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# Rice versus Shrimp Production in Thailand: Is There Really a Conflict?

## Thamrong Mekhora and Laura M.J. McCann

Shrimp farming in Thailand has had disastrous effects on the environment in the past, which has prompted a government ban on shrimp production in inland areas. However, a new low-salinity shrimp farming system has developed that seems to have fewer disease and environmental problems than previous systems but competes with rice production for land and water resources. The present study found that shrimp farming exhibits increasing returns to scale and is much more profitable than rice farming, which offers opportunities for rice farmers to improve their incomes through diversification. No evidence was found for external environmental effects of shrimp production on rice production or vice versa. A total ban on shrimp production in rice farming areas does not seem justified, although further analysis on the environmental effects of this farming system is warranted.

*Key Words:* environment, rice, shrimp, technical change, Thailand

**JEL Classifications:** Q12, Q16, Q24, Q28

For several decades, agricultural development has been central to economic growth in Thailand, contributing to growth in employment and foreign exchange earnings and to improvements in nutrition and standard of living. Rice and shrimp were among the top 10 export commodities for Thailand in 2000. Thailand is the world's largest rice exporter, followed by Vietnam and the United States, and is the world leader in farm-based shrimp production. Because of recent technical changes in shrimp production, these two major agricultural industries, both supported by the government, are potentially in conflict. The present study examines this conflict from the point of view of the environment and land allocation, to evaluate the ban on shrimp production in freshwater areas that has been imposed by the government. A discussion of the developments in the shrimp industry is presented to put the study in perspective.

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## Development of Shrimp Culture in Thailand

In the past, an extensive form of shrimp culture was practiced in low-lying areas that flooded with seawater at certain times of the year. In this system, both rice and shrimp yields were low. This situation changed in the 1980s with the development of new aquaculture technologies that enabled the propagation and cultivation of tiger shrimp in captivity and a government policy goal of increasing production for export rather than for local consumption (FAO). Thailand's investment in shrimp production has led to the development and adoption of modern and intensive culture systems, improved knowledge of nutrition, and well-developed infrastructure and support industries such as hatcheries. Modern intensive shrimp production in Thailand has occurred in three phases.

Thailand's intensive shrimp culture industry was first established in the upper Gulf of Thailand around Bangkok, primarily in mangrove areas, and was very profitable, allowing most farmers to recoup their investment in 1 year (Chong). However, the widespread proliferation of intensive culture systems contributed to the loss of habitat and nursery areas for aquatic species because of the removal of mangrove forests. Inadequate regulation of the operation and expansion of the industry by government allowed shrimp farms to harvest in mangrove reserve areas. Groundwater aquifers, domestic water supplies, and adjacent rice areas became contaminated by saline water intrusion (Baird and Quarto; Dierberg and Kiattisimkul; Flaherty and Karnjanakesorn).

Several problems had also arisen within the shrimp culture industry itself. During the early 1990s, farms began to experience high mortality rates due to disease outbreaks which were quickly transmitted between the densely concentrated farms. A lack of coordination of pond construction and water supply infrastructure led to water quality along the coast quickly deteriorating because of the discharge of pond effluents (Phillips, Lin, and Beveridge). Poor management of the farms due to limited technical skills resulted in high fry densities, overfeeding, plankton blooms, and poor water circulation, which contributed to self-pollution of the earthen ponds. The deteriorating environmental conditions in the upper gulf coastline areas has led to a decline in production since 1994.

The second phase of shrimp production occurred when some farmers realized how vulnerable their operations were to water pollution, and their shrimp culture strategies changed in three main ways. First, there was a movement away from open culture systems, based on high rates of water exchange during the culture period, to semiclosed recycling systems in which pond water was treated after each crop and then reused or drained to the waterways. The system helped protect farmers from the activities of surrounding growers who continued to discharge pond effluent into shared waterways or who had encountered disease problems. Second, management techniques were improved. Farmers had taken note of the problems associated with using high stocking densities, failing to allow sufficient time for proper cleaning and drying of pond bottoms, and the risk involved in using expensive antibiotics to control disease. Third, new culture areas were developed, primarily along the southern Gulf of Thailand coast and the Andaman Sea, by both local farmers and larger absentee operators who migrated from the central region (Lin). Unfortunately, disease outbreaks began in the new areas, and large areas were idled.

Many analysts believed that the shrimp industry had peaked and would continue to decline because there were few new sites to exploit (Dierberg and Kiattismkul; Lin). However, this evaluation might prove to be premature. In the past, it was assumed that shrimp farming should be located and confined to areas close to the sea because of the requirement for large volumes of salt water. The most recent wave of intensive shrimp culture development involves the adoption of low-salinity culture technologies, which has greatly increased the potential for establishing shrimp cultivation much further inland than was previously believed possible, albeit creating competition for land with rice production. The feasibility of low-salinity culture, combined with high market prices for shrimp, made it economically viable to truck salt water in from the coast. Recent studies (Flaherty and Vandergeest; Flaherty, Vandergeest, and Miller) have suggested that there are a number of environmental concerns associated with this trend. In 1998, the government announced an environmental regulation preventing farmers from raising shrimp in the new areas because of the concern over salinity and waste accumulation. However, the farmers are lobbying to force the government to reverse that regulation.

The present article investigates the existing technology and farming systems for inland rice and shrimp production in Thailand. Whole-farm systems differ between the old coastal shrimp farms and the new inland farms. Instead of cultivating only shrimp, many new farms tend to maintain old crops, such as rice and orchards, and incorporate shrimp into the cropping systems, to increase profits. An economic analysis was conducted to examine whether there was a conflict between rice and shrimp farmers as far as resource allocation and externalities and to provide information to guide government policy. A brief summary of the current production technologies is presented to provide a context for the analysis.

