Nonparametric Estimation of Returns to Investment in Honduras Shrimp Research

Eighth Work Plan, Marketing and Economic Analysis Research 1 (8MEAR1)
Final Report

Siddhartha Dasgupta and Carole Engle
Department of Aquaculture and Fisheries
University of Arkansas at Pine Bluff
Pine Bluff, Arkansas, USA

Abstract

Economic returns to the investment in shrimp research in Honduras between 1993 and 1997 by PD/A CRSP researchers were estimated using a nonparametric approach. A survey of shrimp growers in Honduras provided data on yield, input application, and prices for their first year of production and for the year 1997. Research investment data included funding from both public and private sectors. Results showed that total factor productivity indices increased from 1995 to 1997, indicating technical progress due to research. When both private and public investment were considered, the internal rate of return to the investment in research was 45%. However, the internal rate of return to public-sector investment alone was above 6,352%. This indicated that the public funds invested in shrimp research in Honduras have been leveraged effectively with private-sector capital to generate technological progress.

Introduction

Assessment of the effects of agricultural research investment has become increasingly important to justify public-sector funding to research administrators and government policymakers. The United States Agency for International Development (USAID) has provided public-sector funding for shrimp research in Honduras. Using these resources, researchers from Honduras and the US, under the auspices of the Pond Dynamics/Aquaculture Collaborative Research Support Program (PD/A CRSP) (a USAID-funded program involved in global pond aquaculture research), have been conducting experiments to improve shrimp production efficiency in Honduras since 1993. This study estimated the economic returns to this investment, particularly the effects of research on shrimp-farm productivity.

The shrimp industry, with US$77 million in farmgate sales in 1996, is one of the largest and fastest growing sources of foreign exchange for Honduras (ANDAH, 1997). Improving production efficiency for this industry could contribute significantly to economic development of this and other shrimp-producing nations. Auburn University's Memorandum of Agreement with ANDAH called for member farms to provide ponds and production inputs to contribute to this research program. Granjas Marinas San Bernardo (GMSB) is one of the largest Honduran shrimp farms, and, because of its infrastructure and desire to collaborate, it supported PD/A CRSP research by 1) making multiple ponds available for experiments and 2) absorbing shrimp production costs in those ponds by supplying feed, post larvae (PL), labor, energy, and all other production inputs.

Although there is a rich history of returns to research investment studies in agriculture, there is no record of this type of analysis for aquaculture research. Hence, this paper fills a void in the literature with the first attempt to estimate returns to aquaculture research. The remainder of this paper is divided into sections that 1) briefly review the existing literature on measuring returns to research investment, 2) describe the theoretical and empirical models, 3) summarize the data, and 4) discuss results. The paper ends with a concluding section that summarizes key results from the study.

Measuring Returns to Research Investment

Typically, three techniques exist in estimating returns to agricultural research investment: parametric methods, nonparametric methods, and index-number methods. Parametric methods, which have been the traditional approach, involve explicit functional form specifications that link inputs to outputs. In the primal parametric technique, functional forms for the production technology are specified. Research impacts on production are measured by either directly including research expenditures as exogenous shifts to the production function or by measuring technical change using proxy variables such as a time trend and attributing the technical change to research-based information. Other methods include estimating a production function by conditioning the technical coefficients on research investment (Alston et al., 1998). Examples of the primal approach exist in Griliches (1964) and Evenson (1967).

The dual parametric technique estimates the impact of research on profit or cost functions of a firm. After a functional form specification for the profit or cost function, output supply and input demand functions can be derived using standard microeconomic principles. Hence, research expenditure variables included in the profit or cost functions could also be components of the output supply and input demand functions. Joint econometric estimation of output supply and input demand functions measure the research impacts on a firm's profit or cost functions. An example of this type of analysis exists in Huffman and Evenson (1989).

If the analysis uses a single-product technology, the direct estimation of a supply response to research investment model could also be an alternative to the primal approach. Here, "direct estimation" means that the supply-response model is not a derivative of a pre-specified profit or cost function. This technique allows the dynamics of supply response to prices and research investments to be modeled with greater flexibility than in primal and dual models (Alston et al., 1998). An example of this method appears in Fox et al. (1987). Once the research impacts on production have been estimated, the remaining step is to evaluate the resulting benefits. The underlying methodology used in this step is based on, either explicitly or implicitly, the economic surplus concept. Typically, this involves allocating the research benefits to different productive surplus (e.g., producer factors) and different consumer surplus (e.g., consumer groups).

The striking feature of the above methodologies is the *a priori* constraints in the empirical models stemming from an assumed parametric form of the technology. The primal approach usually restricts the technology structure, and the dual approach imposes behavioral constraints (Alston et al., 1998). The nonparametric approach dispenses with the use of functional forms altogether. Here, the data are checked for consistency with cost-minimization or profit-maximization behavior (weak axiom of cost minimization and weak axiom of profit maximization developed by Varian (1984)). If the data are inconsistent with the above axioms, the minimum adjustments to the data necessary to restore consistency are determined. These adjustments refer to the quantity changes in outputs and inputs that can be attributed to an input-using, input-saving, or neutral technical change (Chavas and Cox, 1992). By incorporating research expenditure in the analysis, output and input changes that are not attributable to changes in output and input prices or production scale are used to measure the effects of research (Alston et al., 1998).

