$ for all i and j	2.38	2.98	10,10
2. $\delta_{ij} = 0$ for all $i \neq j$	1.54	3.22	6,10
3. $\delta_{ii} = 0$	0.33	3.48	4,10

$$(6.14)\quad \ln Y = \alpha + \beta_{BS}\ln BS + \beta_{FU}\ln FU + \beta_{LB}\ln LB + \beta_{FD}\ln FD + \delta_{BSBS}(\ln BS)^2 + \delta_{FULB}\ln FU \ln LB + d_1W_1 + d_2W_2 + d_3BT_1 + d_4BT_2 + d_5L_1 + d_6L_2 + d_7T_1 + d_8T_2 + e$$

The results from the estimation of these three equations are presented in **Table 6.4**, columns 2, 3, and 4. Equation (6.14) provided the best results in the sense that all coefficients for input variables were statistically significant. However, for the dummy variables, only the coefficient for W_2 was statistically significant.

The hypothesis that breeding technique, location of the fishery stations, and the difference in time period do not significantly affect the output was tested in terms of the restriction that the coefficients for BT_1, BT_2, L_1, L_2, T_1, and T_2 are all equal to zero for the equation (6.14). This hypothesis was accepted at 95% confidence level (the calculated F-value = 1.34, while F-value at 95% confidence level with 6 and 18 degrees of freedom = 2.66). Therefore, equation (6.14) was respecified as

$$(6.15)\ \ln Y = \alpha + \beta_{BS}\ln BS + \beta_{FU}\ln FU + \beta_{LB}\ln LB + \beta_{FD}\ln FD + \delta_{BSBS}(\ln BS)^2 + \delta_{FULB}\ln FU \ln LB + d_1 W_1 + d_2 W_2 + e$$

As shown in **Table 6.4** (column 5), all coefficients were statistically significant except for the coefficient of W_1 which represents the effect of water condition when it was below normal on the output.

Consequently, the translog model was respecified again by removing the dummy variable W_1 from the previous model. The final model for the modified translog production function can then be written as:

$$(6.16)\ \ln Y = \alpha + \beta_{BS}\ln BS + \beta_{FU}\ln FU + \beta_{LB}\ln LB + \beta_{FD}\ln FD + \delta_{BSBS}(\ln BS)^2 + \delta_{FULB}\ln FU \ln LB + d_2 W_2 + e$$

The estimated equation (6.16) (**Table 6.4**, column 6) was:

$$(6.16.a)\ln Y = 7.36 - 0.99078\ln BS + 0.77914\ln FU + 1.3661\ln LB + 0.30126\ln FD - 0.17877(\ln BS)^2 + 0.2553\ln FU \ln LB + 0.40713W_2$$

with an adjusted $R^2 = 0.9823$.

Table 6.4: The Estimated Translog Production Function,

Equation (6.12)-(6.16).[a]

Variable	Equation (6.12)	Equation (6.13)	Equation (6.14)	Equation (6.15)	Equation (6.16)
Constant	5.4462** (1.0258)	9.4246** (0.71121)	6.1338** (1.0724)	7.6506** (0.52936)	7.3600** (0.49492)
lnBS	-1.30680 (0.66044)	0.36524** (0.06585)	-1.76460** (0.59508)	-0.8776** (0.29775)	-0.99078** (0.29154)
lnFU	0.06844 (0.04788)	0.68567 (0.39131)	0.91512** (0.31338)	0.85208** (0.28661)	0.77914* (0.28687)
lnLB	0.94621** (0.10575)	1.09380** (0.25677)	1.54150** (0.23677)	1.38340** (0.21340)	1.3661** (0.21692)
lnFD	0.17205* (0.07162)	0.33578** (0.08573)	0.26249** (0.07024)	0.30900** (0.06441)	0.30126** (0.06533)
$(\ln BS)^2$	-0.21708* (0.08424)	-	-0.27114** (0.07547)	-0.16380** (0.03853)	-0.17877** (0.03765)
lnFUlnLB	-	0.20061 (0.13858)	0.30694* (0.11261)	0.28265* (0.10458)	0.25530* (0.10457)
W_1	-0.10236 (0.09780)	-0.07775 (0.10810)	-0.18638 (0.08999)	-0.09314 (0.06722)	-
W_2	0.50620** (0.10677)	0.29744* (0.11705)	0.41840** (0.09775)	0.35461** (0.06775)	0.40713** (0.05717)
BT_1	0.00807 (0.11094)	-0.20451 (0.11199)	-0.04769 (0.09806)	-	-
BT_2	0.08348 (0.10263)	0.09439 (0.09924)	0.06143 (0.08908)	-	-
L_1	0.19475 (0.10960)	-0.03084 (0.09558)	0.17846 (0.09492)	-	-
L_2	0.25464 (0.17707)	-0.16060 (0.10345)	0.31175 (0.15449)	-	-
T_1	0.11762 (0.07687)	0.13791 (0.08428)	0.11144 (0.06649)	-	-
T_2	0.04807 (0.07513)	0.11053 (0.08162)	0.06497 (0.06524)	-	-
$\bar{R}^2$	0.9790	0.9745	0.9843	0.9829	0.9823
S	0.14139	0.15588	0.12222	0.12736	0.12968
SSE	0.37984	0.46168	0.26887	0.38926	0.42040
MSE	0.01999	0.02430	0.01494	0.01622	0.01682

[a] Numbers in parentheses are standard errors of the estimated coefficients

* Statistically significant at the 95% confidence level

** Statistically significant at the 99% confidence level

\- Inclusion of the variable in the regression was not attempted

From equation (6.16.a) we can see that while the elasticity of input feed (FD) was constant at 0.30126, the elasticities of other inputs were not constant, and varied with the level of input used. This can be shown by:

$$(6.17) \qquad E_i = \frac{\partial \ln Y}{\partial \ln x_i}$$

where E_i = elasticity of input x_i, i = BS, FU, LB, and FD. Therefore, from (6.16.a) and (6.17):

$$(6.18) \qquad E_{BS} = -0.99078 - 2(0.17877)\ln BS$$

$$(6.19) \qquad E_{FU} = 0.77914 + 0.2553\ln LB$$

$$(6.20) \qquad E_{LB} = 1.3661 + 0.2553\ln FU$$

$$(6.21) \qquad E_{FD} = 0.30126$$

Substituting the minimum and the maximum values of inputs broodstock, labour, and fuel (from **Table 6.5**) into equations (6.18), (6.19), and (6.20), the range of elasticities are calculated as follows: -0.17693 to 0.95419 for broodstock (E_{BS}), -0.07673 to 0.47182 for fuel (E_{FU}), and 0.09043 to 1.02916 for labour (E_{LB}). At the mean level of these inputs, E_{BS} = 0.19441, E_{FU} = 0.22781, E_{LB} = 0.74981, while the elasticity of feed (E_{FD}) = 0.30126. These results are presented in **Table 6.6**.

The elasticity of scale (ε) for this modified translog production function, equation (6.16), was also determined by

$$(6.22) \quad \varepsilon = \Sigma_i E_i$$

$$= E_{BS} + E_{FU} + E_{LB} + E_{FD}$$

$$= 1.45572 - 0.35754 \ln BS + 0.2553(\ln LB + \ln FU)$$

Obviously, this production function is not a homogeneous function, instead the degree of returns-to-scale depends on the level of broodstock, labour, and fuel used in the production process. Substituting the minimum and maximum level of inputs into (6.22), give the elasticity of scale ranged from 1.26915 to 1.62531. Using the mean level for each input, the elasticity of scale is calculated as 1.47329. This result suggests that the modified translog production function, equation (6.16), exhibits increasing returns-to-scale.

Table 6.5: Minimum, Maximum, and Mean of Input Used

Input	Minimum	Maximum	Mean
Broodstock : BS (kg/m^2)	0.00434	0.10267	0.03634
Lime : LI ($bags/m^2$)	0.00000	0.31200	0.05269
Fuel : FU ($litre/m^2$)	0.00676	0.26719	0.08946
Labour : LB ($man\text{-}days/m^2$)	0.03500	0.30006	0.11538
Feed : FD ($Baht/m^2$)	0.69982	7.85320	3.39850
Fertilizer : FR ($Baht/m^2$)	0.00000	1.29630	0.25218

Table 6.6: Factor Elasticities and Elasticity of Scale of the Modified Translog Production Function, Equation (6.16)

Elasticities	Level of Input Used		
	Minimum	Maximum	Mean
E_{BS}	0.95419	-0.17693	0.19441
E_{FU}	-0.07673	0.47182	0.22781
E_{LB}	0.09043	1.02916	0.74981
E_{FD}	0.30126	0.30126	0.30126
ε	1.26915	1.62531	1.47329

6.1.3 Comparison between the Estimated Cobb-Douglas and the Modified Translog Production Function

A comparison of econometric results for the Cobb-Douglas production function, equation (6.4), and the modified translog production function, equation (6.16), can be summarized as follows:

(i) the inputs lime (LI), and fertilizers (FR) do not significantly affect the output level in either model

(ii) if the water condition is below normal, output will decline for the Cobb-Douglas model, while water condition is insignificant for the modified translog model

(iii) differences in breeding technique, location, and time period do not significantly affect output level in either model

(iv) the adjusted R^2 of the modified translog model is slightly higher than that of Cobb-Douglas model. These results are shown in **Table 6.7**, which also presents estimates of the conventional translog model with inputs BS, FU, LB, and FD, together with the dummy variables W_1 and W_2 (equation 6.23)

$$(6.23) \quad \ln Y = \alpha + \Sigma_i \beta_i \ln x_i + \tfrac{1}{2} \Sigma_i \Sigma_j \delta_{ij} (\ln x_i)(\ln x_j) + d_1 W_1 + d_2 W_2 + e$$

$$i = BS, FU, LB, FD$$

(v) as shown in **Table 6.8**, at mean level of all inputs used, the output elasticity for labour (E_{LB}), and the output elasticity for feed (E_{FD}) differ slightly between these two models. However, the output elasticity for broodstock (E_{BS}) in the modified translog model is about 50% lower than in the Cobb-Douglas model, and the output elasticity for fuel (E_{FU}) in the modified translog model is about double the elasticity of the same input in the Cobb-Douglas model.

(vi) the hypothesis of increasing returns-to-scale is not rejected for either model. The 95 percent confidence interval for returns-to-scale was between 1.33762 - 1.57256 for estimates of the Cobb-Douglas model and between 1.36916 - 1.57742 for estimates of the modified translog model.

Due to the restrictiveness of the Cobb-Douglas functional form, and econometric results favoring the modified translog, the modified translog function is judged to be more suitable than the Cobb-Douglas function as a representation of the fish seed production function. Consequently we will refer only to the modified translog model in further discussion.

Table 6.7: Comparison between the Estimated Cobb-Douglas Production Function, Equation (6.4), and the Estimated Modified Translog Production Function, Equation (6.16)

Variables	Cobb-Douglas (equation 6.4)	Modified Translog (equation 6.16)	Translog (equation 6.23)
Constant	8.3983**	7.3600**	9.0938**
lnBS	0.38406**	-0.99078**	-0.03262
lnFU	0.10757**	0.77914*	0.83601
lnLB	0.72678**	1.36610**	0.65064
lnFD	0.23668**	0.30126**	-0.11793
$(\ln BS)^2$	-	-0.17877**	0.00087
$(\ln FU)^2$	-	-	0.11805
$(\ln LB)^2$	-	-	-0.22821
$(\ln FD)^2$	-	-	-0.10372
lnBSlnFU	-	-	-0.26508
lnBSlnLB	-	-	0.02909
lnBSlnFD	-	-	-0.25077
lnFUlnLB	-	0.25530*	0.40213*
lnFUlnFD	-	-	0.05656
lnLBlnFD	-	-	0.10624
W_1	-0.14948*	-	-0.16736
W_2	0.33758**	0.40713**	-0.28428*
$\bar{R}^2$	0.9717	0.9823	0.9865
S	0.16421	0.12968	0.11346
SSE	0.70108	0.42040	0.20597
MSE	0.02696	0.01682	0.01287

* Statistically significant at the 95% confidence level
** Statistically significant at the 99% confidence level
\- Inclusion of the variable in the regression was not attempted

Table 6.8: Comparison of the Factor Elasticities and the Elasticity of Scale between the Estimated Cobb-Douglas Production Function, Equation (6.4), and the Estimated Modified Translog Production Function, Equation (6.16)

Elasticities	Cobb-Douglas (equation 6.4)	Modified Translog (equation 6.16)[a]
E_{BS}	0.38406	0.19441
E_{FU}	0.10757	0.22781
E_{LB}	0.72678	0.74981
E_{FD}	0.23668	0.30126
ε	1.45509	1.47329
Confidence Interval of ε	1.33762 - 1.57256	1.36916 - 1.57742

[a] all elasticities of the modified translog production function are calculated mean levels of inputs

6.2 Interpretation and Implications

Based on the estimates of the modified translog production function, equation (6.16), the main factors affecting output are broodstock, fuel, labour, feed, and water condition. These factors can explain 98.62 percent of the variation in productivity. Other factors, such as lime and fertilizers, do not significantly affect the output level. Differences in location of the fishery station, period of the study, and differences in breeding technique are insignificant. On the other hand, water condition changes from normal or below normal to above normal, then there is an estimated increase in output of 0.40713 units per square metre.