*Rice Production Technology*

Modern cultural practices use improved seed varieties; broadcast seeding; chemicals for weed, insect, and disease control; chemical fertilizers; and machinery inputs. Soils are plowed and excess water drained off. Pregerminated seeds are broadcast by hand on the puddled soils, and some farms apply chemicals or natural herbs to control snails. Three to seven days after broadcasting the seed, herbicides and insecticides are applied to control weeds and insects, especially thrips. N-P-K fertilizers and/or urea are manually applied 20–30 days after sowing and again 65–70 days after sowing. At maturity, the rice is machine harvested, packed in 80–85-kg bags, and sold immediately to a rice mill. Labor input occurs in three categories: (1) labor for soil preparation, using hand tractor power; (2) labor for farm maintenance, including sowing, watering, fertilizing, weeding, spraying chemicals, and field observation; and (3) labor for harvesting and threshing, again machine assisted.

*Shrimp Production Technology*

As described earlier, the technology of shrimp production in Thailand has progressively developed from "coastline extensive" to "coastline intensive saline water" to "inland freshwater closed culture." The latter addresses many of the problems that had been experienced with the previous systems and is the one used in the study areas (Department of Fisheries). Shrimp are grown in ponds constructed in areas of foregone rice production along waterways and/or irrigation canals that provide adequate supplies of good quality fresh water. The ponds are typically rectangular or square shaped, ranging in size from 0.16 to 1 ha, and are 1.2–1.5 m deep. Ponds are separated by dikes that prevent flooding and provide access routes to the ponds for electricity and aerator motors.

Low-salinity shrimp culture relies on artificial feeds, aerators, lime, and a wide variety of drugs and chemicals. It requires saline water at the beginning of cultivation in order for the fry to adjust to the new environment and to obtain a high quality product. Small-scale nurseries have developed which specialize in acclimatizing postlarvae to lower salinity levels. The recommended salinity level for optimal growth of tiger shrimp is in the 10–30 parts per thousand (ppt) range (Chanratchakool, Turnbull, and Limsawan). Low salinity levels may result in slower growth and problems with shell development (Lymsuwan) as well as differences in firmness and flavor of the flesh (Csavas). Slower growth results in a smaller harvest size and lower price. Low-salinity farmers typically have harvests of 50–55 pieces per kilogram, whereas coastal farmers can achieve 30–35 pieces per kilogram.

The water supply for shrimp ponds is drawn from irrigation canals by gravity flow or pumping via trenches. The trenches also serve as cutoff drains between shrimp ponds and rice paddies and as wastewater drains for returning water from the shrimp ponds back to the irrigation canals. No farms within the study locations use waste treatment ponds, although they have waste ponds from which wastewater is discharged to local water bodies. Some farms use reservoir ponds for storing water, which is treated before being used in the shrimp ponds. The use of supplies of fresh water and the closed-pond system of shrimp production minimize introduction of diseases, predators, and competitors. Water quality in the rearing pond, especially in closed systems, deteriorates throughout the production cycle because of excess animal feed and shrimp excretion. Farmers monitor pH, ammonia, color, and odor of the pond water.

The production cycle for shrimp is as follows. Ponds are drained and dried by the sun. Farm tractors are used to move organic and phosphate wastes onto the dykes. The ponds are refilled with seawater and fresh water to produce a salinity of 2–10 ppt and limed to a neutral pH.

Fry selection is the first important step for shrimp production. To ensure healthy fry, farmers purchase fry from reliable hatcheries and also gauge the health of fry by visual inspection. The stocking density of fry in each pond depends on the production capacity of the farm, the cultural system, quality of soil and water, food availability, water management, design and structure of the pond, equipment availability, seasonal variations, target production, and experience of the farmers. New farmers tend to use high stocking densities of fry (>600,000 head per hectare), to guarantee the survival of sufficient stock and to test the capacity of the pond, whereas more experienced farmers use a density of fry <600,000 head per hectare, which is the government recommendation. Fry are examined regularly to evaluate health status, survival rate, and feed intake. Feed containing amino acids, fatty acids, energy, vitamins, and minerals, is matched to the age of shrimp.

Under normal circumstances, the shrimp are harvested after 3 months. A buyer visits the farmer and collects a sample of shrimp to determine their size and quality and agrees on a single price with the farmer. Shrimp are harvested by pumping water from the ponds, catching the shrimp in bag nets, and storing them in an iced basket. Harvested shrimp are graded, put in plastic baskets, weighed, and transported by truck to a cold storage plant.

## Data

Three types of analysis were conducted as part of the present study. A Cobb-Douglas production function was estimated to provide information on economies of scale and elasticity estimates for rice and shrimp production in the study areas. This type of analysis had not previously been conducted on inland freshwater closed culture shrimp systems. The application of costs and returns of production by unit area provides economic evidence of the presence or absence of efficiency of investment by measuring performance in terms of inputs, outputs and outcome. In our study, it was also used to evaluate external effects between rice and shrimp production. The presence of Pareto-relevant externalities between rice and shrimp producers was also examined via cost function analysis. The data set that was used for these analyses is presented below, and then, in separate sections, the relevant theory, results, and discussion for each type of analysis is presented.

Study areas were selected at locations in two river basins in Thailand, the Bang Pakong River Basin, which is the main water source for the eastern region of Thailand, and the Chao Praya River Basin, which is the main water source for the central region. These basins, made up of flat plains with fertile soils, are suitable for rice and shrimp production as well as for other crop and aquaculture activities.

Before undertaking the sampling for the survey, producers were placed in homogeneous groups as suggested by Aldenderfer and Blashfield, according to their activities and technology of production on the basis of recommendations of village or subdistrict heads and district extension service staff. Next, sample farms were selected in two stages. First, a cluster of five villages was selected on the basis of the classification of homogeneous groups. Second, sampled farms of each activity and level of technology were chosen at random in these villages. It is essential to note that data were collected only in areas where rice and shrimp farms were established next to each other. Only dikes and trenches were allowed to separate the two types of farms. The survey was conducted in 1998.

Data were collected from farms in the study areas by means of a questionnaire (based on Camacho, Houston, and Lewis; Hallam; Miller and Posci). The questionnaire was administered via on-farm interviews. It was used to collect technological information on outputs and the utilization of resources (land, labor, and capital), as well as production practices (soil, weed, insect, nutrient, and residue management). Quantities and prices of outputs and inputs from farm operations were recorded. Additional information was collected on human capital (age, education, years of experience, and attitudes toward environmental quality) and farm operating characteristics (the percentage of farm income derived from the product under consideration, tenure status, and full- or part-time producer). These data were transformed into variables for econometric analyses.