The nonparametric algorithms do not restrict input substitution possibilities, joint estimation of the production technology, technical change, or the effects of research on technical progress using disaggregate inputs (Alston et al., 1998). This approach requires only a standard linear programming algorithm. Given its flexibility, this approach is adopted in this study to measure the impacts of public and private research expenditures on Honduran shrimp production.

The index-number approach is useful in developing partial factor and total factor productivity measures that summarize the growth in agricultural output. This method is often used in conjunction with the above techniques to determine research-induced technical changes as exhibited in the pre-change and post-change input and output quantities. An example of this method exists in the Christensen and Jorgenson total productivity index discussed in Christensen and Jorgenson (1970) and Diewert (1976). Partial factor and total factor productivity indices are also used in this paper.

Theoretical and Empirical Model

The nonparametric approach of evaluating the returns to research investment is based on Varian's (1984) weak axiom of profit maximization (WAPM). This hypothesis indicates that a profit-maximizing agent's production decisions are such that profit from any time period is at least as large as the profit that could have been obtained using production decisions from any other time period. Mathematically, this is expressed by the inequalities in Equation 1, which are developed for a single output (y) technology with two variable inputs (x1, x2) such that the following firm-level data are available for time periods t1 and t2: (y_{t1}, $x1_{t1}$, $x2_{t1}$, p_{t1}, $w1_{t1}$, $w2_{t1}$) and (y_{t2}, $x1_{t2}$, $x2_{t2}$, p_{t2}, $w1_{t2}$, $w2_{t2}$), where p_{ti}, $w1_{ti}$, and $w2_{ti}$ are prices during time ti (i = 1, 2) of the output and inputs x1 and x2, respectively.

$$\begin{aligned} &p_{t1}\,y_{t1} - w1_{t1}\,x1_{t1} - w2_{t1}\,x2_{t1} \geq p_{t1}\,y_{t2} - w1_{t1}\,x1_{t2} - w2_{t1}\,x2_{t2} \\ &p_{t2}\,y_{t2} - w1_{t2}\,x1_{t2} - w2_{t2}\,x2_{t2} \geq p_{t2}\,y_{t1} - w1_{t2}\,x1_{t1} - w2_{t2}\,x2_{t1} \end{aligned} \tag{1}$$

Cox and Chavas (1990) have shown that the WAPM inequalities form necessary and sufficient conditions for profit maximization, i.e., in every time period t, if price-taking producers apply inputs to maximize profit: $p_t\,y_t - w1_t\,x1_t - w2_t\,x2_t$, where y is a function of x1 and x2, then the inequalities in Equation 1 would be satisfied, and vice versa.

Technical change is incorporated in the above framework by structuring WAPM behavior on effective inputs and output. Effective inputs and output are the result of the augmentation effect of technical change on actual inputs and output. The underlying concept is that, due to an input-saving (or -using) technical change, a single unit of an input would be equivalent to a larger (or smaller) amount of the same input had the technical change never occurred. Thus, the ith effective input (Xi) is a function of both the actual input quantity (xi) and a technological index (Bi), i.e., Xi = Xi(xi, Bi) (Chavas and Cox 1992). For empirical tractability, Xi(xi, Bi) is expressed as Xi = xi + Bi. The technological indices for the inputs (Bi) capture the input bias effects of technical change. If Bi > (or <) 0, the technical change is said to be input-saving (or -using) in the ith input. If all Bis are zero, the marginal rates of substitution between the two inputs are unaffected by the altering technology, indicating a Hicks neutral technical change (Chambers, 1988). Similarly, a technological index (A) captures the output-augmenting effect of technical change by inter-relating effective (Y) and actual (y) output: Y = y - A or y = Y + A. Thus, higher values of A are associated with higher productivity. If A is positive, the technical change is said to be progressive; negative A values indicate a regressive technical change. The augmented WAPM hypothesis discussed by Chavas and Cox (1992), Cox and Chavas (1990), and Cox et al. (1997) explains producer behavior under technical change by expressing the WAPM inequalities in Equation 1 in terms of effective inputs and output.

$$\begin{aligned} &p_{t1}\,(y_{t1}-A_{t1}) - w1_{t1}\,(x1_{t1}+B1_{t1}) - w2_{t1}\,(x2_{t1}+B2_{t1}) \geq \\ &\quad p_{t1}\,(y_{t2}-A_{t2}) - w1_{t1}\,(x1_{t2}+B1_{t2}) - w2_{t1}\,(x2_{t2}+B2_{t2}) \\ &p_{t1}\,(y_{t1}-A_{t2}) - w1_{t1}\,(x1_{t1}+B1_{t2}) - w2_{t1}\,(x2_{t1}+B2_{t2}) \geq \\ &\quad p_{t1}\,(y_{t2}-A_{t1}) - w1_{t1}\,(x1_{t2}+B1_{t1}) - w2_{t1}\,(x2_{t2}+B2_{t1}) \end{aligned} \tag{2}$$

The idea behind Equation 2 is that although producers maximize profit, WAPM (as shown in Equation 1) may not be satisfied due to technical change. The technological indices in Equation 2 measure the extent by which producer behavior has deviated from WAPM. In doing so, they measure the input and output bias effects of technical change.