At the geometric mean level of input used, the estimated factor elasticity of broodstock indicates that a 10 percent increase in weight of female broodstock per square metre (all other inputs constant) will increase output by 1.94 percent. Similarly a 10 percent increase in fuel used for water pumps will increase output by 2.28 percent, a 10 percent increase in labour will increase output by 7.50 percent, and a 10 percent increase in feed will increase output by 3.02 percent. The sum of all factor elasticities is equal to 1.473, indicating that a simultaneous 10 percent increase in all inputs would increase output by 14.73 percent, which implies that returns-to-scale are substantially above one.

As previously explained in Chapter 4, the first-order condition for profit maximization is that producers should decide to use inputs at the level where:

$$(6.24) \qquad VMP_i = w_i$$

where $\quad VMP_i \equiv p(MPP_i)$

and $\quad MPP_i = \partial Y/\partial x_i$

$$= \frac{\partial \ln Y/\partial \ln x_i}{x_i/Y}$$

$$= (Y/x_i)E_i$$

Therefore,

(6.25) $$VMP_i = (pY/x_i)E_i = w_i$$

where VMP_i is the value of marginal product of input x_i, p is output price, and w_i is price of input x_i.

From estimates of the modified translog production function, equation (6.16.a), and using the geometric mean data on output and input levels and price, the value of marginal products are as follows: 158.26 Baht for broodstock, 75.33 Baht for fuel, 192.25 Baht for labour, and 2.62 Baht for feed. Mean input prices are 24.31 Baht for broodstock, 6.57 Baht for fuel, 90.73 Baht for labour, and 1.17 Baht for feed. A comparison between VMP_i and w_i for each input suggests that input levels should be increased.

In order to test for these first order conditions for competitive profit maximization, it is necessary to construct confidence intervals for value of marginal products.[9] Because VMP_i is calculated from E_i for a given data on prices, the confidence interval of VMP_i can be derived from the confidence interval of E_i.

(6.26) Confidence Interval of E_i $$= E_i \pm t_{\alpha/2,\, n-k-1}(S_{Ei})$$

[9] the derivation of the confidence intervals for VMP_i, as well as E_i, ε, and $MRTS_{ij}$ are presented in **Appendix C.**

where α is the confidence level, (n-k-1) is the degrees of freedom, and S_{Ei} is the standard error of the estimated elasticity E_i.

At 95 percent confidence level, given output price, p = 0.10 Baht, geometric mean of output level, Y = 295.83, and geometric mean of each input from the Table 6.5, the confidence interval of VMP_i can be derived from:

$$(6.27) \qquad \frac{0.10(295.83)[E_i - t_{0.025,n-k-1}(S_{Ei})]}{x_i} \leq VMP_i \leq \frac{0.10(295.83)[E_i + t_{0.025,n-k-1}(S_{Ei})]}{x_i}$$

The estimated 95 percent confidence intervals for both E_i and VMP_i are presented in **Table 6.9**. All input prices are less than the lower limit of VMP_i. Thus the hypothesis of competitive profit maximization should be rejected for fishery stations.

For cost minimization, the first-order conditions are:

$$(6.28) \qquad MRTS_{ij} = w_i/w_j \qquad \text{all } i,j$$

$$\text{where} \qquad MRTS_{ij} \equiv MPP_i/MPP_j$$

$$= [(Y/x_i)E_i]/[(Y/x_j)E_j]$$

Therefore:

$$(6.29) \qquad MRTS_{ij} = [(Y/x_i)E_i]/[(Y/x_j)E_j] = w_i/w_j$$

where $MRTS_{ij}$ is the marginal rate of technical substitution between input i and j, and w_i and w_j are price of input i and j.

There are four inputs in the modified translog production function, equation (6.16.a): broodstock (BS), fuel (FU), labour (LB), and feed (FD). In order to test the first-order conditions for cost minimization, marginal rates of technical substitution for the following pairs of inputs were considered; broodstock and labour ($MRTS_{BS,LB}$), fuel and labour ($MRTS_{FU,LB}$), and feed and labour ($MRTS_{FD,LB}$). These were calculated using mean data: $MRTS_{BS,LB} = 0.82321$, $MRTS_{FU,LB} = 0.39185$, $MRTS_{FD,LB} = 0.01364$, and mean input price ratios are $w_{BS}/w_{LB} = 0.26794$, $w_{FU}/w_{LB} = 0.07241$, $w_{FD}/w_{LB} = 0.01289$. 95 percent confidence intervals were calculated for these marginal rates of substitution (**Appendix C**).

Table 6.10 presents the calculated confidence intervals for MRTS, and corresponding factor price ratios. It was found that w_{BS}/w_{LB} and w_{FD}/w_{LB} were within the 95 percent confidence intervals. However w_{FU}/w_{LB} was slightly less than the lower limit. These results suggest that these fishery stations may minimize costs of production for fish seed. Each first-order condition is accepted at 99 percent level of confidence (the lower limit for the 99 percent confidence interval for $MRTS_{FU,LB}$ was -0.01685).

Table 6.9: Confidence Interval of E_i and VMP_i

Input	E_i at mean	95%confidence interval of E_i		p (Bt)	Y	x_i	VMP_j	95%confidence interval of VMP_i		w_i
		lower limit	upper limit					lower limit	upper limit	
BS	0.19441	0.06995	0.31887	0.10	295.83	0.03634	158.26	56.94	259.58	24.31
FU	0.22781	0.08626	0.36936	0.10	295.83	0.08946	75.33	28.52	122.14	6.57
LB	0.74981	0.58900	0.91062	0.10	295.83	0.11538	192.25	151.02	233.48	90.73
FD	0.30126	0.16780	0.43466	0.10	295.83	3.39850	2.62	1.46	3.78	1.17

Table 6.10: Confidence Interval of $MRTS_{ij}$

Input Pair i,j	$MRTS_{ij}$	95% Confidence Interval of $MRTS_{ij}$		w_i/w_j
		lower limit	upper limit	
BS,LB	0.82321	0.26401	1.38231	0.26794
FU,LB	0.39185	0.08832	0.69537	0.07241
FD,LB	0.01364	0.00550	0.02178	0.01289

Assuming cost minimization, we next consider the dual cost function corresponding to the fishery technology. This permits a simple calculation of comparative static changes in cost minimizing factor demands and marginal costs of production. Constrained cost minimization means to minimize cost subject to a given level of output and the firm's technology. In matrix notation this can be written as:

$$\text{(6.30)} \qquad \underset{\mathbf{x}\geq 0}{\text{Minimize}}\ C = \mathbf{wx}$$

$$\text{subject to} \qquad f(\mathbf{x}) = y$$

where C is the total cost, **w** is a vector of input prices, **x** is a vector of input demand, and $y = f(\mathbf{x})$ is the fishery production function. Solving (6.30) yields the minimum cost which is a function of input prices and output, $C(\mathbf{w},y)$. $C(\mathbf{w},y)$ is called the dual cost function for the fishery technology. Input demands $x(\mathbf{w},y)$ can then be derived by applying **Shephard's lemma** [2,26]:

$$\text{(6.31)} \qquad x_i(\mathbf{w},y) = \partial C(\mathbf{w},y)/\partial w_i \qquad i=1,\ldots\ldots,n$$

The comparative static effects of changes in input prices on input demands can be derived from the second order relations between the production function, $y = f(\mathbf{x})$, and the dual cost function, $C(\mathbf{w},y)$ [4,26]:

$$\text{(6.32)} \qquad \left[\begin{array}{c|c} C_{ww} & C_{wy} \\ \hline C_{wy} & C_{yy} \end{array}\right] = \left[\begin{array}{c|c} (\partial C/\partial y).f_{xx} & f_x \\ \hline f_x & 0 \end{array}\right]^{-1}$$

where $C_{ww} = [\partial(\partial C/\partial w_i)/\partial w_j] = [\partial x_i/\partial w_j]$ which is the matrix of comparative static factor substitution effects,

$C_{wy} = [\partial(\partial C/\partial w_i)/\partial y] = [\partial x_i/\partial y]$ which is the vector of comparative static effects of output scale on factor demands, C_{wy} is also equal to $[\partial(\partial C/\partial y)/\partial w_i]$ which is the effect of a change in input price, w_i, on marginal cost, $\partial C/\partial y$.

$C_{yy} = \partial(\partial C/\partial y)/\partial y = \partial(MC)/\partial y$ which is effect of the change in output, y, on marginal cost, MC. In other words, C_{yy} indicates the slope of marginal cost.

Note that $\partial C/\partial y = w_i/\{\partial f(\mathbf{x})/\partial x_i\}$ (i=1,....,n) from the first-order condition for constrained cost minimization [26].

f_x and f_{xx} are matrices of first and second derivatives of the production function, $y = f(\mathbf{x})$.

The marginal cost $\partial C/\partial y$ was calculated using mean data and the above first-order conditions for cost minimization, as follows. Estimates of marginal products $\partial f(x)/\partial x$ were obtained from the modified translog model, equation (6.16.a).

(6.33)
$$\begin{aligned} \partial C/\partial y &= w_{BS}/\{\partial f(\mathbf{x})/\partial BS\} &= 0.01536 \\ &= w_{FU}/\{\partial f(\mathbf{x})/\partial FU\} &= 0.00872 \\ &= w_{LB}/\{\partial f(\mathbf{x})/\partial LB\} &= 0.04719 \\ &= w_{FD}/\{\partial f(\mathbf{x})/\partial FD\} &= 0.04462 \end{aligned}$$

The average between the value of $\partial C/\partial y$ calculated from first-order conditions for labour (0.04719) and for feed (0.04462) was 0.04591, and this value was used to approximate marginal cost $\partial C/\partial y$ in the further analysis. **Table 6.10** indicates that two inputs satisfy most closely the first-order conditions for cost minimization ($MRTS_{FD,LB}$ = 0.01364, w_{FD}/w_{LB} = 0.01289). Hence first-order conditions for these inputs should provide the most reliable measure of marginal cost. This conclusion is supported by the similarity in marginal costs calculated from first-order cost minimization conditions for these two inputs.

The resulting inverse matrix on the right hand side of equation (6.32) is shown in **Table 6.11**. It can be seen that the own-price factor substitution effects ($\partial x_i/\partial w_i$) are all negative. The own-price effect for feed is quite high compared to the own-price effects of other inputs. This implies that the derived demand for feed is very sensitive to changes in its price. Similarly the own-price elasticities of feed is relatively large at -0.86466. Own-price elasticities for broodstock, fuel, and labour are -0.11372, -0.12338, and -0.35380 respectively (**Table 6.12**).

The cross-price effects ($\partial x_i/\partial w_j$) $i \neq j$ are all positive and symmetric which implies that inputs are substitutes within the framework of cost minimization.

Another interesting result is the value of C_{yy}, indicating the slope of the marginal cost curve at mean data. From **Table 6.11**, C_{yy} is negative, so that marginal cost decreases as output increases. This result is consistent with our earlier calculations of increasing returns-to-scale for fish seed production in the Northeast fishery stations.

In sum, it can be concluded that the Northeast fishery stations do not operate so as to maximize competitive profits, but they may well produce outputs at minimum cost.[10]

Table 6.11: Inverse Matrix from the Equation (6.32)

$$\begin{bmatrix} C_{ww} & C_{wy} \\ & \\ C_{wy} & C_{yy} \end{bmatrix} = \begin{bmatrix} -0.00017 & 0.00010 & 0.00008 & 0.00115 & 0.00002 \\ 0.00010 & -0.00168 & 0.00020 & 0.02760 & 0.00037 \\ 0.00008 & 0.00020 & -0.00045 & 0.02250 & 0.00030 \\ 0.00115 & 0.02760 & 0.02250 & -2.51158 & 0.00414 \\ 0.00002 & 0.00037 & 0.00030 & 0.00414 & -0.00010 \end{bmatrix}$$

[10] the study also attempted to determine the optimum level of inputs used, but the modified translog model could not easily be solved even numerically. However the cost minimizing derived demand equations for the Cobb-Douglas model are as presented in **Appendix D**.

Table 6.12: The Calculated $\partial x_i/\partial w_i$, and the Calculated Own-Price Elasticities

Input	$\partial x_i/\partial w_i$	$(\partial x_i/\partial w_i).(w_i/x_i)$
BS	-0.00017	-0.11372
FU	-0.00168	-0.12338
LB	-0.00045	-0.35386
FD	-2.51158	-0.86466

Chapter VII

CONCLUSIONS AND RECOMMENDATIONS

Since the government began to emphasize policies to reduce poverty in the Northeast region of Thailand, the role of fishery development and extension in this region has been increasing significantly. A prerequisite for effective fisheries policy is basic information about technology and managerial behaviour at fisheries, but such information has not been available. This study was conducted in response to this requirement.

Econometric estimation of a production function for fish seed at the Northeast fishery stations is the main purpose of this study. Cobb-Douglas and translog functional forms for production functions were estimated here. A modified translog functional form (where various second order terms are deleted from the general translog) provided the best fit. In many respects, results were similar for the modified translog and Cobb-Douglas models. In both cases, the main factors affecting fish seed production consisted of quantity of female broodstock, fuel used for water pumps, labours, and feed consumption. A dummy variable for water condition (e.g. availability of an adequate water supply throughout the year) also influenced output in the Cobb-Douglas model but was insignificant in the modified translog. Insignificant variables in both models included lime and fertilizer inputs, differences in breeding techniques, location of the fishery stations, and the time period in which data was collected.