When the study was initiated, there was conflict between rice and shrimp farmers in the inland areas. However, when the data were collected, the farming systems and technology for shrimp production had changed. One reason may be that the conflict provided an incentive for technical change. The other is that the rice farmers were able to produce a more profitable product, shrimp. The expected separate categories of rice and shrimp production had to be altered to the following three categories:

*(1) SR group:* farms use water for shrimp production and then drain the wastewater for rice cultivation. However, this system may be temporary. It was discovered during interviews with shrimp farmers new to the area and in the areas where it is difficult for farmers to drain shrimp wastewater out of the farms. Sample size for this group was 25.

*(2) R or S group:* farms grow rice or shrimp separately, and this group contains most of the data. There were 58 sampled farms for rice production and 46 sampled farms for shrimp production. The sample size for shrimp farms was less than that for rice farms because some shrimp farms were established between rice farms or shrimp ponds had two or three rice farms nearby.

*(3) RS group:* farms use water for rice cultivation first and later use that water for shrimp production. From the survey, most farms harvested shrimp once a year. These farms were concerned about water quality because they believed that water from the irrigation canal was contaminated by various sources. They judged that the appropriate way to manage this problem was to filter it in the rice field. This also helped them prolong the period of shrimp production, which resulted in larger shrimp and thus a higher price. There were 29 sampled farms in this group.

Rice and shrimp data sets were formed with these groups as factor variables to facilitate the investigation of rice or shrimp producer behavior separately. However, the analysis of economic costs and returns is conducted on these original groups.

Production data were collected from 112 farm respondents for rice production. Because each farm produced both wet and dry season rice in one crop year, the data set consisted of 112 samples in the wet season and 112 samples in the dry season. Because preliminary analysis showed that wet and dry seasons were not statistically different in production process and technology, the two data sets were merged to form 224 samples, and production data are summarized in Table 1.[1]

Data on shrimp production were transformed into appropriate variables for econometric analysis (Table 2). In the wet and dry seasons, similar production processes and technology were used; therefore, data from farm operations in both wet and dry seasons were merged together. The final data set included data from 146 farm respondents: 72 farms in the wet season and 74 farms in the dry season.

## Farm Characteristics

A comparison of the characteristics of rice and shrimp farms indicated no significant difference in the age of the farm leader (45 versus 43 years), the number of members of the household (4.12 versus 4.14), the number of members of the household working on the

[1] Although the econometric analysis was conducted using total quantities for each farm (e.g., kilograms of seed), the data in Tables 1 and 2 presents the information in more meaningful units (e.g., kilograms of seed per hectare).

**Table 1.** Summary of Rice Quantitative Data

| Description | Unit | Mean | SD | Min | Max |
|---|---|---|---|---|---|
| Output ($Q_{ri}$) | Kilograms/hectare | 4,294 | 726 | 2,813 | 5,625 |
| Area ($X_a$) | Hectares sown to rice | 4.02 | 2.06 | 1.28 | 9.6 |
| Seed ($X_s$) | Kilograms/hectare | 195 | 24 | 116 | 292 |
| Fertilizers ($X_f$) | Kilograms/hectare, all formulations | 274 | 143 | 42 | 547 |
| Chemicals ($X_c$) | Liters/hectare (sum of insecticides, fungicides, herbicides) | 3.20 | 1.25 | 1.25 | 8.04 |
| Fuel ($X_{fl}$) | Liters/hectare used for water pumping | 166 | 25 | 115 | 240 |
| Land preparation ($X_p$) | Hours/hectare (manual labor and machinery) | 14 | 1.58 | 9.82 | 18 |
| General labor ($X_{lb}$) | Hours/hectare (own and hired labor) | 167 | 21 | 114 | 213 |
| Harvesting ($X_h$) | Hours/hectare (manual labor and machinery) | 1.90 | 0.37 | 1.25 | 3.13 |
| Output price ($P_{ri}$) | $US/kilogram | 0.12 | 0.01 | 0.11 | 0.14 |
| Land price ($P_a$) | $US/hectare (rental price of land) | 44.8 | 4.78 | 39.1 | 58.6 |
| Seed price ($P_s$) | $US/kilogram | 0.14 | 0.004 | 0.13 | 0.15 |
| Fertilizer price ($P_f$) | $US/kilogram | 0.17 | 0.003 | 0.16 | 0.18 |
| Chemical price ($P_c$) | $US/liter (all pesticides were a similar price) | 9.0 | 0.51 | 8.0 | 10.4 |
| Fuel price ($P_{fl}$) | $US/liter (diesel) | 0.28 | 0.003 | 0.28 | 0.30 |
| Land preparation price ($P_p$) | $US/hour | 3.04 | 0.14 | 2.5 | 3.42 |
| Labor price ($P_{lb}$) | $US/hour | 0.51 | 0.004 | 0.50 | 0.52 |
| Harvesting price ($P_h$) | $US/hour | 29 | 2.1 | 21 | 34 |
| Total cost ($TC_{ri}$) | $US/hectare (sum of $X_i \times P_i$) | 376 | 50.4 | 283 | 498 |
| Net return ($NR_{ri}$) | $US/hectare (Total revenue − Total cost) | 147 | 364.8 | 19 | 219 |

farm (2.58 versus 2.28), or the percentage of farm ownership (62% versus 67% own land). Differences occurred in farm size (4.02 versus 0.87 ha), years of experience in production (27 versus 3.7), and the level of education of the farm leader (10% versus 19% have postsecondary education). Shrimp farms are operated intensively on small pieces of land, and farm leaders have much less experience than those on rice farms, although their level of education is somewhat higher. Most of these farms are small, having one pond operated by family labor.