Since the technological indices (A_t and Bi_t) capture the effects of technical change, their relationship to research expenditures is of interest. For any year t, assume that past research expenditures (with a minimum one-year lag) could potentially influence technology (and hence, the technological indices). Since the focus of this study is to evaluate research investment impacts on productivity, only the A_ts are expressed in terms of lagged research expenditures.

$$A_t = a_1 R_{t-1} + a_2 R_{t-2} + a_3 R_{t-3} + ... + a_T R_{t-T} \quad (3)$$

where

$R_{t-\tau}$ = research expenditure made in the $(t-\tau)^{th}$ year and
T = maximum lag length.

Following Chavas and Cox (1992), the a_ts in Equation 3 are restricted to a linear spline function of t by the following process: (I) the space {0, 1, 2, 3,..., T, T+1} is partitioned into s subsets $\{0,...,k_1\}$, $\{k_1,..., k_2\}$, $\{k_2,..., k_3\}$,$\{k_{s-1},..., T+1\}$ and (II) each a_τ is defined to be equal to $(\alpha_j + \beta_j\times\tau)$ if $\tau \in \{k_{j-1},..., k_j\}$, j = 1...s, such that $\alpha_1 = 0 = \alpha_s + \beta_s\times(T+1)$ and $(\alpha_j + \beta_j\times k_j) = (\alpha_{j+1} + \beta_{j+1}\times k_j)$. The a_τs measure of the marginal impact on current output of research expenditures made τ years ago (i.e., R_τ). Hence, as T is the maximum allowed lag in Equation 3, $a_{T+1} = \alpha_s + \beta_s\times(T+1) = 0$. Therefore, the linear spline restrictions allow the a_τs to vary while imposing some degree of continuity or smoothness, so that the marginal research impacts on output are not erratically distributed over time.

For a given farm, if production price and quantity data were available for two time periods, two augmented WAPM inequalities could be specified as shown in Equation 2. Assuming such data are available for several farms that share identical technology and technical change, the empirical model is specified by incorporating the pairs of inequalities in a mathematical programming model. In doing so, Equation 2 is rewritten so that only unknown parameters and their coefficients appear on the left-hand side.

$$\begin{aligned}
&(A_{t2} - A_{t1}) - \frac{w1_{t1}}{p_{t1}}(B1_{t1} - B1_{t2}) - \frac{w2_{t1}}{p_{t1}}(B2_{t1} - B2_{t2}) \geq \\
&\quad -\left[(y_{t1} - y_{t2}) - \frac{w1_{t1}}{p_{t1}}(x1_{t1} - x1_{t2}) - \frac{w2_{t1}}{p_{t1}}(x2_{t1} - x2_{t2})\right] \\
&(A_{t1} - A_{t2}) - \frac{w1_{t2}}{p_{t2}}(B1_{t2} - B1_{t1}) - \frac{w2_{t2}}{p_{t2}}(B2_{t2} - B2_{t1}) \geq \\
&\quad \left[(y_{t1} - y_{t2}) - \frac{w1_{t2}}{p_{t2}}(x1_{t1} - x1_{t2}) - \frac{w2_{t2}}{p_{t2}}(x2_{t1} - x2_{t2})\right] \qquad (4)
\end{aligned}$$

Here, the unknown parameters are the technological indices for output (the A_{ti}s are subject to Equation 3 and two variable inputs ($B1_{ti}$ and $B2_{ti}$). Since the input technological indices could be positive, zero, or negative, it is empirically convenient to express them as a difference of two positive parameters, i.e., $B1_{ti} = B1_{ti}^+ - B1_{ti}^-$ and $B2_{ti} = B2_{ti}^+ - B2_{ti}^-$. Hence, the empirical model consists of a mathematical program with pairs of constraints specified for each farm for which data are available (as shown in Equation 4) and an appropriate objective function so that a solution can be derived for the a_τs, $B1_{ti}^+$s, $B1_{ti}^-$s, $B2_{ti}^+$s and $B2_{ti}^-$s that jointly satisfy the augmented WAPM hypothesis. This assumes the availability of production data for at least two time periods from one or more farms that share nearly identical technology and experience similar technical change. Details of data used in the empirical model are discussed in the next section.

Given the "greater-than-or-equal-to" inequalities in Equation 4 and restrictions that all unknown parameters are non-negative, the objective function minimizes a linear combination of the unknown parameters with positive coefficients in order to keep the solution bounded. The coefficients of the unknown parameters in the objective function are chosen to be large positive numbers so that the solutions give the smallest values for the technological indices. Following Chavas and Cox (1992) and Cox and Chavas (1990), the coefficients of the a_ts in the objective function are taken to be a large positive number (q in Equation 5). The coefficients of the Bs (in Equation 5) are the square of q. Consistent with this layout, changing the values of q did not alter the solution of the empirical model.