The elasticity of scale in both modified translog and Cobb-Douglas models was about 1.4, which implied increasing returns-to-scale. Since dummy variables representing the three annual time periods were insignificant in these models, it appears that estimates of increasing returns-to-scale can not be attributed instead to technical change over these three years.

Assuming that there is increasing returns-to-scale in fish seed production at government fisheries in the Northeast, it is important to speculate on why these returns-to-scale have not been realized. There are some obvious possible explanations. First, given the paucity of empirical studies, it is possible that fisheries managers are unaware that there are increasing returns-to-scale. Second, there are likely to be major political constraints to the realization of economies of scale. For example, the Department of Fisheries may select to establish a new station in order to increase employment in that area rather than realize economies of scale. Third, factor supply schedules presumably are not perfectly elastic. For example, the supply of broodstock may be limited in some areas. Transportation cost also may be an important factor influencing the geographic distribution of production.

This study suggests that increasing returns-to-scale are relatively substantial. Ignoring political constraints and assuming that factor supplies to fisheries are relatively elastic at many locations, and that transportation costs are relatively minor between many locations, the results of this study would suggest that future increases in capacity for government fishery stations in the Northeast should be planned to realize more fully economies of scale.

Hypotheses of competitive profit maximization and cost minimization in fisheries management were also tested in terms of their first order conditions. Since factor prices were outside (less than) the 95 percent confidence intervals for value marginal products, the hypothesis that the Northeast fishery stations are profit maximizers clearly can not be accepted. On the other hand, most factor price ratios fell within the 95 percent confidence intervals for marginal rates of technical substitution (all price ratios fell within 99 percent confidence intervals). Thus the hypothesis that fisheries minimize (competitive) costs of producing levels of output can not be rejected. There is some indication (**Table 6.10**) that fuel should be substituted for labour in order to minimize costs of production, but this would contradict policies to increase employment and conserve fuel.

The major limitation of this study is the unavailability of considerable data that is required for a thorough analysis. The reliability of the results depends on the reliable of data used in the analysis. Fortunately, most of the results are consistent with each other and seem plausible. This is reassuring; but more detailed analysis is still necessary.

Based on the results of this study, several recommendations can be made for further study.

1) in order to improve the quality of data for such analyses, the Department of Fisheries should become more concerned about recording data. Since computers are recently available in many fishery stations, recording and processing data is now more feasible.

2) data about water quality (such as water temperature, dissolved oxygen) should be included in the analysis instead of or in addition to water condition. Water condition is at best a poor proxy for water quality, which may have a substantial influence on

variation in production across stations.

3) policy purposes similar research should be conducted in other regions.

4) studies on fishery production should be complemented by further studies of market performance, market structure, and demand and supply of both fish seed and table fish. Factor supplies and transportation costs should be studied in relation to policies concerning location and size of fisheries.

5) in order to check speculation by fisheries biologists that production functions for different species of fish seed are identical by weight, a further study should try to disaggregate these outputs. Ideally this requires disaggregate data for inputs.

APPENDIX

Appendix A

DATA INPUT

This appendix comprises two sections. The first section presents the raw data collected from the Northeast fishery stations such as the total output and output by species of fish seed produced, and the input used in the production process. The second section shows the data which was transformed from the raw data, for example feed and fertilizer which were calculated based on 1987 price, and were used in the analysis of this study.

A.1 Raw Data

Raw data collected from the sample fishery stations is contained in the five tables. **Table A.1** shows the total output and output by species of fish seed produced. **Table A.2** presents the input broodstock used in total and by species. **Table A.3** contains input lime used, fuel, labour, aggregate feed, aggregate fertilizer, and pond area. **Table A.4** and **Table A.5** present details of feed and fertilizer, respectively.

Table A.1: Total Output and Output by Species

OBS	STATION/YEAR	Output Total (฿)	Output Tilapia (฿)	Output C.Carp (฿)	Output Tawes (฿)	Output Rohu (฿)	Output Mrigal (฿)	Output Others (฿)
1	Loei,1987	4,508,541	398,949	890,700	1,110,650	758,750	1,098,250	251,242
2	Loei,1988	5,192,759	347,920	672,450	1,764,290	1,194,350	1,030,200	183,549
3	Loei,1989	4,551,360	413,650	761,200	1,424,350	812,350	934,700	205,110
4	Udon Thani,1987	8,040,470	939,620	1,100,350	4,173,300	888,150	765,500	173,550
5	Udon Thani,1988	7,440,890	605,590	690,920	2,882,820	1,455,650	1,519,500	286,410
6	Udon Thani,1989	7,599,510	711,400	782,350	3,137,950	1,686,150	1,125,560	156,100
7	Nong Khai,1987	9,973,424	299,250	741,450	1,205,450	2,006,000	3,213,500	2,507,774
8	Nong Khai,1988	9,529,085	285,200	1,069,840	1,609,200	3,656,200	1,243,950	1,664,695
9	Nong Khai,1989	6,835,870	647,900	1,130,100	1,441,350	1,700,700	1,674,500	241,320
10	Sakon Nakhon,1987	12,299,887	4,050,938	640,686	2,118,693	645,124	4,841,446	0
11	Sakon Nakhon,1988	11,932,130	5,082,650	848,500	1,651,900	789,300	3,203,830	355,950
12	Sakon Nakhon,1989	12,936,400	2,385,400	970,900	3,551,500	1,122,700	4,799,300	106,600
13	Khon Kaen,1987	9,816,875	894,525	1,637,820	5,159,000	712,320	703,390	709,820
14	Khon Kaen,1988	8,848,760	1,161,940	814,800	2,719,250	2,619,480	1,219,140	314,150
15	Khon Kaen,1989	11,073,050	988,650	1,465,200	6,733,850	520,750	1,337,650	26,950
16	Maha Sarakham,1987	9,055,800	546,000	937,100	4,133,650	1,996,400	1,358,700	83,950
17	Maha Sarakham,1988	9,677,330	624,800	419,000	4,810,000	2,051,450	993,500	778,580
18	Maha Sarakham,1989	9,618,250	250,000	507,050	4,222,650	1,564,700	2,561,450	512,400
19	Kalasin,1987	15,666,346	475,350	1,720,670	2,344,057	2,855,382	7,688,367	582,520
20	Kalasin,1988	12,465,595	711,830	1,854,060	3,997,610	1,758,000	3,728,900	415,195
21	Kalasin,1989	10,824,725	848,950	2,001,700	2,193,500	1,393,100	4,305,650	81,925
22	Ubon Ratchathani,1987	9,904,676	2,228,700	1,569,500	5,919,476	160,000	11,000	16,000
23	Ubon Ratchathani,1988	8,751,666	2,202,476	1,567,104	3,395,776	1,176,800	660	408,850
24	Ubon Ratchathani,1989	9,250,930	2,059,580	847,050	5,373,600	607,900	224,600	138,200
25	Surin,1987	10,213,605	4,012,180	88,700	4,156,250	837,025	1,058,750	60,700
26	Surin,1988	9,067,049	1,465,250	262,800	5,652,300	1,231,200	325,900	129,599
27	Surin,1989	8,155,419	1,385,819	1,456,100	2,679,250	1,006,200	1,137,950	490,100
28	Burirum,1987	2,074,829	302,650	557,260	373,500	386,149	339,560	115,710
29	Burirum,1988	2,527,550	377,400	549,300	1,151,050	151,350	228,050	70,400
30	Burirum,1989	2,174,480	631,050	281,075	802,900	176,950	233,450	49,055
31	Nakhon Ratchasima,1987	9,922,855	500,695	957,720	7,200,040	656,550	468,340	139,510
32	Nakhon Ratchasima,1988	10,559,874	259,610	412,450	7,189,800	346,335	1,628,394	723,285
33	Nakhon Ratchasima,1989	11,774,006	164,930	844,130	7,787,560	497,400	2,407,636	72,350

Table A.2: Input Broodstock in Total and by Species

OBS	STATION/YEAR	Broodstock Total (kg)	Broodstock Tilapia (kg)	Broodstock C.Carp (kg)	Broodstock Tawes (kg)	Broodstock Rohu (kg)	Broodstock Mrigal (kg)	Broodstock Others (kg)
1	Loei,1987	1,363.25	750.00	67.50	70.98	89.38	64.99	20.40
2	Loei,1988	1,067.00	750.00	91.20	60.20	64.00	77.00	24.60
3	Loei,1989	1,077.76	750.00	111.60	44.80	67.32	80.64	23.40
4	Udon Thani,1987	707.69	294.50	191.00	39.71	96.57	39.25	46.66
5	Udon Thani,1988	661.94	197.54	140.35	95.39	100.72	85.52	42.42
6	Udon Thani,1989	932.41	232.05	172.90	177.15	137.95	157.36	54.50
7	Nong Khai,1987	575.47	125.00	50.00	95.47	80.00	95.00	130.00
8	Nong Khai,1988	560.60	120.00	70.00	136.00	104.90	59.70	70.00
9	Nong Khai,1989	604.50	270.00	77.50	124.00	70.00	48.00	15.00
10	Sakon Nakhon,1987	2,810.00	1,560.00	200.00	430.00	190.00	430.00	0.00
11	Sakon Nakhon,1988	3,055.00	1,960.00	260.00	325.00	210.00	280.00	20.00
12	Sakon Nakhon,1989	2,748.00	920.00	320.00	720.00	360.00	420.00	8.00
13	Khon Kaen,1987	1,351.03	217.00	299.39	554.68	114.69	65.94	99.43
14	Khon Kaen,1988	1,472.95	274.00	151.44	598.71	253.30	115.70	79.30
15	Khon Kaen,1989	1,433.86	250.00	265.20	562.96	249.20	90.90	16.60
16	Maha Sarakham,1987	593.04	245.00	90.00	106.01	80.13	48.40	21.50
17	Maha Sarakham,1988	596.43	245.00	60.00	68.18	71.09	28.16	124.00
18	Maha Sarakham,1989	707.09	105.00	75.00	255.24	114.30	62.75	94.80
19	Kalasin,1987	1,446.95	198.40	242.90	186.85	200.70	363.00	255.10
20	Kalasin,1988	1,363.11	386.36	100.00	342.13	152.15	234.55	147.92
21	Kalasin,1989	2,145.55	354.40	1,121.20	376.15	122.30	146.50	25.00
22	Ubon Ratchathani,1987	1,577.72	1,017.85	366.87	148.80	23.70	10.00	10.50
23	Ubon Ratchathani,1988	1,603.27	992.60	326.31	86.60	119.76	5.00	76.00
24	Ubon Ratchathani,1989	1,417.45	943.75	198.00	126.00	56.70	54.00	39.00
25	Surin,1987	2,840.40	2,400.00	23.15	173.25	100.00	135.00	9.00
26	Surin,1988	1,353.13	850.00	68.58	231.00	147.00	41.55	15.00
27	Surin,1989	1,615.52	830.00	380.00	110.42	120.00	145.10	30.00
28	Burirum,1987	295.00	60.00	70.00	76.00	36.00	33.00	20.00
29	Burirum,1988	365.50	81.00	85.90	91.00	48.00	45.50	15.00
30	Burirum,1989	422.70	106.00	104.50	102.00	45.00	55.20	10.00
31	Nakhon Ratchasima,1987	1,066.69	200.00	117.00	438.73	211.76	61.35	37.85
32	Nakhon Ratchasima,1988	1,235.39	350.00	73.50	444.28	139.91	150.78	76.92
33	Nakhon Ratchasima,1989	1,314.19	200.00	126.50	400.95	154.30	413.70	18.74

Table A.3: Input Lime, Fuel, Labour, Feed, Fertilizer, and Pond Area

OBS	STATION/YEAR	Lime (bags)	Fuel (litre)	Labour (man-days)	Aggregate Feed (Baht)	Aggregate Fertilizers (Baht)	Pond Area (sq.m)
1	Loei,1987	1,010	3,126.00	2,952	77,410.00	200	79,200
2	Loei,1988	1,200	2,872.90	4,356	76,388.50	0	79,200
3	Loei,1989	1,540	2,903.00	2,772	116,738.36	1,750	79,200
4	Udon Thani,1987	0	2,021.00	2,988	28,974.00	400	10,798
5	Udon Thani,1988	300	1,966.00	2,988	78,516.00	285	10,798
6	Udon Thani,1989	0	1,461.00	3,240	59,563.00	450	10,798
7	Nong Khai,1987	700	3,842.00	5,040	245,935.00	12,050	47,800
8	Nong Khai,1988	425	3,681.00	5,040	203,595.55	7,200	47,800
9	Nong Khai,1989	400	2.380.00	5,040	196,699.73	6,335	47,800
10	Sakon Nakhon,1987	1,550	3,019.00	5,364	275,638.00	4,200	72,640
11	Sakon Nakhon,1988	2,900	2,805.00	5,364	371,622.00	9,600	72,640
12	Sakon Nakhon,1989	1,026	2,650.00	5,364	348,159.90	8,086	72,640
13	Khon Kaen,1987	2,426	11,669.00	4,608	124,922.00	16,250	99,000
14	Khon Kaen,1988	2,400	10,800.00	4,608	189,745.75	0	99,000
15	Khon Kaen,1989	643	8,000.00	4,680	239,517.70	0	99,000
16	Maha Sarakham,1987	6,240	2,917.00	3,924	77,021.00	15,950	20,000
17	Maha Sarakham,1988	5,200	2,364.72	4,212	173,779.00	19,000	20,000
18	Maha Sarakham,1989	1,825	2,265.00	4,752	110,509.00	6,880	20,000
19	Kalasin,1987	300	820.00	5,868	247,312.90	47,300	100,000
20	Kalasin,1988	63	1,031.00	5,832	217,116.00	34,400	100,000
21	Kalasin,1989	1,663	1,839.00	5,832	95,650.00	34,400	100,000
22	Ubon Ratchathani,1987	1,600	2,991.00	3,528	224,601.00	18,450	28,600
23	Ubon Ratchathani,1988	1,200	2,659.00	3,528	182,971.00	7,120	28,600
24	Ubon Ratchathani,1989	720	2,166.00	3,528	261,138.75	10,510	28,600
25	Surin,1987	3,656	5,165.00	3,168	142,135.00	540	40,400
26	Surin,1988	5,098	3,250.00	3,420	204,673.00	10,900	40,400
27	Surin,1989	400	3,695.00	3,096	155,645.00	2,400	40,400
28	Burirum,1987	2,900	460.00	3,852	126,324.00	5,850	68,000
29	Burirum,1988	0	670.00	3,852	92,035.00	4,680	68,000
30	Burirum,1989	0	855.00	3,888	98,376.00	10,841	68,000
31	Nakhon Ratchasima,1987	2,500	2,553.00	2,340	58,440.00	14,040	12,800
32	Nakhon Ratchasima,1988	2,500	2,825.00	2,340	49,200.00	0	12,800
33	Nakhon Ratchasima,1989	444	3,420.00	2,340	73,205.00	16,640	12,800