## Economies of Scale and Elasticity Estimates

Production elasticities for each input were obtained by direct estimates from the production functions for rice and shrimp, under the assumption of the following Cobb-Douglas production function:

$$(1)\quad \log Q = \log A + \sum \beta_i \log X_i + \text{Type} + \text{LOC} + \text{Season} + \epsilon,$$

where the quantitative variables are the total output and inputs per farm. Three factor variables were included in the analysis. "Type" denotes the three categories of rice and shrimp production (*SR*, *R*, or *RS*) on the basis of activities and farm practice previously mentioned. "Location" (LOC) was included to investigate the effect of the two different river basin locations: Bang Pakong River Basin (170 samples) and Chao Praya River Basin (54 samples). "Season" referred to whether the

**Table 2.** Summary of Shrimp Quantitative Data

| Description | Unit | Mean | SD | Min | Max |
|---|---|---|---|---|---|
| Output ($Q_{sh}$) | Kilograms harvested/hectare/crop | 5,395 | 1,037 | 2,667 | 7,460 |
| Area ($X_a$) | Hectares of pond area | 0.55 | 0.23 | 0.10 | 1.02 |
| Pond maintenance ($X_{im}$) | Hours/hectare (manual labor and machinery) | 10.34 | 4.63 | 4.69 | 30.3 |
| Number of fry ($X_{fy}$) | Head/hectare released into ponds | 485,281 | 111,679 | 250,000 | 808,080 |
| Feed ($X_{fd}$) | Kilograms/hectare/crop | 7,554 | 1,738 | 3,750 | 12,083 |
| Lime ($X_{lm}$) | Kilograms/hectare/crop | 6,460 | 2,635 | 1,500 | 20,202 |
| General labor ($X_{lb}$) | Person-days/hectare (own and hired labor) | 321 | 69.9 | 182 | 529 |
| Fuel ($X_{fl}$) | Liters/hectare | 4,016 | 917 | 2,503 | 6,256 |
| Saline water ($X_{sa}$) | Liters/hectare used during pond filling | 92,693 | 75,937 | 25,000 | 468,750 |
| Chemicals ($X_c$) | Liters/hectare (chemicals and antibiotics) | 8.96 | 9.05 | 0.31 | 50 |
| Output price ($P_{sh}$) | $US/kilogram | 6.13 | 1.83 | 3.51 | 10 |
| Land price ($P_a$) | $US/hectare (rental price of land) | 361 | 42.8 | 312 | 469 |
| Pond maintenance price ($P_{im}$) | $US/hour | 17 | 1.53 | 15 | 20 |
| Fry price ($P_{fy}$) | $US/head | 0.0036 | 0.0005 | 0.0018 | 0.0055 |
| Feed price ($P_{fd}$) | $US/kilogram | 0.95 | 0.0075 | 0.93 | 0.96 |
| Lime price ($P_{lm}$) | $US/kilogram | 0.07 | 0.011 | 0.05 | 0.10 |
| Labor price ($P_{lb}$) | $US/day | 4.08 | 0.057 | 3.87 | 4.22 |
| Fuel price ($P_{fl}$) | $US/liter | 0.31 | 0.015 | 0.28 | 0.39 |
| Saline water price ($P_{sa}$) | $US/liter (delivered) | 0.0044 | 0.0012 | 0.0021 | 0.0072 |
| Chemical price ($P_c$) | $US/liter (varies by product) | 33 | 4.47 | 21 | 42 |
| Total cost ($TC_{sh}$) | $US/hectare (sum of $X_i \times P_i$) | 13,107 | 2,434 | 7,793 | 21,098 |
| Net return ($NR_{sh}$) | $US/hectare (Total revenue − Total cost) | 20,479 | 12,374 | 910 | 53,423 |
| Survival rate | Percentage (shrimp harvested/fry released) | 56 | 12.9 | 33 | 98 |
| Feed conversion ratio ($FCR$) | Feed/harvested product | 1.40 | 0.15 | 1.11 | 1.85 |
| Size | Head/kilogram at harvest | 50 | 10.8 | 27 | 85 |
| Days to harvest | Days | 116 | 8.0 | 90 | 136 |

**Table 3.** Production Function Estimates of Rice Production with the Response $\log(Q_{ri})$

| Terms | Value | SE | $t$ value | Pr(>\|t\|) |
|---|---|---|---|---|
| Intercept | 4.856 | 0.40 | 12.22 | 0.00 |
| $\log(X_a)$ | 0.196 | 0.09 | 2.22 | 0.03 |
| $\log(X_s)$ | 0.035 | 0.03 | 1.07 | 0.29 |
| $\log(X_f)$ | 0.155 | 0.02 | 10.58 | 0.00 |
| $\log(X_c)$ | 0.057 | 0.02 | 3.80 | 0.00 |
| $\log(X_{fl})$ | 0.036 | 0.05 | 0.78 | 0.44 |
| $\log(X_p)$ | 0.010 | 0.04 | 0.25 | 0.80 |
| $\log(X_{lb})$ | 0.408 | 0.07 | 5.79 | 0.00 |
| $\log(X_h)$ | 0.130 | 0.02 | 5.40 | 0.00 |
| Type 1 | 0.020 | 0.01 | 1.84 | 0.07 |
| Type 2 | −0.009 | 0.01 | −1.73 | 0.09 |
| Location | −0.017 | 0.01 | −2.88 | 0.00 |
| Season | −0.015 | 0.01 | −2.41 | 0.02 |

Notes: Residual standard error: 0.0551 on 211 degrees of freedom. Multiple $R^2$: 0.991. $F$-statistic: 1980 on 12 and 211 degrees of freedom, the $p$-value is 0. The test for constant returns to scale,[a] $F_{1,211} = 3.06$.

[a] For testing for constant returns to scale (a single linear restriction), the $F$-statistic is (Greene) $\{(Rb - q)'[s^2R(X'X)^{-1}R']^{-1}(Rb - q)\}/j$, where $R$ = $R$-matrix where each row of $R$ is a single linear restriction on the coefficient vector, $b$ = standard error of estimated coefficient, $q$ = particular value, and $s^2R(X'X)^{-1}$ = estimated variance of $b$.