Empirical Model:

$$\text{Min } q\,a_1 + q\,a_2 + q\,a_3 + \ldots + q^2 B1_{t1}^+ + q^2 B1_{t1}^- + q^2 B1_{t2}^+ + q^2 B1_{t2}^- + \ldots + q^2 B2_{t1}^+ + q^2 B2_{t1}^- + q^2 B2_{t2}^+ + q^2 B2_{t2}^- + \ldots$$

Subject to: Augmented WAPM constraint pairs (Equation 4) for each farm

$$a_1, a_2, a_3, \ldots, B1_{t1}^+, B1_{t1}^-, B1_{t2}^+, B1_{t2}^-, \ldots, B2_{t1}^+, B2_{t1}^-, B2_{t2}^+, B2_{t2}^-, \ldots \geq 0 \qquad (5)$$

DATA

Shrimp production data from Honduras were collected from a survey of 21 farms that represented 48.25% of the Honduran shrimp industry. Each survey questionnaire elicited information from each farm on production practices (including input application intensity and shrimp yield) for their first production year and for 1997 (survey year). Feed and PL are key variable inputs in shrimp production (Dunning, 1989; Stanley, 1993) and were used in the empirical model (Expressions 4 and 5).

Price data from the survey provided prices of shrimp tails for the first production year and for the year 1997. Estimates of PL prices were provided by Ralph Parkman of Grupo Granjas Marinas (Parkman, pers. comm.). Data on shrimp feed prices were available for 1997 only. Shrimp feed price estimates for other years were obtained by adjusting contemporaneous catfish feed prices (Engle and Kouka, 1996) in the same proportion as the 1997 ratio of shrimp feed prices to catfish feed prices. This assumes that shrimp and catfish feed prices exhibit similar fluctuations that are determined by world grain market prices. All Honduran price data in lempiras were converted to US dollars using exchange rates provided by the Banco Central de Honduras. All price time series in US dollars were deflated by a US Purchasing Power Index (USDA, 1996).

Table 1 summarizes information from 13 of the 21 farms related to yield of shrimp tails (kg ha^{-1} yr^{-1}) and the partial factor productivity indices (average product) for stocking and feeding rates for the first year of operation and the year 1997. Farms that returned incomplete questionnaires and new farms were excluded. Farms were selected for the empirical analysis after evaluation of the potential for constraint redundancy (or degeneracy) problems. These problems arise in mathematical programming models when coefficients for multiple constraints are nearly identical (McCarl, 1977).

PD/A CRSP research investment data were obtained from PD/A CRSP budgets for shrimp research in Honduras from the work plans covering the period 1993-94 to 1996-97 (Seventh, Interim, and Eighth Work Plans) (PD/A CRSP, 1993, 1995, 1996). The PD/A CRSP data came from four annual investment periods, which are illustrated in Table 2; Table 2 also contains a list of shrimp-related research projects conducted during this time-period. Specific research studies targeted primarily pond management studies (to improve production efficiency) and estuarine water-quality studies (to determine whether or not pond management strategies should involve the exchange of pond water). Pond water exchange could also affect optimal feeding and stocking strategies in shrimp ponds. PD/A CRSP research investment per hectare of shrimp farms was calculated for each time period by dividing the cumulative budgeted

Table 1. Partial factor productivity (PFP) for stocking and feeding rate. The PFP of an input is the ratio of the output over the input (i.e., average product) (Alston et al., 1998). "First yr" indicates the first year of operation; "Last yr" indicates the most recent year of operation (1997).

Farm	First Year	Last Year	Yield (Shrimp Tails)		Partial Factor Productivity Index			
			kg ha^{-1} yr^{-1}[a]		*Stocking Rate*[b]		*Feeding Rate*[c]	
			First yr	Last yr	First yr	Last yr	First yr	Last yr
1[d]	1982	1997	499	386	0.00126	0.00088	0.130	0.220
2	1987	1997	538	579	0.00354	0.00318	0.320	0.340
3[d]	1982	1997	445	265	0.00125	0.00049	_[e]	0.160
4	1993	1997	907	726	0.00179	0.00239	0.159	0.163
5	1992	1997	817	776	0.00336	0.00274	0.384	0.531
6	1986	1997	572	454	0.00188	0.00224	0.117	0.357
7	1993	1997	690	828	0.00284	0.00292	0.324	0.567
8[d]	1995	1997	818	744	0.00367	0.00193	0.411	0.375
9[d]	1995	1997	1,021	889	0.00336	0.00231	0.466	0.462
10	1990	1997	680	454	0.00336	0.00149	0.429	0.286
11	1995	1997	953	1,216	0.00262	0.00297	0.411	0.524
12[d]	1993	1997	686	714	0.00242	0.00177	0.216	0.321
13	1985	1997	363	544	0.00199	0.00245	0.171	0.446

[a] Average per-year yield computed from aggregating dry and wet season yields.
[b] The PFP of stocking rate is measured in kg of shrimp tails per PL ha^{-1} yr^{-1}.
[c] The PFP of feeding rate is measured in kg of shrimp tails per kg of feed ha^{-1} yr^{-1}.
[d] Farms used in the empirical analysis.
[e] Farm 3 reported no feed applied during their first year of operation.

Table 2. PD/A CRSP shrimp research studies from 1993 to 1997.