Table A.4: Detail of Feed Input

OBS	STATION/YEAR	Aggregate Feed (Baht)	Eggs Quantity (#)	Eggs Value (Baht)	Eggs Price (Baht)	Rice Bran Quantity (Kg)	Rice Bran Value (Baht)	Rice Bran Price (Baht)
1	Loei,1987	77,410.00	1,800	2,298.00	1.28	9,090	27,387.00	3.01
2	Loei,1988	76,388.50	380	555.00	1.46	6,360	25,854.00	4.07
3	Loei,1989	116,738.36	400	615.00	1.54	9,840	39,292.00	3.99
4	Udon Thani,1987	28,974.00	744	1,089.00	1.46	1,080	2,700.00	2.50
5	Udon Thani,1988	78,516.00	438	781.00	1.78	1,340	5,970.00	4.46
6	Udon Thani,1989	59,563.00	252	452.00	1.79	5,120	21,110.00	4.12
7	Nong Khai,1987	245,935.00	1,199	1,376.00	1.15	22,500	61,700.00	2.74
8	Nong Khai,1988	203,595.55	1,330	2,045.00	1.54	19,800	70,223.00	3.55
9	Nong Khai,1989	196,699.73	980	1,623.50	1.66	15,120	52,206.00	3.45
10	Sakon Nakhon,1987	275,638.00	1,200	1,455.00	1.21	54,360	136,408.00	2.51
11	Sakon Nakhon,1988	371,622.00	400	510.00	1.28	51,000	174,252.00	3.42
12	Sakon Nakhon,1989	348,159.90	200	270.00	1.35	38,400	123,288.00	3.21
13	Khon Kaen,1987	124,322.00	3,274	3,629.00	1.11	11,760	32,436.00	2.76
14	Khon Kaen,1988	189,745.75	1,590	2,161.00	1.36	15,050	55,354.50	3.68
15	Khon Kaen,1989	239,517.70	1,960	2,964.50	1.51	14,835	56,633.50	3.82
16	Maha Sarakham,1987	77,021.00	200	250.00	1.25	8,100	23,790.00	2.94
17	Maha Sarakham,1988	173,779.00	352	480.00	1.36	12,600	55,200.00	4.38
18	Maha Sarakham,1989	110,509.00	1,026	1,529.00	1.49	13,200	60,700.00	4.60
19	Kalasin,1987	247,312.90	0	0.00	0.00	27,300	73,075.00	2.68
20	Kalasin,1988	217,116.00	0	0.00	0.00	14,100	51,675.00	3.66
21	Kalasin,1989	95,650.00	0	0.00	0.00	21,300	75,100.00	3.53
22	Ubon Ratchathani,1987	224,601.00	2,040	3,111.00	1.53	9,420	35,570.00	3.78
23	Ubon Ratchathani,1988	182,971.00	1,974	3,171.00	1.61	4,620	18,480.00	4.00
24	Ubon Ratchathani,1989	261,138.75	2,319	3,705.00	1.60	8,040	31,740.00	3.95
25	Surin,1987	142,135.00	1,895	2,590.00	1.37	14,000	49,700.00	3.55
26	Surin,1988	204,673.00	450	835.00	1.86	15,100	75,500.00	5.00
27	Surin,1989	155,645.00	300	510.00	1.70	8,000	31,100.00	3.89
28	Burirum,1987	126,324.00	490	638.00	1.30	9,900	29,820.00	3.01
29	Burirum,1988	92,035.00	0	0.00	0.00	5,940	23,490.00	3.95
30	Burirum,1989	98,376.00	60	95.00	1.58	5,580	21,220.00	3.80
31	Nakhon Ratchasima,1987	58,440.00	300	380.00	1.27	1,200	3,800.00	3.17
32	Nakhon Ratchasima,1988	49,200.00	60	105.00	1.75	3,600	13,800.00	3.83
33	Nakhon Ratchasima,1989	73,205.00	0	0.00	0.00	2,400	8,400.00	3.50

Table A.4: Detail of Feed Input (cont'd)

OBS	STATION/YEAR	Broken Rice Quantity (Kg)	Broken Rice Value (Baht)	Broken Rice Price (Baht)	Fish Meal Quantity (Kg)	Fish Meal Value (Baht)	Fish Meal Price (Baht)	Bean Meal Quantity (Kg)	Bean Meal Value (Baht)	Bean Meal Price (Baht)
1	Loei,1987	2,400	7,030.00	2.93	1,000	12,500.00	12.50	1,500	14,250.00	9.50
2	Loei,1988	1,297	4,819.50	3.72	700	13,550.00	19.36	1,600	15,200.00	9.50
3	Loei,1989	3,440	14,052.00	4.09	823	13,892.24	16.88	2,872	30,881.12	10.75
4	Udon Thani,1987	0	0.00	0.00	500	6,125.00	12.25	0	0.00	0.00
5	Udon Thani,1988	300	1,480.00	4.93	310	4,480.00	14.45	0	0.00	0.00
6	Udon Thani,1989	1,900	11,200.00	5.89	1,020	16,320.00	16.00	821	9,031.00	11.00
7	Nong Khai,1987	0	0.00	0.00	5,820	72,750.00	12.50	7,972	75,734.00	9.50
8	Nong Khai,1988	1,700	7,335.00	4.31	2,947	41,061.85	13.93	4,988	51,215.60	10.27
9	Nong Khai,1989	0	0.00	0.00	4,593	68,343.20	14.88	5,918	67,322.03	11.36
10	Sakon Nakhon,1987	5,000	16,425.00	3.29	0	0.00	0.00	0	0.00	0.00
11	Sakon Nakhon,1988	7,200	32,560.00	4.52	190	2,540.00	13.37	120	980.00	8.17
12	Sakon Nakhon,1989	6,500	29,700.00	4.57	400	6,600.00	16.50	200	2,400.00	12.00
13	Khon Kaen,1987	6,800	21,800.00	3.21	2,860	35,575.00	12.44	1,200	10,550.00	8.79
14	Khon Kaen,1988	8,093	34,023.25	4.20	4,340	57,712.00	13.30	3,685	37,395.00	10.15
15	Khon Kaen,1989	7,900	39,370.00	4.98	5,242	81,349.70	15.52	4,416	55,880.00	12.65
16	Maha Sarakham,1987	2,500	10,550.00	4.22	900	12,600.00	14.00	600	6,900.00	11.50
17	Maha Sarakham,1988	1,800	10,950.00	6.08	1,800	26,800.00	14.89	1,500	20,500.00	13.67
18	Maha Sarakham,1989	1,100	7,600.00	6.91	1,000	18,000.00	18.00	0	0.00	0.00
19	Kalasin,1987	20,200	63,890.00	3.16	4,026	48,407.30	12.02	7,702	61,940.60	8.04
20	Kalasin,1988	8,000	35,990.00	4.50	4,939	68,407.10	13.85	6,387	61,043.90	9.56
21	Kalasin,1989	4,100	20,550.00	5.01	0	0.00	0.00	0	0.00	0.00
22	Ubon Ratchathani,1987	6,500	25,510.00	3.92	3,700	52,200.00	14.11	2,800	27,650.00	9.88
23	Ubon Ratchathani,1988	8,200	39,290.00	4.79	1,700	28,200.00	16.59	1,000	12,000.00	12.00
24	Ubon Ratchathani,1989	10,605	47,478.75	4.48	2,700	51,300.00	19.00	2,120	27,660.00	13.05
25	Surin,1987	5,600	20,200.00	3.61	2,400	30,000.00	12.50	4,000	38,000.00	9.50
26	Surin,1988	6,000	33,000.00	5.50	3,500	54,000.00	15.43	2,500	15,750.00	6.30
27	Surin,1989	7,700	22,330.00	2.90	2,900	43,150.00	14.88	1,300	14,000.00	10.77
28	Burirum,1987	3,300	11,080.00	3.36	3,240	40,398.00	12.47	2,720	22,093.00	8.12
29	Burirum,1988	3,000	17,250.00	5.75	1,260	16,470.00	13.07	1,280	12,440.00	9.72
30	Burirum,1989	1,000	5,140.00	5.14	990	13,785.00	13.92	1,120	12,340.00	11.02
31	Nakhon Ratchasima,1987	0	0.00	0.00	0	0.00	0.00	600	5,700.00	9.50
32	Nakhon Ratchasima,1988	0	0.00	0.00	0	0.00	0.00	0	0.00	0.00
33	Nakhon Ratchasima,1989	0	0.00	0.00	0	0.00	0.00	0	0.00	0.00

Table A.4: Detail of Feed Input (cont'd)

OBS	STATION/YEAR	Sup. Feed Quantity (bags)	Sup. Feed Value (Baht)	Sup. Feed Price (Baht)	Pellete Quantity (#)	Pellete Value (Baht)	Pellete Price (Baht)	Other Value (Baht)
1	Loei,1987	54	13,945.00	258.24	0	0.00	0.00	0.00
2	Loei,1988	58	16,410.00	282.93	0	0.00	0.00	0.00
3	Loei,1989	58	18,006.00	310.45	0	0.00	0.00	0.00
4	Udon Thani,1987	2	530.00	240.91	120	18,530.00	154.42	0.00
5	Udon Thani,1988	0	0.00	0.00	350	65,805.00	188.01	0.00
6	Udon Thani,1989	0	0.00	0.00	5	1,450.00	290.00	0.00
7	Nong Khai,1987	8	1,450.00	181.25	175	30,925.00	176.71	2,000.00
8	Nong Khai,1988	32	8,828.00	275.87	105	21,025.00	200.24	2,000.00
9	Nong Khai,1989	0	0.00	0.00	11	3,060.00	278.18	4,145.00
10	Sakon Nakhon,1987	400	105,250.00	263.13	95	16,100.00	169.47	0.00
11	Sakon Nakhon,1988	450	129,300.00	287.33	156	31,480.00	201.79	0.00
12	Sakon Nakhon,1989	573	175,665.00	306.57	41	10,236.90	249.68	0.00
13	Khon Kaen,1987	80	19,700.00	246.25	0	0.00	0.00	1,232.00
14	Khon Kaen,1988	0	0.00	0.00	0	0.00	0.00	3,100.00
15	Khon Kaen,1989	2	620.00	310.00	0	0.00	0.00	2,700.00
16	Maha Sarakham,1987	81	20,231.00	249.77	15	2,700.00	180.00	0.00
17	Maha Sarakham,1988	67	15,999.00	238.64	200	43,500.00	217.50	360.00
18	Maha Sarakham,1989	0	0.00	0.00	120	22,680.00	189.00	0.00
19	Kalasin,1987	0	0.00	0.00	0	0.00	0.00	0.00
20	Kalasin,1988	0	0.00	0.00	0	0.00	0.00	0.00
21	Kalasin,1989	0	0.00	0.00	0	0.00	0.00	0.00
22	Ubon Ratchathani,1987	192	54,780.00	285.31	158	25,780.00	163.16	0.00
23	Ubon Ratchathani,1988	201	62,270.00	309.80	117	19,560.00	167.18	0.00
24	Ubon Ratchathani,1989	235	78,375.00	333.51	116	20,880.00	180.00	0.00
25	Surin,1987	7	1,645.00	235.00	0	0.00	0.00	0.00
26	Surin,1988	82	15,430.00	188.17	59	10,158.00	172.17	0.00
27	Surin,1989	44	17,185.00	390.57	135	27,370.00	202.74	0.00
28	Burirum,1987	69	22,295.00	323.12	0	0.00	0.00	0.00
29	Burirum,1988	59	22,385.00	379.41	0	0.00	0.00	0.00
30	Burirum,1989	42	18,261.00	434.79	137	27,535.00	200.99	0.00
31	Nakhon Ratchasima,1987	190	29,060.00	152.95	130	19,500.00	150.00	0.00
32	Nakhon Ratchasima,1988	0	0.00	0.00	189	35,295.00	186.75	0.00
33	Nakhon Ratchasima,1989	0	0.00	0.00	321	64,805.00	201.88	0.00