**Table 4.** Production Function Estimates of Shrimp Production with the Response $\log(Q_{sh})$

| Terms | Value | SE | $t$ value | Pr(>\|t\|) |
|---|---|---|---|---|
| Intercept | 1.194 | 0.47 | 2.56 | 0.01 |
| $\log(X_a)$ | 0.181 | 0.05 | 3.67 | 0.00 |
| $\log(X_{im})$ | 0.006 | 0.04 | 0.15 | 0.88 |
| $\log(X_{fy})$ | −0.052 | 0.04 | −1.39 | 0.17 |
| $\log(X_{fd})$ | 0.790 | 0.05 | 17.20 | 0.00 |
| $\log(X_{lm})$ | −0.008 | 0.03 | −0.31 | 0.76 |
| $\log(X_{lb})$ | 0.119 | 0.06 | 2.15 | 0.03 |
| $\log(X_{fl})$ | 0.059 | 0.04 | 1.47 | 0.14 |
| $\log(X_{sa})$ | −0.004 | 0.02 | −0.24 | 0.81 |
| $\log(X_c)$ | 0.020 | 0.01 | 1.64 | 0.10 |
| Location | −0.002 | 0.02 | −0.14 | 0.89 |
| Season | −0.014 | 0.01 | −1.89 | 0.06 |

Notes: Residual standard error: 0.0845 on 134 degrees of freedom. Multiple $R^2$: 0.98. $F$-statistic: 594 on 11 and 134 degrees of freedom, the p-value is 0. The test for constant returns to scale,[a] $F_{1,134} = 12.89$, p-value $< 0.01$.

[a] For testing for constant returns to scale (a single linear restriction), the $F$-statistic is (Greene) $\{(Rb - q)'[s^2R(X'X)^{-1}R']^{-1}(Rb - q)\}/j$, where $R$ = $R$-matrix where each row of $R$ is a single linear restriction on the coefficient vector, $b$ = standard error of estimated coefficient, $q$ = particular value, and $s^2R(X'X)^{-1}$ = estimated variance of $b$.

crop was grown in the wet or dry season. The direct estimate of returns to scale is calculated from the sum of the estimated parameters of log-inputs in the Cobb-Douglas production function. The economies of scale can be defined as $\Omega_Q$, where $\Omega_Q < 1$ implies decreasing returns to scale, $\Omega_Q = 1$ implies constant returns, and $\Omega_Q > 1$ implies increasing returns. Results for rice production are shown in Table 3.

The model has a goodness of fit ($R^2$) equal to 0.991 and an $F$-statistic equal to 1980, indicating that the model is statistically significant. Estimated individual coefficients are significantly different from zero at the 5% level, except for $\log(X_s)$, $\log(X_{fl})$, $\log(X_p)$ and Type. The lack of significance may be due to the high correlations between these complementary inputs. The estimated parameters of LOC and Season are significantly different from zero, indicating that outputs from the two locations and two seasons are significantly different. For seed, the government-recommended seeding rate for broadcasting methods is ~90 kg/ha, whereas the average rate used in the study areas is 180 kg. From the survey, farmers used high seed density to control weeds. The test for constant returns to scale is accepted. Returns to scale is calculated to be 1.03.

For shrimp production, the estimated production function is shown in Table 4. This model has a goodness of fit ($R^2$) equal to 0.98 and an $F$-statistic equal to 594, which indicates that the model is statistically significant. However, few parameters are significant at the 5% level: $\log(X_a)$, $\log(X_{fd})$, and $\log(X_{lb})$. The sign of the estimates for fry and lime is problematic but not significantly different from zero at the 5% level. Fuel is highly correlated with several of the other variables but fry, lime, saltwater, and chemicals are not, indicating that these results are not due to multicollinearity. LOC and Season are also not significant at the 5% level, indicating no significant difference in yields between the two locations and two seasons. For shrimp production, estimates of elasticity of production reveal animal feed and land to be the dominant factors and important sources of output growth, whereas the least important factors are labor for pond maintenance and chemicals. Low elasticities of production are also found in the use of lime and saline water. This latter result would indicate that we will not see dramatic increases in the amounts of saline water used per hectare. The test for constant returns to scale is rejected. Returns to scale is calculated to be 1.11. From the returns to scale results, it is expected that the shrimp industry will continue to expand in the inland areas.

**Costs and Returns Analysis**

The conceptual framework is derived from USDA's Economic Research Service (USDA 1990) and Hallam. The extension of this concept underpins the Farm Level Budget Model (FLBM) (Miller and Posci), in which costs and returns are calculated for each farm observation and unit of land by area.[2] The concepts of costs and returns from agricultural production used in the present study are also from the USDA (1992, 1993).

From the farming systems described earlier, rice and shrimp production would be expected to affect each other, especially in the case of the *SR* and *RS* groups. These effects may show up in the costs and/or outputs of production. The results for rice (Table 5) indicate that

1. Fixed costs of rice production for the three groups are similar. Variable costs for the *SR* and *R* groups are higher than those for the *RS* group. The difference occurs in the use of fertilizers and chemicals, whereas the other variable costs are nearly the same. As mentioned, the *RS* group used fewer of these inputs to control the quality of water that was subsequently supplied to the shrimp pond. This results in the lowest yield, because the improved varieties used are very responsive to these factors. In particular, some farms experienced insect infestations because of reduced use of pesticides.
2. All farm systems and technologies provide a small positive net return to the rice producers. This indicates the ability of all the farm systems, even the *RS* group, to maintain their activities in the long run at a world market price of U.S.$0.12 per kilogram. However, Flaherty, Vandergeest, and Miller indicate that "In most of Thailand, smallholder irrigated paddy can no longer provide the basis for a growing, or even stable household economy" (p. 2050).
3. The *R* group is representative of a typical rice farm in the study areas. Compared with the *R* group, the *SR* group, which used wastewater from shrimp on rice, obtained higher yields and also higher net return. On the other hand, the *RS* farm system, which decreased the level of technology to keep water clean, obtained the lowest yield and also the lowest net return.