Years	Study
1993–1994 Seventh Work Plan	1. Estuarine water quality 2. Farm nutrient budgets 3. Reduction of feed input by inorganic fertilizers 4. Influence of frequency and quantity of water exchange on water quality and shrimp production
1994–1995 Seventh Work Plan	1. Estuarine water quality 2. Farm nutrient budgets 3. Reduction of feed input by inorganic fertilizers 4. Influence of frequency and quantity of water exchange on water quality and shrimp production 5. Relationship among stocking density, mean shrimp size, survival, and carrying capacity during wet and dry seasons of Honduras
1995–1996 Interim Work Plan	1. Effect of diet protein on feed conversion and nitrogen discharge during semi-intensive production of *Peneaus vannamei* 2. Estuarine water quality 3. Tidal effects on nutrient, oxygen, temperature and salinity profiles in estuaries of two major shrimp-producing areas in southern Honduras
1996–1997 Eighth Work Plan	1. Estuarine water quality monitoring and estuarine carrying capacity 2. Influence of daily water exchange volume on water quality and shrimp production 3. Water exchange to rectify low dissolved oxygen

Source: Green, pers. comm.

expenditure on all shrimp projects by the total Honduran shrimp farm area. However, PD/A CRSP research expenditures did not include the pond costs of raising shrimp for experiments conducted in GMSB ponds. For these experiments, GMSB absorbed all variable costs of the studies, including PLs, feed, labor, and energy expenses as well as the sales revenue from the harvested shrimp. Due to the unavailability of historical cost data from GMSB, it is assumed that costs per hectare per year of shrimp cultivation remained approximately constant ($1,792 ha^{-1}) from 1993 to 1997 (Valderrama, unpubl. data). This cost includes expenses for PL, feed, labor, fuel, interest for operating loans, and machinery depreciation. Given that the research was initiated by public-sector (PD/A CRSP) funds, our intention was to estimate the returns from the total research investment. The total research expenditure, which combines both public- and private- (GMSB) sector investments, represents the research costs that would have to have been incurred by the public sector, had there been no private-sector support. Hence, the output-enhancing technological indices (A_t in Equation 3) included research expenditures ($R_{t-\tau}$) without adjustment for the GMSB income from sales of shrimp grown in the experimental ponds. Given that PD/A CRSP shrimp research expenditure per hectare varied from $5.39 (in the 1993-94 time period) to $7.46

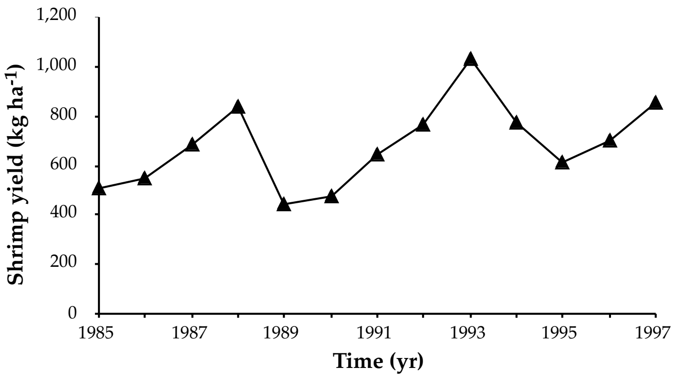

Figure 1. Average shrimp yield in Honduras from 1985 to 1997.

(in the 1995-96 time period), it is clear that GMSB assumed most of the research expenses. Evaluating the returns to PD/A CRSP investment alone without accounting for the pond production costs associated with the experiments would inflate the internal rate of return to the total investment in research. Hence, the empirical model was analyzed by 1) considering the total public and private research investment and 2) exclusively considering the public research investment.

In March 1994, the Taura Syndrome Virus (TSV) affected shrimp cultivation in Honduras (Teichert-Coddington, 1999). The impact of the virus surfaced during the decline of pond productivity (of shrimp tails) from 1,032 kg ha^{-1} yr^{-1} in 1993 to 774 kg ha^{-1} yr^{-1} in 1994 (Figure 1) (ANDAH, 1997). Although production declined dramatically at the initial onslaught of the TSV, the industry was able to partially compensate, and production increased after 1995 (Figure 1). In this framework, the empirical model was analyzed by first using survey data that reflect TSV-related yield reduction and second, using survey data with 1995 and 1997 yield levels adjusted by factors of 1.7 and 1.25, respectively, as a sensitivity analysis to evaluate the effects of the TSV-related yield declines on the results of this study (Teichert-Coddington, pers. comm.).

RESULTS AND DISCUSSION

Table 3 reports the technological indices that solve the empirical model (Equation 5) under four scenarios: with (or without) considering the private research expenditures and with (or without) considering the effect of TSV. These results correspond to a minimum one-year lag in determining the research impacts on production. This minimum lag specifies that research conducted cannot begin to impact farm technology until the succeeding year. All data analyses were conducted on a per-hectare basis. The available data did not allow estimation of any spill-in effects (i.e., impacts of information obtained from non-PD/A CRSP research efforts) or spillover effects (i.e., impacts of PD/A research on non-Honduran shrimp production) of research. Since PD/A CRSP shrimp research investment began with the 1993-94 time period, output and input technological indices for all years prior to 1994 were taken to be zero (i.e., A_t, $B1_t$, and $B2_t$ were zero for all t less than 1994). With respect to the "research years" (1994 to 1997), since data exist for only 1995 and 1997, Table 3 reports values for (A_{95}, $B1_{95}$, $B2_{95}$) and (A_{97}, $B1_{97}$, $B2_{97}$).