Table A.5: Detail of Fertilizer Input

OBS	STATION/YEAR	Aggregate Fertilizers (Baht)	Organic Quantity (Kg)	Organic Value (Baht)	Organic Price (Baht)	Chemical Quantity (Kg)	Chemical Value (Baht)	Chemical Price (Baht)
1	Loei,1987	200	100	200	2.00	0	0	0.00
2	Loei,1988	0	0	0	0.00	0	0	0.00
3	Loei,1989	1,750	450	900	2.00	150	850	5.67
4	Udon Thani,1987	400	50	100	2.00	50	300	6.00
5	Udon Thani,1988	285	0	0	0.00	48	285	6.00
6	Udon Thani,1989	450	50	100	2.00	50	350	7.00
7	Nong Khai,1987	12,050	28,000	11,200	0.40	25	850	34.00
8	Nong Khai,1988	7,200	18,000	7,200	0.40	0	0	0.00
9	Nong Khai,1989	6,335	8,650	3,490	0.40	450	2,845	6.32
10	Sakon Nakhon,1987	4,200	0	0	0.00	950	4,200	4.42
11	Sakon Nakhon,1988	9,600	0	0	0.00	1,800	9,600	5.33
12	Sakon Nakhon,1989	8,086	0	0	0.00	1,350	8,086	5.99
13	Khon Kaen,1987	16,250	0	0	0.00	2,500	16,250	6.50
14	Khon Kaen,1988	0	0	0	0.00	0	0	0.00
15	Khon Kaen,1989	0	0	0	0.00	0	0	0.00
16	Maha Sarakham,1987	15,950	2,000	3,650	1.83	3,075	12,300	4.00
17	Maha Sarakham,1988	19,000	1,000	1,900	1.90	3,300	17,100	5.18
18	Maha Sarakham,1989	6,880	400	1,000	2.50	1,050	5,880	5.60
19	Kalasin,1987	47,300	110,000	47,300	0.43	0	0	0.00
20	Kalasin,1988	34,400	80,000	34,400	0.43	0	0	0.00
21	Kalasin,1989	34,400	80,000	34,400	0.43	0	0	0.00
22	Ubon Ratchathani,1987	18,450	1,600	1,600	1.00	3,350	16,850	5.03
23	Ubon Ratchathani,1988	7,120	4,000	4,000	1.00	600	3,120	5.20
24	Ubon Ratchathani,1989	10,510	0	0	0.00	1,950	10,510	5.39
25	Surin,1987	540	0	0	0.00	100	540	5.40
26	Surin,1988	10,900	50	100	2.00	2,000	10,800	5.40
27	Surin,1989	2,400	1,200	2,400	2.00	0	0	0.00
28	Burirum,1987	5,850	2,150	4,300	2.00	250	1,550	6.20
29	Burirum,1988	4,680	200	430	2.15	750	4,250	5.67
30	Burirum,1989	10,841	365	730	2.00	1,662	10,111	6.08
31	Nakhon Ratchasima,1987	14,040	0	0	0.00	2,200	14,040	6.38
32	Nakhon Ratchasima,1988	0	0	0	0.00	0	0	0.00
33	Nakhon Ratchasima,1989	16,640	0	0	0.00	2,600	16,640	6.40

A.2 Data Used in the Analysis

Details of data in this section includes data of total output, total broodstock, lime, fuel, labour, and pond area, which are the same as the corresponding data in the previous section. However, the data of feed and fertilizer used differ from the previous section in that these two input presented in this section were calculated based on 1987 prices. The details are shows in **Table A.6, Table A.7, and Table A.8**.

For the regression analysis, each variable was defined in unit of "per square metre". Therefore, data in **Table A.6** was divided by pond area, and the results presented in **Table A.9** are used in the regression. The dummy variables representing water condition, breeding technique, location of the fishery stations, and the differences in three year time period are also presented in **Table A.10**. Finally the details of output price, and input prices are showed in **Table A.11**.

Table A.6: Total Output and Total Inputs Used in the Analysis

OBS	STATION/YEAR	Output Total (₿)	Broodstock Total (kg)	Lime (bags)	Fuel (litre)	Labour (man-days)	Aggregate Feed Input Quantity Index (Baht)	Aggregate Fer. Input Quantity Index (Baht)	Pond Area (sq.m)
1	Loei,1987	4,508,541	1,063.25	1,010	3,126.00	2,952	77,410.00	200.00	79,200
2	Loei,1988	5,192,759	1,067.00	1,200	2,872.90	4,356	62,374.09	0.00	79,200
3	Loei,1989	4,551,360	1,077.76	1,540	2,903.90	2,772	92,783.12	1,750.00	79,200
4	Udon Thani,1987	8,040,470	707.69	0	2,021.00	2,988	28,974.00	400.00	10,798
5	Udon Thani,1988	7,440,890	661.94	300	1,966.00	2,988	63,019.44	285.00	10,798
6	Udon Thani,1989	7,599,510	932.41	0	1,461.00	3,240	41,535.19	400.00	10,798
7	Nong Khai,1987	9,973,424	575.47	700	3,842.00	5,040	245,935.00	12,050.00	47,300
8	Nong Khai,1988	9,529,085	560.60	425	3,681.00	5,040	172,044.84	7,200.00	47,800
9	Nong Khai,1989	6,835,870	604.50	400	2,380.00	5,040	159,459.43	6,335.00	47,800
10	Sakon Nakhon,1987	12,299,887	2,810.00	1,550	3,019.00	5,364	275,638.00	4,200.00	72,640
11	Sakon Nakhon,1988	11,932,130	3,055.00	2,900	2,805.00	5,364	300,246.25	7,957.89	72,640
12	Sakon Nakhon,1989	12,936,400	2,748.00	1,026	2,650.00	5,364	282,166.23	5,968.42	72,640
13	Khon Kaen,1987	9,816,875	1,351.03	2,426	11,669.00	4,608	124,922.00	16,250.00	99,000
14	Khon Kaen,1988	8,848,760	1,472.95	2,400	10,800.00	4,608	158,699.70	0.00	99,000
15	Khon Kaen,1989	11,073,050	1,433.86	643	8,000.00	4,680	175,637.09	0.00	99,000
16	Maha Sarakham,1987	9,055,800	593.04	6,240	2,917.00	3,924	77,021.00	15,950.00	20,000
17	Maha Sarakham,1988	9,677,330	596.43	5,200	2,364.72	4,212	140,586.95	15,025.00	20,000
18	Maha Sarakham,1989	9,618,250	707.09	1,825	2,265.00	4,752	80,293.39	4,930.00	20,000
19	Kalasin,1987	15,666,346	1,446.95	300	820.00	5,868	247,312.90	47,300.00	100,000
20	Kalasin,1988	12,465,595	1,363.11	63	1,031.00	5,832	173,795.09	34,400.00	100,000
21	Kalasin,1989	10,824,725	2,145.55	1,663	1,839.00	5,832	69,982.33	34,400.00	100,000
22	Ubon Ratchathani,1987	9,904,676	1,577.72	1,600	2,991.00	3,528	224,601.00	18,450.00	28,600
23	Ubon Ratchathani,1988	8,751,666	1,603.27	1,200	2,659.00	3,528	162,934.20	7,017.91	28,600
24	Ubon Ratchathani,1989	9,250,930	1,417.45	720	2,166.00	3,528	220,518.55	9,808.21	28,600
25	Surin,1987	10,213,605	2,840.40	3,656	5,165.00	3,168	142,135.00	540.00	40,400
26	Surin,1988	9,067,049	1,353.13	5,098	3,250.00	3,420	171,904.75	10,900.00	40,400
27	Surin,1989	8,155,419	1,615.52	400	3,695.00	3,096	136,740.28	2,400.00	40,400
28	Burirum,1987	2,074,829	295.00	2,900	460.00	3,852	126,324.00	5,850.00	68,000
29	Burirum,1988	2,527,550	365.50	0	670.00	3,852	73,135.61	5,050.00	68,000
30	Burirum,1989	2,174,480	422.70	0	855.00	3,888	76,490.16	11,034.40	68,000
31	Nakhon Ratchasima,1987	9,922,855	1,066.69	2,500	2,553.00	2,340	58,440.00	14,040.00	12,800
32	Nakhon Ratchasima,1988	10,559,874	1,235.39	2,500	2,825.00	2,340	39,826.00	0.00	12,800
33	Nakhon Ratchasima,1989	11,774,006	1,314.19	444	3,420.00	2,340	55,750.00	16,592.73	12,800

Table A.7: Detail of Aggregate Feed Input Quantity Index[a]

OBS	STATION/YEAR	Aggregate Feed Input Quantity Index (Baht)	Eggs Quantity (#)	Eggs Value (Baht)	Eggs Price (Baht)	Rice Bran Quantity (Kg)	Rice Bran Value (Baht)	Rice Bran Price (Baht)
1	Loei,1987	77,410.00	1,800	2,298.00	1.28	9,090	27,387.00	3.01
2	Loei,1988	62,374.09	380	555.00	1.46	6,360	25,854.00	4.07
3	Loei,1989	92,783.12	400	615.00	1.54	9,840	39,292.00	3.99
4	Udon Thani,1987	28,974.00	744	1,089.00	1.46	1,080	2,700.00	2.50
5	Udon Thani,1988	63,019.44	438	781.00	1.78	1,340	5,970.00	4.46
6	Udon Thani,1989	41,535.19	252	452.00	1.79	5,120	21,110.00	4.12
7	Nong Khai,1987	245,935.00	1,199	1,376.00	1.15	22,500	61,700.00	2.74
8	Nong Khai,1988	172,044.84	1,330	2,045.00	1.54	19,800	70,223.00	3.55
9	Nong Khai,1989	159,459.43	980	1,623.50	1.66	15,120	52,206.00	3.45
10	Sakon Nakhon,1987	275,638.00	1,200	1,455.00	1.21	54,360	136,408.00	2.51
11	Sakon Nakhon,1988	300,246.25	400	510.00	1.28	51,000	174,252.00	3.42
12	Sakon Nakhon,1989	282,166.23	200	270.00	1.35	38,400	123,288.00	3.21
13	Khon Kaen,1987	124,922.00	3,274	3,629.00	1.11	11,760	32,436.00	2.76
14	Khon Kaen,1988	158,699.70	1,590	2,161.00	1.36	15,050	55,354.50	3.68
15	Khon Kaen,1989	175,637.09	1,960	2,964.50	1.51	14,835	56,633.50	3.82
16	Maha Sarakham,1987	77,021.00	200	250.00	1.25	8,100	23,790.00	2.94
17	Maha Sarakham,1988	140,586.95	352	480.00	1.36	12,600	55,200.00	4.38
18	Maha Sarakham,1989	80,293.39	1,026	1,529.00	1.49	13,200	60,700.00	4.60
19	Kalasin,1987	247,312.90	0	0.00	0.00	27,300	73,075.00	2.68
20	Kalasin,1988	173,795.09	0	0.90	0.00	14,100	51,675.00	3.66
21	Kalasin,1989	69,982.33	0	0.00	0.00	21,300	75,100.90	3.53
22	Ubon Ratchathani,1987	224,601.00	2,040	3,111.00	1.53	9,420	35,570.00	3.78
23	Ubon Ratchathani,1988	162,934.29	1,974	3,171.00	1.61	4,620	18,480.00	4.00
24	Ubon Ratchathani,1989	220,518.55	2,319	3,705.00	1.60	8,040	31,740.00	3.95
25	Surin,1987	142,135.00	1,895	2,590.00	1.37	14,000	49,700.00	3.55
26	Surin,1988	171,904.75	450	835.00	1.86	15,100	75,500.00	5.00
27	Surin,1989	136,740.28	300	510.00	1.70	8,000	31,100.00	3.89
28	Burirum,1987	126,324.00	490	638.00	1.30	9,900	29,820.00	3.01
29	Burirum,1988	73,135.61	0	0.00	0.00	5,940	23,490.00	3.95
30	Burirum,1989	76,490.16	60	95.00	1.58	5,580	21,220.00	3.80
31	Nakhon Ratchasima,1987	58,440.00	300	380.00	1.27	1,200	3,800.00	3.17
32	Nakhon Ratchasima,1988	39,826.00	60	105.00	1.75	3,600	13,800.00	3.83
33	Nakhon Ratchasima,1989	55,750.00	0	0.00	0.00	2,400	8,400.00	3.50

[a] the aggregate feed input quantity index was calculated as follows:

using 1987 prices as weight, aggregate feed input quantity index at station "s" in year "t" = $\Sigma_i Q_{s,i,t} P_{i,1987\ (i=1,...8)}$, where $Q_{s,i,t}$ is the quantity of feed type i used at station s in year t, and $P_{i,1987}$ is the price of feed type i in year 1987.