Cost analysis and measurement of economic returns for shrimp enterprises, shown in Table 6, indicate that

1. Cost structures for the three groups are quite different. Fixed cost for the *RS* farms is the highest, followed by the *S* and *SR* farms. This is because they raised shrimp only once a year. Conversely, the variable cost and total cost for the *SR* farms were the highest, followed by the *S* and *RS* farms, because the *SR* farms used more labor for pond maintenance, lime, chemicals, fry, and feed. One explanation for the difference is the lack of experience of the *SR* group. Newcomers may expect to obtain rapid returns from investment and tend to use high-density technology. The high fry density may lead to higher use of the other variable inputs (and thus higher costs), but this does not mean higher net return be-

[2] The total cost of each item was obtained by converting own and noncash inputs to commercial and cash values using market valuations. The local rental price for land in $ per ha was used to calculate the opportunity cost of land. If rent was paid in kind, it was converted to a dollar value. Depreciation was calculated by the straight-line method. The interest rate used for estimating the opportunity cost is the one that the Bank of Agriculture and Agricultural Cooperatives (Thailand) charges farmers for a loan (14.5%).

**Table 5.** Cost Analysis and Measurement of Economic Returns to Rice Production in U.S.$ per Hectare, per One Crop, Separated by Technology and Farm System

| Details | *SR* Group | % of Total Cost | *R* Group | % of Total Cost | *RS* Group | % of Total Cost |
|---|---|---|---|---|---|---|
| Number of observations | 50 | | 116 | | 58 | |
| **Fixed Cost** (Coefficient of variation) | **75.33** (11.03) | **16.86** | **78.16** (9.10) | **17.39** | **73.04** (7.10) | **21.00** |
| Tool, equipment and machinery | 3.17 | 0.71 | 2.78 | 0.62 | 1.91 | 0.55 |
| Maintenance of machinery | 27.35 | 6.12 | 26.99 | 6.00 | 27.05 | 7.78 |
| Opportunity cost of land | 43.02 | 9.63 | 46.66 | 10.38 | 42.39 | 12.19 |
| Opportunity cost of fixed cost[a] | 1.78 | 0.40 | 1.74 | 0.39 | 1.69 | 0.49 |
| **Variable Cost** (Coefficient of variation) | **371.36** (8.67) | **83.14** | **371.28** (10.12) | **82.61** | **274.84** (3.65) | **79.00** |
| Soil preparation | 42.90 | 9.60 | 43.18 | 9.61 | 40.17 | 11.55 |
| Seed | 26.49 | 5.93 | 27.78 | 6.18 | 27.39 | 7.87 |
| Fertilizers | 56.25 | 12.59 | 55.21 | 12.28 | 10.50 | 3.02 |
| Chemicals | 34.20 | 7.66 | 31.47 | 7.00 | 16.45 | 4.73 |
| Fuel | 45.45 | 10.18 | 47.31 | 10.53 | 46.20 | 13.28 |
| General labor | 89.85 | 20.11 | 89.70 | 19.96 | 71.30 | 20.49 |
| Harvesting labor | 56.95 | 12.75 | 57.35 | 12.76 | 48.77 | 14.02 |
| Opportunity cost[b] | 19.28 | 4.32 | 19.29 | 4.29 | 14.09 | 4.05 |
| **Total Cost** (Coefficient of variation) | **446.69** (7.44) | **100.00** | **449.44** (8.81) | **100.00** | **347.89** (3.39) | **100.00** |
| Total yield (kg) | 4,673.64 | | 4,564.26 | | 3,227.98 | |
| Farm-gate selling price (US$/kg) | 0.12 | | 0.12 | | 0.12 | |
| Total revenue | 572.79 | | 556.20 | | 389.23 | |
| **Return over variable cost** | **201.43** | | **187.92** | | **114.39** | |
| **Net return** (coefficient of variation) | **126.10** (40.09) | | **106.76** (56.71) | | **41.34** (115.87) | |

[a] Depreciation on owned equipment and machinery.
[b] Opportunity cost of all variable inputs, except own labor for soil preparation and general labor.

**Table 6.** Cost Analysis and Measurement of Economic Returns to Shrimp Production, U.S.$ per Hectare per Cultivated Area per One Crop, Separated by Technology and Farm System

| Details | *SR* Group | % of Total Cost | *S* Group | % of Total Cost | *RS* Group | % of Total Cost |
|---|---|---|---|---|---|---|
| Number of observations | 31 | | 86 | | 29 | |
| **Fixed Cost** (Coefficient of variation) | **1,837.81** (18.73) | **11.47** | **2,206.28** (68.88) | **14.23** | **2,388.45** (16.12) | **15.60** |
| Pond and waterway construction | 421.53 | 2.63 | 415.02 | 2.68 | 397.21 | 2.59 |
| Buildings | 21.40 | 0.13 | 24.45 | 0.16 | 33.25 | 0.22 |
| Water pump and pumping | 42.50 | 0.27 | 63.00 | 0.41 | 66.38 | 0.43 |
| Aerators | 519.75 | 3.24 | 451.86 | 2.91 | 429.85 | 2.81 |
| Feeding tools | 5.71 | 0.04 | 2.93 | 0.02 | 2.27 | 0.01 |
| Electricity connection | 13.56 | 0.08 | 10.17 | 0.07 | 6.14 | 0.04 |
| Fixing machine | 402.36 | 2.51 | 872.56 | 5.63 | 1,048.41 | 6.85 |
| Opportunity cost of land | 351.23 | 2.19 | 309.86 | 2.00 | 350.40 | 2.29 |
| Opportunity cost of fixed costs[a] | 59.76 | 0.37 | 56.43 | 0.36 | 54.55 | 0.36 |
| **Variable Cost** (Coefficient of variation) | **14,182.70** (27.08) | **88.53** | **13,298.01** (17.42) | **85.77** | **12,925.97** (9.37) | **84.40** |
| Pond maintenance | 237.45 | 1.48 | 160.88 | 1.04 | 132.45 | 0.86 |
| Lime | 614.74 | 3.84 | 423.99 | 2.73 | 400.70 | 2.62 |
| Chemicals | 293.82 | 1.83 | 150.55 | 0.97 | 142.47 | 0.93 |
| Fry | 1,843.75 | 11.51 | 1,737.95 | 11.21 | 1,624.05 | 10.60 |
| Saline water | 224.63 | 1.40 | 544.73 | 3.51 | 176.01 | 1.15 |
| Fuel | 1,057.41 | 6.60 | 1,126.79 | 7.27 | 1,263.02 | 8.25 |
| Electricity | 100.47 | 0.63 | 99.30 | 0.64 | 68.57 | 0.45 |
| Animal feed and additional feed | 7,452.66 | 46.52 | 7,024.33 | 45.31 | 7,171.20 | 46.83 |
| pH and water quality measurements | 27.46 | 0.17 | 16.01 | 0.10 | 14.13 | 0.09 |
| Labor | 1,530.37 | 9.55 | 1,258.17 | 8.11 | 1,210.36 | 7.90 |
| Other costs | 31.59 | 0.20 | 29.91 | 0.19 | 17.87 | 0.12 |
| Opportunity cost on variable costs[b] | 782.50 | 4.88 | 733.40 | 4.73 | 712.88 | 4.65 |
| **Total Cost** (Coefficient of variation) | **16,020.51** (25.02) | **100.00** | **15,504.29** (18.45) | **100.00** | **15,314.42** (8.81) | **100.00** |
| Total yield (kg) | 5,161.32 | | 5,351.44 | | 5,769.40 | |
| Farm-gate price (US$/kg) | 4.91 | | 6.06 | | 7.66 | |
| Total revenue | 26,022.04 | | 32,838.64 | | 44,002.82 | |
| **Return over variable cost** | **11,839.33** | | **19,540.63** | | **31,076.86** | |
| **Net return** (Coefficient of variation) | **10,001.52** (78.80) | | **17,334.36** (67.50) | | **28,688.41** (36.53) | |