$$A_{95} = a_1 R_{94\text{-}93} \tag{6}$$
$$A_{97} = a_1 R_{96\text{-}95} + a_2 R_{95\text{-}94} + a_3 R_{94\text{-}93}$$

The parameters a_1, a_2, and a_3 provide information on the lag relationship between research and productivity (Chavas and Cox, 1992). Since $a_3 \geq a_2 \geq a_1$, research from the more distant past has a higher productivity impact than more recent research. Technically, the parameters a_1, a_2, and a_3 indicate the marginal impacts of research expenditure on output (per hectare). Hence, it is clear from Table 3 that the marginal research impacts are higher if output is inflated to correct for TSV. Further, a_1, a_2, and a_3 are larger in magnitude if private research investments are excluded from computing the R_ts.

Table 3 also gives the values of the estimated input bias effects of research. The input bias parameters $B1_{95}$ and $B2_{95}$ indicate that the technical changes from past years to 1995 are neutral for stocking rate but input-saving for feed (Cox et al., 1997). Given that the results are on a per-hectare basis, Table 3 shows that shrimp producers have benefited from the 1993–94 time period by reducing feeding rates for equivalent stocking rates. Further evidence of this technological improvement in feed use from the pre-research years (prior to 1994) to the post-research years (after 1994) appears in the feed partial factor productivity (PFP) indices shown in Table 1. Except for farms 8 and 9, the PFP of feed improved in the post-research years in all farms, implying that a lower feeding rate in the post-research years resulted in at least the same yield as in the pre-research years.

From 1995 to 1997, the negative input bias indicated by $B1_{97}$ and $B2_{97}$ showed that the technical changes were input-using in both inputs. This result can be interpreted by considering the consequences of TSV in 1994. Reports from the PD/A CRSP shrimp research indicate that, although TSV had a considerable effect in reducing pond productivity in 1994, producers were "able to quickly adjust management to partially compensate for low survivals [of PLs] by avoiding the nursery stage and doubling or tripling the stocking rates" (Teichert-Coddington, 1999). This increase in stocking rate for a less-than-proportional increase in yield (yield actually fell due to TSV) explains the negative value of $B1_{97}$. In the empirical model, production data from 1995 and 1997 were used from only two farms

Table 3. Technical indices satisfying the augmented weak axiom of profit maximization (WAPM) hypothesis.

Without TSV[a] Correction	With TSV Correction
PUBLIC AND PRIVATE RESEARCH INVESTMENT[b]	
$A_1 = 0.068$, $a_2 = 0.136$, $a_3 = 0.3472$[c]	$A_1 = 0.1618$, $a_2 = 0.3236$, $a_3 = 0.3236$
$B1_{95} = 0$, $B2_{95} = 152.45$[d]	$B1_{95} = 0$, $B2_{95} = 9{,}876.32$
$B1_{97} = -535{,}064$, $B2_{97} = -6{,}780.78$	$B1_{97} = -605{,}736$, $B2_{97} = -7{,}496.56$
PUBLIC RESEARCH INVESTMENT ALONE	
$A_1 = 23.15$, $a_2 = 46.3$, $a_3 = 123.52$	$a_1 = 49.31$, $a_2 = 98.62$, $a_3 = 98.62$
$B1_{95} = 0$, $B2_{95} = 118.16$	$B1_{95} = 0$, $B2_{95} = 10{,}071.24$
$B1_{97} = -535{,}064$, $B2_{97} = -6{,}780.78$	$B1_{97} = -605{,}738$, $B2_{97} = -7{,}496.56$

[a] TSV: Taura Syndrome Virus
[b] Public research investment (ha^{-1} yr^{-1}): \$5.39 (1993–1994 work plan), \$5.63 (1994–1995 work plan), \$7.46 (1995–1996 work plan). Private research investment (ha^{-1} yr^{-1}) assumed to be \$1,792 from 1993 to 1997.
[c] "a_τ" represents the marginal impact on current output of research completed τ years ago.
[d] ($B1_t$ - $B1_s$) > (<) 0 indicates input-saving (-using) bias due to technical change in the PL stocking input, measured in number of PL ha^{-1}, from year t to year s (Cox et al., 1997). Similarly, ($B2_t$ - $B2_s$) gives the bias effect due to technical change for the feeding input measured in kg ha^{-1}.

(farms 8 and 9 in Table 1). Survey data indicate that both these farms did not reduce feeding rates over the 1995–97 time period. However, the remaining farms in the empirical analysis had been reducing feeding rates over time. The low TSV-related yield during 1995–97 and the nondecreasing feeding rate for farms 8 and 9 explain the negative feed-input bias $B2_{97}$. These results are further supported by the stocking and feeding PFPs for farms 8 and 9 in Table 1. Data from both farms indicate that the PFP for PLs and feed declined from 1995 to 1997, implying more inputs were being used during 1997 for less than a proportionate increase in output. Hence, the negative input bias indicated by $B1_{97}$ and $B2_{97}$ reflects 1) higher stocking rates adopted by producers to reduce TSV-related losses and 2) nondecreasing feeding rates of farms 8 and 9 over the 1995–97 time period, respectively.