Table A.7: Detail of Aggregate Feed Input Quantity Index (cont'd)

OBS	STATION/YEAR	Broken Rice Quantity (Kg)	Broken Rice Value (Baht)	Broken Rice Price (Baht)	Fish Meal Quantity (Kg)	Fish Meal Value (Baht)	Fish Meal Price (Baht)	Bean Meal Quantity (Kg)	Bean Meal Value (Baht)	Bean Meal Price (Baht)
1	Loei,1987	2,400	7,030.00	2.93	1,000	12,500.00	12.50	1,500	14,250.00	9.50
2	Loei,1988	1,297	4,819.50	3.72	700	13,550.00	19.36	1,600	15,200.00	9.50
3	Loei,1989	3,440	14,052.00	4.08	823	13,892.24	16.88	2,872	30,881.12	10.75
4	Udon Thani,1987	0	0.00	0.00	500	6,125.00	12.25	0	0.00	0.00
5	Udon Thani,1988	300	1,480.00	4.93	310	4,480.00	14.45	0	0.00	0.00
6	Udon Thani,1989	1,900	11,200.00	5.89	1,020	16,320.00	16.00	821	9,031.00	11.00
7	Nong Khai,1987	0	0.00	0.00	5,820	72,750.00	12.50	7,972	75,734.00	9.50
8	Nong Khai,1988	1,700	7,335.00	4.31	2,947	41,061.95	13.93	4,988	51,215.60	10.27
9	Nong Khai,1989	0	0.00	0.00	4,593	68,343.20	14.88	5,618	67,322.00	11.98
10	Sakon Nakhon,1987	5,000	16,425.00	3.29	0	0.00	0.00	0	0.00	0.00
11	Sakon Nakhon,1988	7,200	32,560.00	4.52	190	2,540.00	13.37	120	980.00	8.17
12	Sakon Nakhon,1989	6,500	29,700.00	4.57	400	6,600.00	16.50	200	2,400.00	12.00
13	Khon Kaen,1987	6,800	21,800.00	3.21	2,860	35,575.00	12.44	1,200	10,550.00	8.79
14	Khon Kaen,1988	8,093	34,023.25	4.20	4,340	57,712.00	13.30	3,685	37,395.00	10.15
15	Khon Kaen,1989	7,900	39,370.00	4.98	5,242	81,349.70	15.52	4,416	55,880.00	12.65
16	Maha Sarakham,1987	2,500	10,550.00	4.22	900	12,600.00	14.00	600	6,900.00	11.50
17	Maha Sarakham,1988	1,800	10,950.00	6.08	1,800	26,800.00	14.89	1,500	20,500.00	13.67
18	Maha Sarakham,1989	1,100	7,600.00	6.91	1,000	18,000.00	18.00	0	0.00	0.00
19	Kalasin,1987	20,200	63,890.00	3.16	4,026	48,407.30	12.02	7,702	61,940.60	8.04
20	Kalasin,1988	8,000	35,990.00	4.50	4,939	68,407.10	13.85	6,387	61,043.90	9.56
21	Kalasin,1989	4,100	20,550.00	5.01	0	0.00	0.00	0	0.00	0.00
22	Ubon Ratchathani,1987	6,500	25,510.00	3.92	3,700	52,200.00	14.11	2,800	27,650.00	9.88
23	Ubon Ratchathani,1988	8,200	39,290.00	4.79	1,700	28,200.00	16.59	1,000	12,000.00	12.00
24	Ubon Ratchathani,1989	10,605	47,478.75	4.48	2,700	51,300.00	19.00	2,120	27,660.00	13.05
25	Surin,1987	5,600	20,200.00	3.61	2,400	30,000.00	12.50	4,000	38,000.00	9.50
26	Surin,1988	6,000	33,000.00	5.50	3,500	54,000.00	15.43	2,500	15,750.00	6.30
27	Surin,1989	7,700	22,330.00	2.90	2,900	43,150.00	14.88	1,300	14,000.00	10.77
28	Burirum,1987	3,300	11,080.00	3.36	3,240	40,398.00	12.47	2,720	22,093.00	8.12
29	Burirum,1988	3,000	17,250.00	5.75	1,260	16,470.00	13.07	1,280	12,440.00	9.72
30	Burirum,1989	1,000	5,140.00	5.14	990	13,785.00	13.92	1,120	12,340.00	11.02
31	Nakhon Ratchasima,1987	0	0.00	0.00	0	0.00	0.00	600	5,700.00	9.50
32	Nakhon Ratchasima,1988	0	0.00	0.00	0	0.00	0.00	0	0.00	0.00
33	Nakhon Ratchasima,1989	0	0.00	0.00	0	0.00	0.00	0	0.00	0.00

Table A.7: Detail of Aggregate Feed Input Quantity Index (cont'd)

OBS	STATION/YEAR	Sup. Feed Quantity (bags)	Sup. Feed Value (Baht)	Sup. Feed Price (Baht)	Pellete Quantity (#)	Pellete Value (Baht)	Pellete Price (Baht)	Other Value (Baht)
1	Loei,1987	54	13,945.00	258.24	0	0.00	0.00	0.00
2	Loei,1988	58	16,410.00	282.93	0	0.00	0.00	0.00
3	Loei,1989	58	18,006.00	310.45	0	0.00	0.00	0.00
4	Udon Thani,1987	2	530.00	240.91	120	18,530.00	154.42	0.00
5	Udon Thani,1988	0	0.00	0.00	350	65,805.00	188.01	0.00
6	Udon Thani,1989	0	0.00	0.00	5	1,450.00	290.00	0.00
7	Nong Khai,1987	8	1,450.00	181.25	175	30,925.00	176.71	2,000.00
8	Nong Khai,1988	32	8,690.00	275.87	105	21,025.00	200.24	2,000.00
9	Nong Khai,1989	0	0.00	0.00	11	3,060.00	278.18	4,145.00
10	Sakon Nakhon,1987	400	105,250.00	263.13	95	16,100.00	169.47	0.00
11	Sakon Nakhon,1988	450	129,300.00	287.33	156	31,480.00	201.79	0.00
12	Sakon Nakhon,1989	573	175,665.00	306.57	41	10,236.90	249.68	0.00
13	Khon Kaen,1987	80	19,700.00	246.25	0	0.00	0.00	1,232.00
14	Khon Kaen,1988	0	0.00	0.00	0	0.00	0.00	3,100.00
15	Khon Kaen,1989	2	620.00	310.00	0	0.00	0.00	2,700.00
16	Maha Sarakham,1987	81	20,231.00	249.77	15	2,700.00	180.00	0.00
17	Maha Sarakham,1988	67	15,989.00	238.64	200	43,500.00	217.50	360.00
18	Maha Sarakham,1989	0	0.00	0.00	120	22,680.00	189.00	0.00
19	Kalasin,1987	0	0.00	0.00	0	0.00	0.00	0.00
20	Kalasin,1988	0	0.00	0.00	0	0.00	0.00	0.00
21	Kalasin,1989	0	0.00	0.00	0	0.00	0.00	0.00
22	Ubon Ratchathani,1987	192	54,780.00	285.31	158	25,780.00	163.16	0.00
23	Ubon Ratchathani,1988	201	62,270.00	309.80	117	19,560.00	167.18	0.00
24	Ubon Ratchathani,1989	235	78,375.00	333.51	116	20,880.00	180.00	0.00
25	Surin,1987	7	1,645.00	235.00	0	0.00	0.00	0.00
26	Surin,1988	82	15,430.00	188.17	59	10,158.00	172.17	0.00
27	Surin,1989	44	17,185.00	390.57	135	27,370.00	202.74	0.00
28	Burirum,1987	69	22,295.00	323.12	0	0.00	0.00	0.00
29	Burirum,1988	59	22,385.00	379.41	0	0.00	0.00	0.00
30	Burirum,1989	42	18,261.00	434.79	137	27,535.00	200.99	0.00
31	Nakhon Ratchasima,1987	190	29,060.00	152.95	130	19,500.00	150.00	0.00
32	Nakhon Ratchasima,1988	0	0.00	0.00	189	35,295.00	186.75	0.00
33	Nakhon Ratchasima,1989	0	0.00	0.00	321	64,805.00	201.88	0.00

Table A.8: Detail of Aggregate Fertilizer Input Quantity Index[a]

OBS	STATION/YEAR	Aggregate Fer. Input Quantity Index (Baht)	Organic Quantity (Kg)	Organic Value (Baht)	Organic Price (Baht)	Chemical Quantity (Kg)	Chemical Value (Baht)	Chemical Price (Baht)
1	Loei,1987	200.00	100	200	2.00	0	0	0.00
2	Loei,1988	0.00	0	0	0.00	0	0	0.00
3	Loei,1989	1,750.00	450	900	2.00	150	850	5.67
4	Udon Thani,1987	400.00	50	100	2.00	50	300	6.00
5	Udon Thani,1988	285.00	0	0	0.00	48	285	5.90
6	Udon Thani,1989	400.00	50	100	2.00	50	350	7.00
7	Nong Khai,1987	12,050.00	28,000	11,200	0.40	25	850	34.00
8	Nong Khai,1988	7,200.00	18,000	7,200	0.40	0	0	0.00
9	Nong Khai,1989	6,335.00	8,650	3,460	0.40	450	2,845	6.32
10	Sakon Nakhon,1987	4,200.00	0	0	0.00	950	4,200	4.42
11	Sakon Nakhon,1988	7,957.89	0	0	0.00	1,800	9,600	5.33
12	Sakon Nakhon,1989	5,968.42	0	0	0.00	1,350	8,086	5.99
13	Khon Kaen,1987	16,250.00	0	0	0.00	2,500	16,250	6.50
14	Khon Kaen,1988	0.00	0	0	0.00	0	0	0.00
15	Khon Kaen,1989	0.00	0	0	0.00	0	0	0.00
16	Maha Sarakham,1987	15,950.00	2,000	3,650	1.83	3,075	12,300	4.00
17	Maha Sarakham,1988	15,025.00	1,000	1,900	1.90	3,300	17,100	5.18
18	Maha Sarakham,1989	4,930.00	400	1,000	2.50	1,050	5,880	5.60
19	Kalasin,1987	47,300.00	110,000	47,300	0.43	0	0	0.00
20	Kalasin,1988	34,400.00	80,000	34,400	0.43	0	0	0.00
21	Kalasin,1989	34,400.00	80,000	34,400	0.43	0	0	0.00
22	Ubon Ratchathani,1987	18,450.00	1,600	1,600	1.00	3,350	16,850	5.03
23	Ubon Ratchathani,1988	7,017.91	4,000	4,000	1.00	600	3,120	5.20
24	Ubon Ratchathani,1989	9,808.21	0	0	0.00	1,950	10,510	5.39
25	Surin,1987	540.00	0	0	0.00	100	540	5.40
26	Surin,1988	10,900.00	50	100	2.00	2,000	10,800	5.40
27	Surin,1989	2,400.00	1,200	2,400	2.00	0	0	0.00
28	Burirum,1987	5,850.00	2,150	4,300	2.00	250	1,550	6.20
29	Burirum,1988	5,050.00	200	430	2.15	750	4,250	5.67
30	Burirum,1989	11,034.40	365	730	2.00	1,662	10,111	6.08
31	Nakhon Ratchasima,1987	14,040.00	0	0	0.00	2,200	14,040	6.38
32	Nakhon Ratchasima,1988	0.00	0	0	0.00	0	0	0.00
33	Nakhon Ratchasima,1989	16,592.73	0	0	0.00	2,600	16,640	6.40

[a] the aggregate fertilizer input quantity index was calculated as follows:
using 1987 prices as weight, aggregate fertilizer input quantity index at station "s" in year "t" = $\Sigma_i Q_{s,i,t} P_{i,1987\ (i=1,2)}$, where $Q_{s,i,t}$ is the quantity of fertilizer type i used at station s in year t, and $P_{i,1987}$ is the price of fertilizer type i in year 1987.