[a] Opportunity cost of pond and waterway construction, buildings, water pump, aerators, feeding tools, and electricity connection.
[b] Opportunity cost of all variable inputs, except own labor cost.

cause it is more difficult to maintain suitable pond and water conditions for shrimp.

2. The *RS* farms are of particular interest, because they earned the largest net return, although this was because they produced shrimp only once a year. They developed their farm systems by retaining water in the rice field, which can grow rice twice a year, to prolong the period of production, and by using a low fry density technology. On a *per crop* basis, they had the highest yield and price (because of the large size) and thus the highest return, but on an annual basis they were intermediate between the *SR* ($20,002) and *S* ($34,669) systems.
3. The poor performance of the *SR* farms can be expected. High-density technology and intensive farming make it difficult to control the environment, viruses, and diseases and to maintain suitable conditions for shrimp production. Although the yields for *SR* farms were still high, the farm-gate price was very low. This indicates that the size of the product is small compared with the other groups. Moreover, even though these farms raised shrimp twice a year, the net return was still lower than *RS* farms on an annual basis. Note that this group is new to shrimp production. The average experience of the *SR* group is 2 years, whereas that for the other (*R* or *S* and *RS*) is 5 years. What may be happening is that the *SR* producers have poorer shrimp farm management skills than either the *S* or *RS* farms.

The results from the FLBM provide economic evidence not only on rice and shrimp production but also on the farming system when incorporating technical effects. The *SR* farms have the highest net return for rice production, which does not support the hypothesis that shrimp production has negative external effects on rice in the short term. Our study indicates there may even be a positive effect of water from shrimp production on rice production that may be due to excess nitrogen from the shrimp. Wastewater from shrimp is high in both nitrogen and phosphorus. Further research is required, because these farms are new and salinity effects on rice may not yet be apparent. The fact that *RS* farmers' net return from shrimp was higher than the *SR* farms does not support the hypothesis that rice has negative externalities on shrimp, although the *RS* group did take actions to internalize externalities by reducing input use. Although these data are only indicative as to the lower externalities from these new shrimp production systems, what is clear is that rice farmers can dramatically improve their incomes by incorporating shrimp production in their farming systems and that externalities would have to be extremely large to justify a ban.

**Test for Externalities via the Cost Function**

This section further investigates production externalities via the cost function. An empirical framework was generated based on a two-firm model in which each firm produces a technological externality that affects the other. As proposed by Davis and Whinston (1962, 1966), followed by Marchand and Russell, and illustrated by Shubik, a partial-equilibrium analysis of production externalities under optimizing conditions can be used to address resource allocation problems and provide policy implications.

Let $C_R(Q_R, Q_S)$ and $C_S(Q_S, Q_R)$ be the total cost functions of rice and shrimp firms, as indicated by the subscripts, which incur mutual (separable or nonseparable) externalities. Similarly, let $P_{QR}$ and $P_{QS}$ be the competitive prices of the outputs. The individual and uncoordinated optimizing objectives for the firms are

$$(2)\qquad \max_{Q_R} \pi_R = P_{QR}Q_R - C_R(Q_R, Q_S), \quad \text{and}$$

$$\max_{Q_S} \pi_S = P_{QS}Q_S - C_S(Q_S, Q_R).$$

The first-order conditions for optimization are

$$(3)\qquad \frac{\partial \pi_R}{\partial Q_R} = P_{QR} - \frac{\partial C_R}{\partial Q_R} = 0, \quad \text{and}$$

$$\frac{\partial \pi_S}{\partial Q_S} = P_{QS} - \frac{\partial C_S}{\partial Q_S} = 0.$$

The joint optimizing problem is

**Table 7.** Summary of Variables Used in Testing for Externalities

| Detail | Rice | Shrimp |
|---|---|---|
| **Output** (kg/ha) | | |
| $q_r$ for rice | | |
| $q_s$ for shrimp | | |
| Min | 2,856 | 2,745 |
| Median | 4,500 | 5,310 |
| Lower half | 4,564 | 5,351 |
| Max | 5,625 | 7,460 |
| **Total Cost** (US$/ha) | | |
| $TC_r$ for rice | | |
| $TC_s$ for shrimp | | |
| Min | 298 | 7,790 |
| Median | 368 | 12,850 |
| Lower half | 371 | 13,298 |
| Max | 498 | 21,200 |
| **Fixed Cost** (US$/ha) | 78 | 2,206 |
| **Output Price** (US$/ha) | 0.12 | 6.06 |

(4) $$\max_{Q_R, Q_S} \pi = P_{QR}Q_R + P_{QS}Q_S - C_R(Q_R, Q_S) - C_S(Q_S, Q_R),$$

and the necessary conditions for optimization are

(5) $$\frac{\partial \pi}{\partial Q_R} = P_{QR} - \frac{\partial C_R}{\partial Q_R} - \frac{\partial C_S}{\partial Q_R} = 0, \quad \text{and}$$

$$\frac{\partial \pi}{\partial Q_S} = P_{QS} - \frac{\partial C_R}{\partial Q_S} - \frac{\partial C_S}{\partial Q_S} = 0.$$

Let the values of $Q_R$ and $Q_S$ that satisfy the joint optimizing problem be denoted $Q_R^*$ and $Q_S^*$. On the basis of the assumption that the externalities exist and are relevant, $\partial C_S/\partial Q_R \neq 0$ and $\partial C_R/\partial Q_S \neq 0$; thus, it is apparent that the Pareto optimal outputs ($Q_R^*$ and $Q_S^*$) will not satisfy the private optimizing problem.