The Total Factor Productivity index (TFP) measures, at any point in time, the total output produced by a unit of an aggregate input (Alston et al., 1998). The nonparametric TFP index, which can be derived from a_1, a_2, and a_3, indicates the extent of technical progression (or regression) over time. The nonparametric TFP index at time t2 using time t1 as a reference is given by

$$\left[1 + \frac{(A_{t2} - A_{t1})}{y_{t1}}\right]$$

where

y_{t1} is the output level in time period t1 (Chavas and Cox, 1992).

Using 1990 as a base year, nonparametric TFP indices are reported in Table 4 for 1995 and 1997 only, because A_ts are zero for all other years. The increasing value of the TFP index from 1995 to 1997 gives evidence of technical progress due to research investment.

The internal rate of return (IRR) is a parameter that is often used to evaluate the profitability of a research program. The research program is said to be profitable if the internal rate of return is greater than the rate of return associated with the opportunity costs of the research funds (Alston et al., 1998).

Table 4. Nonparametric total factor productivity (TFP) indices for the years 1995 and 1997. Given a base year of 1990, the nonparametric TFP index for 1995 measures the relative shift in the production function in 1995 when compared to 1990. Therefore, the 1995 TFP index measures the proportionately higher output produced in 1995 than in 1990 due to technological improvement, keeping the amount of effective inputs identical in both years. Similar interpretation is applicable for the 1997 TFP index.

Source of Research Funds	Without TSV[a] Correction	With TSV Correction
PUBLIC AND PRIVATE RESEARCH INVESTMENT		
1995	1.08	1.19
1997	1.66	1.97
PUBLIC RESEARCH INVESTMENT ALONE		
1995	1.08	1.18
1997	1.73	1.97

[a] TSV: Taura Syndrome Virus

Given that a_τ is the marginal impact of research on output, i.e.,

$$a_\tau = \frac{\partial y_t}{\partial R_{t-\tau}},$$

it could also be interpreted as the marginal physical product of the "research" input. Hence, following Chavas and Cox (1992) and Bredahl and Peterson (1976), the IRR can be expressed as:

$$\sum_{\tau=1}^{T} \left[p \frac{\partial y_{t+\tau}}{\partial R_\tau} / (1 + IRR)^\tau\right] = 1 \qquad (7)$$

where

T = maximum lag length.

IRRs are reported for the four empirical scenarios in Table 5. The estimated IRR to the total research investment (i.e., combined public- and private-sector investments) was 18% (or 45%, with the adjustment for TSV-related shrimp losses). Both these IRR estimates indicate a favorable return to the investment in research. If the private-sector research costs are excluded and returns to the public-sector research expenditures alone are calculated, the resulting IRRs are very high. This is due to the high percentage of research costs that have been borne by the shrimp industry. Indeed, these results illustrate a very effective leveraging of US federal research dollars with private-sector capital.

CONCLUSIONS

Relevant conclusions from this study include evidence of technological progress in Honduran shrimp production from the middle to the late 1990s. The nonparametric TFP indices showed that yields have been proportionately higher in the post-research years. The technological innovations from the 1980s to the middle/late 1990s allowed producers to apply shrimp feed more efficiently (i.e., with higher PFPs). Thus, equivalent yields were obtained at lower feed rates and lower costs. Other evidence indicated that between 1995 and 1997 producers were induced to stock at higher rates without receiving proportionately higher returns in output. This change is attributed to the onset of TSV in Honduras due to the reported tendency of producers to significantly increase PL stocking rates to allow for the high mortality rate that is typical of TSV infestation. However, in spite of TSV, TFP indices increased from 1995 to 1997, indicating continued technical progress.

The private-sector investment was considerably higher than the public-sector investment, which can be an indicator of the importance that commercial shrimp farms place on the PD/A CRSP. This sharing of public- and private-sector funding responsibilities supports the notion that the research benefits

Table 5. Internal rates of return for public and private research investment and public research investment alone with and without Taura Syndrome Virus (TSV) correction.

Source of Research Funds	Without TSV Correction	With TSV Correction
Public and Private Research Investment	18%	45%
Public Research Investment Alone	6,352%	13, 412%

spill over both spatial and temporal boundaries, and the beneficiaries often include the producers, consumers, and scientists who perhaps do not live in the same region, country, or time (Alston et al., 1998). Taking into account both private and public research investment, the IRR was 18% without accounting for TSV and 45% with adjustments for TSV. Extremely high rates of return to public research expenditures alone reflected effective leveraging of public research with private research funds to generate technological progress in shrimp production in Honduras.

ANTICIPATED BENEFITS

This study indicated a positive and profitable return on the investment of the PD/A CRSP in shrimp research in Honduras. This level of return, especially since it was measured only a few years after the actual investment should encourage bi- and multi- lateral agencies to fund aquaculture research initiatives.