Table A.9: Output and Inputs per square Metre

OBS	STATION/YEAR	Output (Y) (฿/sq.m)	Broodstock (BS) (kg/sq.m)	Lime (LI) (bags/sq.m)	Fuel (FU) (l/sq.m)	Labour (LB) (m-d/sq.m)	Aggregate Feed Input Quantity Index (FD) (Baht/sq.m)	Aggregate Fer. Input Quantity Index (FR) (Baht/sq.m)
1	Loei,1987	56.92602	0.01342	0.01275	0.03947	0.03727	0.97740	0.00253
2	Loei,1988	65.56514	0.01347	0.01515	0.03627	0.05500	0.78755	0.00000
3	Loei,1989	57.46667	0.01361	0.01944	0.03665	0.03500	1.17150	0.02210
4	Udon Thani,1987	744.62586	0.06554	0.00009	0.18716	0.27672	2.68327	0.03704
5	Udon Thani,1988	689.09891	0.06130	0.02778	0.13297	0.27672	5.83621	0.02639
6	Udon Thani,1989	703.78866	0.08635	0.00000	0.13530	0.30006	3.84656	0.03704
7	Nong Khai,1987	208.64904	0.01204	0.01464	0.08038	0.10544	5.14508	0.25209
8	Nong Khai,1988	199.35324	0.01173	0.00889	0.07701	0.10544	3.59926	0.15063
9	Nong Khai,1989	143.00983	0.01265	0.00837	0.04979	0.10544	3.33597	0.13253
10	Sakon Nakhon,1987	169.32664	0.03868	0.02134	0.04156	0.07384	3.79458	0.05782
11	Sakon Makhon,1988	164.26390	0.04206	0.03992	0.03862	0.07384	4.13335	0.10955
12	Sakon Nakhon,1989	178.08921	0.03783	0.01412	0.03648	0.07384	3.88445	0.08216
13	Khon Kaen,1987	99.16035	0.01365	0.02451	0.11787	0.04655	1.26184	0.16414
14	Khon Kaen,1988	89.38141	0.01488	0.02424	0.10909	0.04655	1.60303	0.00000
15	Khon Kaen,1989	111.84899	0.01448	0.00649	0.08031	0.04727	1.77411	0.00000
16	Maha Sarakham,1987	452.79000	0.02965	0.31200	0.14595	0.19620	3.35105	0.79750
17	Maha Sarakham,1988	483.36650	0.02932	0.26000	0.11824	0.21060	7.02935	0.75125
18	Maha Sarakham,1989	480.91250	0.03535	0.09125	0.11325	0.23760	4.01467	0.24650
19	Kalasin,1987	156.66346	0.01447	0.00309	0.00820	0.05368	2.47313	0.47300
20	Kalasin,1988	124.65595	0.01363	0.00063	0.01031	0.05832	1.73795	0.34400
21	Kalasin,1989	108.24725	0.02146	0.01663	0.01839	0.05832	0.69982	0.34400
22	Ubon Ratchathani,1987	346.31734	0.05517	0.05594	0.10458	0.12336	7.85318	0.64510
23	Ubon Ratchathani,1988	306.00231	0.05606	0.04196	0.09297	0.12336	5.69700	0.24538
24	Ubon Ratchathani,1989	323.45909	0.04956	0.02517	0.07573	0.12336	7.71044	0.34294
25	Surin,1987	252.81200	0.07031	0.09050	0.12785	0.07842	3.51819	0.01337
26	Surin,1988	224.43191	0.03349	0.12619	0.08045	0.08465	4.25507	0.26980
27	Surin,1989	201.86681	0.03999	0.00990	0.09146	0.07663	3.38466	0.05941
28	Burirum,1987	30.51219	0.00434	0.04265	0.00676	0.05665	1.85771	0.08603
29	Burirum,1988	37.16985	0.00538	0.00000	0.00985	0.05665	1.07552	0.07426
30	Burirum,1989	31.97765	0.00622	0.00000	0.01257	0.05718	1.12486	0.16227
31	Nakhon Ratchasima,1987	775.22305	0.08334	0.19531	0.19945	0.18281	4.56563	1.09688
32	Nakhon Ratchasima,1988	824.99016	0.09651	0.19531	0.22070	0.18281	3.11141	0.00000
33	Nakhon Ratchasima,1989	919.84422	0.10267	0.03469	0.26719	0.18281	4.35547	1.29631

Table A.10: Dummy Variables[a]

OBS	STATION/YEAR	W1	W2	BT1	BT2	L1	L2	T1	T2
1	Loei,1987	1	0	0	1	1	0	1	0
2	Loei,1988	1	0	0	1	1	0	0	1
3	Loei,1989	1	0	1	0	1	0	0	0
4	Udon Thani,1987	0	0	1	0	1	0	1	0
5	Udon Thani,1988	0	0	1	0	1	0	0	1
6	Udon Thani,1989	0	0	0	1	1	0	0	0
7	Nong Khai,1987	0	0	1	0	1	0	1	0
8	Nong Khai,1988	0	0	1	0	1	0	0	1
9	Nong Khai,1989	0	0	0	0	1	0	0	0
10	Sakon Nakhon,1987	0	0	1	0	1	0	1	0
11	Sakon Nakhon,1988	0	0	1	0	1	0	0	1
12	Sakon Nakhon,1989	0	0	0	1	1	0	0	0
13	Khon Kaen,1987	0	1	1	0	0	0	1	0
14	Khon Kaen,1988	0	1	1	0	0	0	0	1
15	Khon Kaen,1989	0	1	0	1	0	0	0	0
16	Maha Sarakham,1987	0	0	1	0	0	0	1	0
17	Maha Sarakham,1988	0	0	1	0	0	0	0	1
18	Maha Sarakham,1989	0	0	0	1	0	0	0	0
19	Kalasin,1987	0	1	0	1	0	0	1	0
20	Kalasin,1988	0	1	0	0	0	0	0	1
21	Kalasin,1989	0	1	0	0	0	0	0	0
22	Ubon Ratchathani,1987	1	0	1	0	0	1	1	0
23	Ubon Ratchathani,1988	1	0	0	1	0	1	0	1
24	Ubon Ratchathani,1989	1	0	0	0	0	1	0	0
25	Surin,1987	0	0	1	0	0	1	1	0
26	Surin,1988	1	0	1	0	0	1	0	1
27	Surin,1989	0	0	0	0	0	1	0	0
28	Burirum,1987	1	0	1	0	0	1	1	0
29	Burirum,1988	1	0	1	0	0	1	0	1
30	Burirum,1989	1	0	1	0	0	1	0	0
31	Nakhon Ratchasima,1987	0	1	1	0	0	1	1	0
32	Nakhon Ratchasima,1988	0	1	1	0	0	1	0	1
33	Nakhon Ratchasima,1989	0	1	0	1	0	1	0	0

[a] W1 and W2 are dummy variables for water condition, where W1 represents below normal condition, and W2 represents above normal condition.

BT1 and BT2 are dummy variables for breeding technique, where BT1 represents the technique using pituitary gland and BT2 represents the technique using both pituitary gland and hormone.

L1 and L2 are dummy variables for location of fishery stations, where L1 represents the station located in the upper Northeast and L2 represents the station located in the lower Northeast.

T1 and T2 are dummy variables for time period, where T1 represents year 1987 and T2 represents year 1988.

Table A.11: Output and Input Prices

OBS	STATION/YEAR	Output Price (p)	Broodstock Price (wBS)	Lime Price (wLI)	Fuel Price (wFU)	Wage per day (wLB)	Feed Input Price [a] (wFD)	Fer. Input Price [b] (wFR)
1	Loei,1987	0.10	20.00	6.00	6.75	75.78	1.00	1.00
2	Loei,1988	0.10	20.00	6.00	6.75	73.90	1.22	0.00
3	Loei,1989	0.10	25.00	6.03	6.55	102.27	1.26	1.00
4	Udon Thani,1987	0.10	25.00	0.00	6.65	72.10	1.00	1.00
5	Udon Thani,1988	0.10	30.00	6.33	6.65	76.45	1.25	1.00
6	Udon Thani,1989	0.10	25.00	0.00	6.45	98.12	1.43	1.13
7	Nong Khai,1987	0.10	20.00	5.32	6.68	74.14	1.00	1.00
8	Nong Khai,1988	0.10	25.00	6.12	6.68	79.98	1.18	1.00
9	Nong Khai,1989	0.10	25.00	5.63	6.48	88.34	1.23	1.00
10	Sakon Nakhon,1987	0.10	20.00	7.13	6.65	73.50	1.00	1.00
11	Sakon Nakhon,1988	0.10	20.00	6.17	6.65	78.17	1.24	1.21
12	Sakon Nakhon,1989	0.10	20.00	6.58	6.45	105.00	1.23	1.35
13	Khon Kaen,1987	0.10	20.00	6.00	6.59	139.79	1.00	1.00
14	Khon Kaen,1988	0.10	25.00	6.00	6.59	110.35	1.20	0.00
15	Khon Kaen,1989	0.10	30.00	6.22	6.39	133.79	1.36	0.00
16	Maha Sarakham,1987	0.10	20.00	5.02	6.63	98.20	1.00	1.00
17	Maha Sarakham,1988	0.10	25.00	5.75	6.63	104.39	1.24	1.26
18	Maha Sarakham,1989	0.10	40.00	7.00	6.43	132.31	1.38	1.40
19	Kalasin,1987	0.10	20.00	7.00	6.63	88.48	1.00	1.00
20	Kalasin,1988	0.10	20.00	6.98	6.63	95.55	1.25	1.00
21	Kalasin,1989	0.10	25.00	7.00	6.43	125.93	1.37	1.00
22	Ubon Ratchathani,1987	0.10	20.00	6.00	6.64	68.83	1.00	1.00
23	Ubon Ratchathani,1988	0.10	20.91	6.00	6.64	78.17	1.12	1.01
24	Ubon Ratchathani,1989	0.10	25.00	6.00	6.44	111.67	1.18	1.07
25	Surin,1987	0.10	25.00	7.96	6.59	73.50	1.00	1.00
26	Surin,1988	0.10	24.00	6.99	6.59	78.17	1.19	1.00
27	Surin,1989	0.10	23.75	5.00	6.49	105.00	1.14	1.00
28	Burirum,1987	0.10	30.00	6.86	6.59	49.02	1.00	1.00
29	Burirum,1988	0.10	25.00	0.00	6.59	49.69	1.26	0.93
30	Burirum,1989	0.10	30.00	0.00	6.49	76.90	1.29	0.98
31	Nakhon Ratchasima,1987	0.10	22.97	7.00	6.50	83.26	1.00	1.00
32	Nakhon Ratchasima,1988	0.10	25.00	7.00	6.50	87.17	1.24	0.00
33	Nakhon Ratchasima,1989	0.10	30.59	7.26	6.30	106.28	1.31	1.00

[a] the feed price index was defined as total cost of feed divided by the aggregate feed input quantity index.

[b] the fertilizer price index was defined as total cost of fertilizer divided by the aggregate fertilizer input quantity index.

Appendix B

CORRELATION MATRIX

	Y	BS	LI	FU	LB	FD	FR
Y	1						
BS	0.87678	1					
LI	0.43290	0.29164	1				
FU	0.90252	0.81224	0.44881	1			
LB	0.87921	0.66571	0.37929	0.72132	1		
FD	0.48394	0.48708	0.35057	0.39903	0.51280	1	
FR	0.48054	0.35085	0.50053	0.43247	0.28653	0.41959	1

	lnY	lnBS	lnLI	lnFU	lnLB	lnFD	lnFR
lnY	1						
lnBS	0.88489	1					
lnLI	0.26272	0.27667	1				
lnFU	0.79904	0.75070	0.34296	1			
lnLB	0.89014	0.69107	0.02842	0.66045	1		
lnFD	0.74349	0.63927	0.35669	0.55252	0.70080	1	
lnFR	0.20406	0.10812	-0.04039	-0.10528	0.28657	0.39755	1

Appendix C

DERIVATION OF CONFIDENCE INTERVALS

In general, the confidence interval for a coefficient can be calculated from:

(C.1) $$b_i = \hat{b}_i \pm t(S\hat{b}_i)$$

where $\hat{b}_i$ is the estimated coefficient

t is the t-statistic at n-k-1 degrees of freedom and a chosen confidence level

$S\hat{b}_i$ is the standard error of $\hat{b}_i$

For more than one coefficient, the confidence interval can be calculated as follows:

(C.2) $$\hat{y} = \Sigma_i \hat{b}_i x_i = \mathbf{x}^T \hat{\mathbf{b}}_i$$

where $\mathbf{x}^T$ is the transpose of vector x, and $\hat{\mathbf{b}}_i$ is vector of $\hat{b}_i$ which are stochastic, and $\hat{y}$ is a linear function of $\hat{b}$.

The variance of $\hat{y}$ can be derived from:

(C.3) $$\mathrm{Var}\ (\hat{y}) = \mathbf{x}^T\ \mathbf{Var}(\hat{\mathbf{b}}_i)\ \mathbf{x}$$

where $\mathbf{Var}(\hat{\mathbf{b}}_i)$ is variance covariance matrix of $\hat{\mathbf{b}}_i$. The confidence interval of $\hat{y}$ is then:

(C.4) $$y = \hat{y} \pm t \{Var(\hat{y})\}^{\frac{1}{2}}$$

C.1 Confidence Interval for E_i

From the Chapter 6, the factor elasticities for the modified translog are derived from ($\partial \ln Y/\partial \ln x_i$), and they do not constant but depend on level of input used (except for input feed cost which its elasticity is constant), for example $E_{BS} = ß_{BS} + 2ß_{BSBS}\ln BS$.