An econometric analysis is used to construct cost functions, focusing only on the relationship among cost, output, and expected externality variables. The generalized additive model was used (Hastie and Tibshirani). The data sets for rice and shrimp production are merged for this analysis (Table 7). Only *R* or *S* farms are taken into account because they separately produce rice or shrimp next to each other and thus both may affect each other through technical externalities. For *RS* and *SR* farms, on the other hand, technology and farm systems may have incorporated the consideration of external effects as explained earlier. To form the data set, it is essential to reexamine the location of established farms. Some shrimp farms were located in the middle of rice farms, and others have two or three rice farms adjacent to them. Each firm is assumed to affect the other. To make the observations equal, the shrimp samples that were adjacent to multiple rice farms were repeated. Thus there were 172 total observations, both rice and shrimp.

The analysis examined the contribution of the expected external diseconomy variables of one firm on the cost function of the other firm. In the rice model, shrimp output was included as an explanatory variable. Similarly, rice output was included in the shrimp cost model. A cross-output variable was also used to represent technological externalities. The cost function was constrained only by the terms of own output, cross output, and their interaction. These cost functions were estimated from the general form $\log(TC_i) \sim \log(q_i) + \log(q_j) + \log(q_j) \times \log(q_i)^2$. The results are shown in Table 8.

The estimated coefficients of the rice cost function are not statistically significant at the 10% level, whereas the estimated coefficients of the shrimp cost function are not even statistically significant at the 20% level. However, the *F*-statistic for overall coefficient testing is highly significant in both rice and shrimp cases. These data do not support the assertion that there are externalities between rice and shrimp production. It should be noted however, that effects on third parties, such as households that use water from the irrigation canals and rivers, are not accounted for, nor are any effects on groundwater quality. Water discharged from shrimp ponds at harvest would have elevated levels of salt, nutrients, and pathogens. It may also be that the cumulative impacts of salinity take a number of years to manifest themselves in rice yield reductions. The low-salt shrimp production systems have only recently moved into the central plain. On the other hand, flushing may miti-

**Table 8.** Estimated Coefficients of Cost Functions with the Predictors of Own and Cross Output and Their Interaction for Farms Producing Only Rice or Shrimp but Located Adjacent to Each Other

| | Rice | | | | Shrimp | | | |
|---|---|---|---|---|---|---|---|---|
| Coefficients: | Value | SE | $t$ value | Pr(>\|$t$\|) | Value | SE | $t$ value | Pr(>\|$t$\|) |
| Intercept | 38.7951 | 23.80 | 1.63 | 0.11 | 35.0204 | 27.65 | 1.27 | 0.21 |
| log $q_i$ | −3.8417 | 2.8091 | −1.37 | 0.17 | −3.1995 | 3.19 | −1.00 | 0.32 |
| log $q_j$ | −2.2360 | 1.3955 | −1.60 | 0.11 | −2.0331 | 1.66 | −1.22 | 0.22 |
| log $q_j(\log q_i)^2$ | 0.0308 | 0.0194 | 1.58 | 0.12 | 0.0275 | 0.02 | 1.24 | 0.22 |
| Residual standard error | 0.0641 | | | | 0.0907 | | | |
| Multiple $R^2$ | 0.5713 | | | | 0.7492 | | | |
| $F$-statistic | 75.1 | | | | 166 | | | |
| $p$-value of $F$-statistic | 0 | | | | 0 | | | |

gate the buildup of salinity, or these new shrimp production technologies may be less likely to have negative effects on rice production. Further research involving a number of disciplines such as hydrologists and soil scientists is needed. To our knowledge, there are no studies from these disciplines that have demonstrated salinity problems caused by these new systems.

## Conclusion

The results from this analysis show that shrimp production is extremely profitable and is at a point of increasing returns to scale. Therefore, shrimp production in the fresh areas of Thailand will expand in the absence of policies to restrict it. The ban on the expansion of shrimp production in these areas seems to have been based on results from the older technologies that were used in mangrove areas or along the coast. The new production systems seem to be much less problematic than those earlier systems. These results conflict with the dire predictions of Flaherty, Vandergeest, and Miller. Even if there are some negative externalities, it would be optimal to allow some expansion of the shrimp industry given the low returns to rice production. Also, most of the shrimp farming is on a small scale and is often conducted in conjunction with rice production. Therefore, there may be a resource allocation conflict between rice and shrimp production but not necessarily a conflict between rice and shrimp farmers. In addition, the fact that farmers are often producing both rice and shrimp would tend to lead to internalization of externalities, and our study provided some evidence that that is occurring. From both a welfare-maximizing and a distributional criterion, it seems that a ban is not supported by the evidence. Rigorous scientific studies of the long-term environmental effects of the new shrimp systems are needed. A go-slow policy, coupled with further research, rather than a complete ban, would be appropriate.

This research is important from the point of view of other regions of Thailand and other countries. Given the profitability of these shrimp production systems, there will be significant pressure to expand production into other areas. Expansion of the industry will happen and happen quickly once successful technologies are developed. Therefore, concerned governments need to manage this industry using appropriate policies to try to minimize negative consequences while allowing farmers to improve their incomes. The fact that successful new low-salinity technologies have developed also means that extension programs on these new technologies in other areas may lead to the development of a less polluting industry.

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