ACKNOWLEDGMENTS

The authors wish to thank Bart Green and David Teichert-Coddington for numerous discussions on study assumptions and the factors that affect management of shrimp ponds. Green provided invaluable assistance with the logistics of conducting the survey. Ing. Alberto Zelaya and the Asociación Nacional de Acuicultores de Honduras (ANDAH) provided support and assistance with data collection. Ari Mwachofi, Nathan Stone, Bart Green, and David Teichert-Coddington provided valuable review comments. This study was supported in part with financial support from the Pond Dynamics/Aquaculture Collaborative Research Support Program. This paper is published with the approval of the Director, Arkansas Agricultural Experiment Station, manuscript # 99064.

LITERATURE CITED

Alston, J.M., G.W. Norton, and P.G. Pardey, 1998. Science Under Scarcity: Principles and Practice of Agricultural Research Evaluation and Priority Setting. Center for Agricultural and Biosciences International, Wallingford, U.K., 585 pp.

ANDAH (Asociación Nacional de Acuicultores de Honduras), 1997. Boletin Informativo Técnico, Choluteca, Honduras, 39 pp. (In Spanish.)

Bredahl, M. and W. Peterson, 1976. The productivity and allocation of research: U.S. agricultural experiment stations. Am. J. of Agric. Econ., 58:684–692.

Chambers, R.G., 1988. Applied Production Analysis: A Dual Approach. Cambridge University Press, New York, 331 pp.

Chavas, J.P. and T.L. Cox, 1992. A nonparametric analysis of the influence of research on agricultural productivity. Am. J. Agric. Econ., 64:583–591.

Christensen, L.R. and D. Jorgenson, 1970. U.S. real product and real factor input, 1929–1987. Rev. Inc. Wealth, 16:19–50.

Cox, T.L. and J.P. Chavas, 1990. A nonparametric analysis of productivity: The case of U.S. agriculture. Eur. Rev. Agric. Econ., 17:449–464.

Cox, T.L., J. Mullen, and W. Hu, 1997. Nonparametric measures of the impact of public research expenditures on Australian broadacre agriculture. Aust. J. Agric. and Res. Econ., 41:333–360.

Diewert, W.E., 1976. Exact and superlative index numbers. J. Econometrics, 4:115–145.

Dunning, R., 1989. Economic optimization of shrimp culture in Ecuador. M.S. thesis, Auburn University, Alabama.

Engle, C.R. and P.J. Kouka, 1996. Effects of inflation on the cost of producing catfish: Report submitted to the Catfish Bargaining Association. Department of Aquaculture and Fisheries, University of Arkansas at Pine Bluff, Pine Bluff, Arkansas, pp. 59–60.

Evenson, R.E., 1967. The contributions of agricultural research to production. J. Farm Econ., 49:1415–1425.

Fox, G., G. Brinkman, and N. Brown-Andison, 1987. An Economic Analysis of the Returns to the Animal Productivity Research Program of Agriculture Canada from 1968 to 1984. Intercambia Limited, Guelph, Ontario, Canada. Unpublished report.

Griliches, Z., 1964. Research expenditures, education and the aggregate agricultural production function. Am. Econ. Rev., 54:961–974.

Green, B., Personal communication, 1998.

Huffman, W.A. and R.E. Evenson, 1989. Supply and demand functions for multi-product U.S. cash grain farms: Biases caused by research and other policies. Amer. J. Agric. Econ., 71:761–773.

McCarl, B.A., 1977. Degeneracy, duality and shadow prices in linear programming. Can. J. Agric. Econ., 25:70–73.

Parkman, R., Personal communication, 1998.

Pond Dynamics/Aquaculture Collaborative Research Support Program, 1993. Seventh Work Plan. Pond Dynamics/Aquaculture CRSP, Oregon State University, Corvallis, Oregon, 85 pp.

PD/A CRSP, 1995. Interim Work Plan. Pond Dynamics/Aquaculture CRSP, Oregon State University, Corvallis, Oregon, 47 pp.

PD/A CRSP, 1996. Eighth Work Plan. Pond Dynamics/Aquaculture CRSP, Oregon State University, Corvallis, Oregon, 173 pp.

Stanley, D.L., 1993. Optimización económica y social de la maricultura Hondureña. Memorias del segundo simposio centroamericano sobre camarón cultivado. Federación de Productores y Agroexportadores de Honduras and Asociación Nacional de Acuicultores de Honduras, Tegucigalpa, Honduras, pp. 94–118. (In Spanish.)

Teichert-Coddington, D., Personal communication, 1998.

Teichert-Coddington, D., 1999. Shrimp farming in southern Honduras: A case for sustainable production. In: L.U. Hatch and M.E. Swisher (Editors), Managed Ecosystems: The Mesoamerican Experience. Oxford University Press, New York, 292 pp.

USDA (United States Department of Agriculture), 1996. Aquaculture Situation and Outlook Report. Economics Research Service, Washington, D.C. Available at <www.econ.ag.gov/briefing/foodmark/markets/data/chars/table43.htm>.

Valderrama, D., 1998. Unpublished data.

Varian, H.R., 1984. The nonparametric approach to production analysis. Econometrica, 52:579–597.

Cite as: [Author(s), 2000. Title.] In: K. McElwee, D. Burke, M. Niles, X. Cummings, and H. Egna (Editors), Seventeenth Annual Technical Report. Pond Dynamics/Aquaculture CRSP, Oregon State University, Corvallis, Oregon, [pp. ___.]