By applying (C.3):

(C.5) $$Var(\hat{E}_{BS}) = [1 \ 2\ln BS] \begin{bmatrix} Var\hat{ß}_{BS} & Cov(\hat{ß}_{BS} \ \hat{ß}_{BSBS}) \\ Cov(\hat{ß}_{BS} \ \hat{ß}_{BSBS}) & Var\hat{ß}_{BSBS} \end{bmatrix} \begin{bmatrix} 1 \\ 2\ln BS \end{bmatrix}$$

Therefore, after calculate Var ($\hat{E}_{BS}$) the confidence interval for $\hat{E}_{BS}$ at 95% confidence level can be derived from

(C.6) $$E_{BS} = \hat{E}_{BS} \pm t_{95\%,n-k-1}(Var \ \hat{E}_{BS})^{\frac{1}{2}}$$

Similarly, the confidence interval for $\hat{E}_{FU}$, and $\hat{E}_{LB}$ can be derived by the same procedure. For the confidence interval for $\hat{E}_{FD}$:

(C.7) $$E_{FD} = \hat{E}_{FD} \pm t_{95\%,n-k-1}(S_{\hat{ß}FD})$$

C.2 Confidence Interval for ε

From the modified translog function, the elasticity of scale (ε) was calculated from adding all E_i:

$$(C.7) \qquad \varepsilon = E_{BS} + E_{FU} + E_{LB} + E_{FD}$$

$$= (\beta_{BS} + 2\beta_{BSBS}\ln BS) + (\beta_{FU} + \beta_{FULB}\ln LB) + (\beta_{LB} + \beta_{FULB}\ln FU) + \beta_{FD}$$

$$= \underset{(\mathbf{x})^T}{[1 \;\; 2\ln BS \;\; 1 \;\; \ln LB \;\; 1 \;\; \ln FU \;\; 1]} \underset{(\hat{\boldsymbol{\beta}})}{\begin{bmatrix} \beta_{BS} \\ \beta_{BSBS} \\ \beta_{FU} \\ \beta_{FULB} \\ \beta_{LB} \\ \beta_{FULB} \\ \beta_{FD} \end{bmatrix}} \underset{(\mathbf{x})}{\begin{bmatrix} 1 \\ 2\ln BS \\ 1 \\ \ln LB \\ 1 \\ \ln FU \\ 1 \end{bmatrix}}$$

By the same concept of confidence interval for E_i, confidence interval for ε can be calculated from:

$$(C.8) \qquad \mathrm{Var}\hat{\varepsilon} = \mathbf{x}^T \, \mathbf{Var}(\hat{\boldsymbol{\beta}}) \, \mathbf{x}$$

where $\mathbf{Var}(\hat{\boldsymbol{\beta}})$ is the variance-covariance of matrix $\hat{\boldsymbol{\beta}}$, and the confidence interval of ε is:

$$(C.9) \qquad \varepsilon = \hat{\varepsilon} \pm t_{95\%,n-k-1}(\mathrm{Var}\hat{\varepsilon})^{1/2}$$

C.3 Confidence Interval for VMP_i

From the equation (6.25) $VMP_i = (pY/x_i)E_i$, given p, Y and x_i, the confidence interval for VMP_i can be calculated from the confidence interval for E_i.

$$\text{(C.10)} \qquad VMP_i = (pY/x_i)\{\hat{E}_i \pm t_{95\%,n-k-1}(Var\hat{E}_i)^{1/2}\}$$

C.4 Confidence Interval for $MRTS_{ij}$

From the equation (6.29), $MRTS_{ij} = \{(Y/x_i)E_i\}/\{(Y/x_j)E_j\}$. For instance

$$\text{(C.11)} \qquad MRTS_{BSLB} = \{(Y/BS)E_{BS}\}/\{(Y/LB)E_{LB}\}$$

$$= (E_{BS}/E_{LB})\ (LB/BS)$$

$$= \frac{(ß_{BS} + 2ß_{BSBS}\ln BS)}{(ß_{LB} + ß_{FULB}\ln FU)} \cdot \frac{(LB)}{(BS)}$$

It can be seen that $MRTS_{ij}$ is nonlinear in coefficients ß. So the formula (C.3) cannot be used to determine $Var(MRTS_{ij})$. However, we can form approximation to $Var(MRTS_{ij})$ by using the following rules [10].

$$\text{(C.12) suppose} \qquad y = f(\mathbf{x}, \mathbf{ß}) + u$$

$$\text{then} \qquad Var\ \hat{y} \approx (\partial f/\partial \hat{\mathbf{ß}})^T\ \mathbf{Var}(\hat{\mathbf{ß}})\ (\partial f/\partial \hat{\mathbf{ß}})$$

for the modified translog model:

$$\text{(C.13)} \qquad \ln Y = f(\mathbf{lnx}, \mathbf{ß}) + u$$

then $\quad Var(\ln\hat{Y}) \approx (\partial f/\partial\hat{\beta})^T \mathbf{Var(\hat{\beta})} (\partial f/\partial\hat{\beta})$

and $\quad Var(\partial\ln\hat{Y}/\partial\ln x_i) \approx (\partial^2\ln\hat{Y}/\partial\ln x_i\partial\hat{\beta})^T \mathbf{Var\beta} (\partial^2\ln\hat{Y}/\partial\ln x_i\partial\ln\hat{\beta})$

Similarly, let $MRTS_{ij} = f_{ij}(\mathbf{x}, \mathbf{\beta})$

then $\quad Var(\widehat{MRTS}_{ij}) \approx (\partial f_{ij}/\partial\hat{\beta})^T \mathbf{Var\hat{\beta}} (\partial f_{ij}/\partial\hat{\beta})$

for example:

(C.14) $\quad Var(\widehat{MRTS}_{BSLB}) = (\partial f/\partial\hat{\beta})^T \mathbf{Var\hat{\beta}} (\partial f/\partial\hat{\beta})$

where from (C.11) $\partial f/\partial\hat{\beta}$ is $(\partial f/\partial\hat{\beta}_{BS}, \partial f/\partial\hat{\beta}_{BSBS}, \partial f/\partial\hat{\beta}_{LB}, \partial f/\partial\hat{\beta}_{FULB})$ and in turn:

(C.15)

$$\partial f/\partial\hat{\beta}_{BS} = \{1/(\hat{\beta}_{LB} + \hat{\beta}_{FULB}\ln FU)\}.(LB/BS)$$

$$\partial f/\partial\hat{\beta}_{BSBS} = \{2\ln BS/(\hat{\beta}_{LB} + \hat{\beta}_{FULB}\ln FU)\}.(LB/BS)$$

$$\partial f/\partial\hat{\beta}_{LB} = -\{(\hat{\beta}_{BS} + 2\hat{\beta}_{BSBS} lbBS)/(\hat{\beta}_{LB} + \hat{\beta}_{FULB}\ln FU)^2\}.(LB/BS)$$

$$\partial f/\partial\hat{\beta}_{FULB} = -\ln FU\{(\hat{\beta}_{BS} + 2\hat{\beta}_{BSBS} lbBS)/(\hat{\beta}_{LB} + \hat{\beta}_{FULB}\ln FU)^2\}.(LB/BS)$$

$\mathbf{Var\hat{\beta}}$ is variance-covariance matrix of the coefficient $\hat{\beta}_{BS}$, $\hat{\beta}_{BSBS}$, $\hat{\beta}_{LB}$, and $\hat{\beta}_{FULB}$. Therefore, the confidence interval of $MRTS_{ij}$ at 95% confidence level is approximated as

(C.16) $\quad MRTS_{ij} \approx \widehat{MRTS}_{ij} \pm t_{95\%,n-k-1} (Var\ \widehat{MRTS}_{ij})^{1/2}$

Appendix D

DERIVED INPUT DEMAND FROM COBB-DOUGLAS MODEL

For cost minimization which firm minimized cost subject to a given production function, the model can be specified as:

(D.1) $$\min_{\mathbf{x}} \mathbf{wx}$$

$$\text{s.t. } f(\mathbf{x}) = y$$

where **w** is vector of input prices , **x** is vector of input demand, and $y = f(\mathbf{x})$ is firm's production function.

The model (D.1) can be written in largrange function as:

(D.2) $$C = \mathbf{wx} + \mu\{ y - f(\mathbf{x})\}$$

The first-order conditions can then be stated as:

(D.3) $$\partial C/\partial x_i = w_i - \mu f_i(\mathbf{x}) = 0$$

(D.4) $$\partial C/\partial \mu = y - f(\mathbf{x}) = 0$$

Solving (D.3) and (D.4) yields the optimum level of input demand $x_i(\mathbf{w},y)$

From Chapter 6, the estimated Cobb-Douglas production function, equation (6.4) and (6.4.a), written in normal form is:

$$\text{(D.5)} \qquad Y = e^{\alpha} BS^{\beta BS} FU^{\beta FU} LB^{\beta LB} FD^{\beta FD} e^{(d1W1 + d2W2)}$$

and

$$\text{(D.6)} \qquad Y = e^{8.3983} BS^{0.38406} FU^{0.10757} LB^{0.72678} FD^{0.23668} e^{(-0.14948W1 + 0.33758W2)}$$

Assume that cost minimization exists, the optimum level of input BS, FU, LB, and FD can be derived by setting the largrange function as (D.2) and then solving the first-order conditions as (D.3) and (D.4) which yielding:

$$\text{(D.7)} \quad BS = [Y/A]^{1/b} [\beta_{BS}/W_{BS}]^{(b-\beta BS)/b} [\beta_{FU}/W_{FU}]^{-\beta FU/b} [\beta_{LB}/W_{LB}]^{-\beta LB/b} [\beta_{FD}/W_{FD}]^{-\beta FD/b} [e^{\tau}]^{-1/b}$$

$$\text{(D.8)} \quad FU = [Y/A]^{1/b} [\beta_{BS}/W_{BS}]^{-\beta BS/b} [\beta_{FU}/W_{FU}]^{(b-\beta FU)/b} [\beta_{LB}/W_{LB}]^{-\beta LB/b} [\beta_{FD}/W_{FD}]^{-\beta FD/b} [e^{\tau}]^{-1/b}$$

$$\text{(D.9)} \quad LB = [Y/A]^{1/b} [\beta_{BS}/W_{BS}]^{-\beta BS/b} [\beta_{FU}/W_{FU}]^{-\beta FU/b} [\beta_{LB}/W_{LB}]^{(b-\beta LB)/b} [\beta_{FD}/W_{FD}]^{-\beta FD/b} [e^{\tau}]^{-1/b}$$

$$\text{(D.10)} \quad FD = [Y/A]^{1/b} [\beta_{BS}/W_{BS}]^{-\beta BS/b} [\beta_{FU}/W_{FU}]^{-\beta FU/b} [\beta_{LB}/W_{LB}]^{-\beta LB/b} [\beta_{FD}/W_{FD}]^{(b-\beta FD)/b} [e^{\tau}]^{-1/b}$$

where

$$A = e^{\alpha} = e^{8.3983} = 4439.51316$$

$$\beta_{BS} = 0.38406$$

$$\beta_{FU} = 0.10757$$

$$\beta_{LB} = 0.72678$$

$$\beta_{FD} = 0.23668$$

$$b = \beta_{BS} + \beta_{FU} + \beta_{LB} + \beta_{FD} = 1.45509$$

$$\tau = d_1W_1 + d_2W_2 = -0.14948W_1 + 0.33758W_2$$

and mean value of Y = 295.83, mean value of w_{BS} = 24.31, mean value of w_{FU} = 6.57, mean value of w_{LB} = 90.73, and mean value of w_{FD} = 1.17.

Appendix E

ESTIMATED RESULTS USING TWO-STAGE LEAST SQUARES

Based on results reported in Chapter 6, the fish seed production function can be specified in terms of significant variables as:

$$(E.1) \qquad Y = f(BS, FU, LB, FD, W_1, W_2)$$

Equation (E.1) in the Cobb-Douglas case was estimated by two-stage least squares where inputs broodstock (BS), fuel (FU), labour (LB), and feed (FD) were treated as endogenous variables. The exogenous variables for two stage estimation were specified as prices of broodstock (w_{BS}), fuel (w_{FU}), labour (w_{LB}), feed (w_{FD}), quantity of fish seed output (Y), and the dummy variables representing water condition (W_1 and W_2).

Results for the first stage estimation are shown in equations (E.2)-(E.5), and results for the second stage estimation are shown in equation (E.6) (numbers in parentheses are t-statistics).

$$(E.2) \qquad \ln BS = \underset{(-2.9032)}{-6.8864} + \underset{(9.6281)}{0.8617\ln Y} - \underset{(-1.3336)}{0.6824\ln(w_{BS}/w_{LB})} - \underset{(-0.1312)}{0.0781\ln(w_{FU}/w_{LB})} + \underset{(0.7228)}{0.5758\ln(w_{FD}/w_{LB})} + \underset{(1.4967)}{0.3126W_1} + \underset{(0.0796)}{0.0154W_2}$$

$$(E.3) \qquad \ln FU = \underset{(-4.1679)}{-14.5120} + \underset{(6.0710)}{0.7975\ln Y} + \underset{(0.9849)}{0.7398\ln(w_{BS}/w_{LB})} - \underset{(-0.0986)}{0.0861\ln(w_{FU}/w_{LB})} - \underset{(-1.6308)}{1.9070\ln(w_{FD}/w_{LB})} + \underset{(0.6699)}{0.2054W_1} - \underset{(-0.8815)}{0.2508W_2}$$

$$(E.4) \qquad \ln LB = \underset{(-3.5750)}{-4.3087} + \underset{(12.709)}{0.5779\ln Y} + \underset{(2.4935)}{0.6483\ln(w_{BS}/w_{LB})} - \underset{(-1.7297)}{0.5230\ln(w_{FU}/w_{LB})} + \underset{(0.8641)}{0.3497\ln(w_{FD}/w_{LB})} - \underset{(-0.7547)}{0.0801W_1} - \underset{(-2.7116)}{0.2671W_2}$$

(E.5) $\ln FD = -3.0244 + 0.5388\ln Y + 0.0118\ln(w_{BS}/w_{LB}) + 0.5939\ln(w_{FU}/w_{LB}) - 0.6677\ln(w_{FD}/w_{LB}) + 0.0365W_1 - 0.4876W_2$
(-1.2626) (5.9617) (0.0229) (0.9883) (-0.8301) (0.1730) (-2.4911)

(E.6) $\ln Y = 7.2454 + 0.25585\ln BS + 0.11062\ln FU + 0.44094\ln LB + 0.34816\ln FD - 0.36787W_1 + 0.23517W_2$
(4.1613) (0.89555) (0.67284) (1.94880) (0.86142) (-1.73850) (1.03350)

Most coefficients of relative prices in the first stage estimates of factor demand equations (E.2)-(E.5) are statistically insignificant. As a result, coefficients in the second stage estimates of the production function are insignificant, in contrast to ordinary least squares estimates of the production function.

These results do not imply that factor demands at fisheries are not responsive to factor prices (we have already accepted the hypothesis of competitive cost minimization, see **Table 6.10**). Instead, these poor results are presumably due to the low variation in prices over the data set. These results confirm our wisdom in adopting a primal approach rather than a dual approach to the econometric estimation of technology.

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