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PRODUCTION PERFORMANCE INDICATORS WITH EXTERNALITIES: ENVIRONMENTALLY-ADJUSTED PRODUCTIVITY AND EFFICIENCY INDICATORS OF A SAMPLE OF SEMI-INTENSIVE SHRIMP FARMS IN MEXICO.

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Abstract

Sustainability in operations is a key consideration when discussing aquaculture's current and future role in providing food and increasing coastal and rural employment and incomes, among other social benefits. An important problem from the economics point of view is how the externalities generated by aquaculture and those that the industry suffers are internalized.

This paper extends the analysis reported in Martínez-Cordero and Leung (2004) for a group of semi-intensive shrimp farms in Mexico. Modifications to the traditional Total Factor Productivity (TFP) and Technical Efficiency (TE) indicators are carried out in order to incorporate in the evaluation the environmental effects of aquacultural activities. In a framework of sustainable operations and development, these indicators (called environmentally-adjusted Total Factor Productivity EATFP and environmentally-adjusted Technical Efficiency EATE) allow for a better assessment of aquacultural activities, where enterprises are evaluated not only for obtaining the target product but also for how successfully farms are in generating the minimum amount of undesirable outputs (wastes or pollutants). In this paper the years 1994, 1996-1998 and 2001-2003 are analyzed using an input distance function, and the environmental effects evaluated are total Nitrogen (N) and Phosphorous (P) discharges in farm´s effluents, calculated using mass balances for N and P reported for semi-intensive shrimp farms in Mexico.

The results show that in all years EATE and EATFP were lower than the traditional TE and TFP scores. In the first period of evaluation (1994, 1996-1998) the TE and TFP trend is opposite to yields. As expected, years following diseases outbreaks result in a drop in all the economic indicators, but the fall is bigger in 2001 compared to 1996. In the second period (2001-2003) and despite drastic reductions in annual yields, productivity and efficiency don't fall in the same proportion, meaning that both private and governmental efforts

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to assure that shrimp farming operations are carried out more efficiently, with higher productivity, are producing results, even though the fact that production continues being impacted by viral diseases. For example, currently several Good Management Practices (GMPs) are already implemented or in the process of being adopted in semi-intensive farms. Two of the most important GMPs are present in the operation and management of the farms during 2001-2003: reduced water exchange rates and more controlled feeding strategies. Both have a direct effect on the discharges of shrimp farms to the environment and this study shows that EATFP and EATE properly capture these externalities. Farms that produce higher yields but also have a reduced impact on the environment (N and P discharges) achieve higher values for these economic indicators.

Keywords: externalities, production performance, shrimp farming, TFP, efficiency

JEL classification: Q22, Q51, Q56

1. Introduction

Shrimp was the aquatic species with the largest production by volume in Mexico in 2003 at 123,905 tons, including fisheries and aquaculture. Shrimp produced by aquaculture reached a value of USD $246.8 millions in that same year, the highest among all reared species in the country. Since the first official register of 35 tons in 1985, production area and total shrimp harvest from aquaculture have been increasing every year, with a record 61,704 tons obtained in the year 2003 (SAGARPA, 2002). With scarce resources and a growing population, decision-makers (policy-makers and farmers) face the challenge of developing a sustainable aquaculture industry.

The shrimp farming industry is generally perceived, however, as an activity that negatively impacts the environment. By-products and wastes in water outflows (phosphates and nitrates, suspended solids, among others) are discharged to farms' surrounding water bodies or land. Hence, the challenge for sustainable industry growth is to improve production performance while, at the same time, to minimize the environmental impacts. Therefore, measurement and analysis of producer performance becomes critical. At the farm level, farmers must produce at maximum efficiency and productivity, while high levels of efficiency, productivity and productivity growth are also the policy maker's goals.

Productivity in its most elemental definition is a ratio of outputs to inputs (Fried et al, 1993), with a more productive unit achieving higher outputs for a given set of inputs. The efficiency of a production unit, on the other hand, is a

comparison between observed and optimal values of its output/input combinations (Fried et al, 1993). A production unit is more efficient the closer it is to the frontier for its technology. Hence, efficiency and productivity are indicators of how the producers are making use of different inputs to obtain outputs.

Following the methodological advances in efficiency and productivity analysis, several applications to aquaculture operations have emerged recently with a predominant focus in the Asia-Pacific region (see Sharma and Leung (2003) for a recent review). These include assessments of shrimp farming (Gunaratne and Leung, 1996 and 1997), carp farming (Sharma and Leung, 1998; Iinuma et al., 1999; Sharma et al., 1999, Sharma and Leung, 2000a and 2000b), tilapia growout in ponds (Dey et al., 2000), tilapia hatchery operations (Bimbao et al., 2000), mariculture of sea bass and sea bream (Karagiannis et al., 2000) and salmon aquaculture (Tveteras and Battese, 2000, Vassdal and Roland, 1998). Martinez-Cordero et al. (1999) measured Total Factor Productivity (TFP) in polyculture systems in Indonesia. However, all of these studies as applied to aquaculture do not include the generation of undesirable outputs in their productivity and efficiency assessments. Martínez-Cordero (2003) and Martínez-Cordero and Leung (2004) were the first study to measure aquaculture production performance adjusted by the generation of undesirable outputs. This and other economic studies (Martinez Cordero et al., 1995, 1996a, 1996b; Martinez and Seijo, 2001) have focused on shrimp farming, the most important aquacultural industry in Mexico.

This paper broadens the preliminary study by Martínez-Cordero and Leung (2004), measuring and analyzing production performance based on a sustainable perspective, for a group of shrimp farms in Mexico. The input distance function approach is used to determine the technical efficiency of the farms, taking into account the generation of undesirable outputs (nitrogen and phosphorus loads in outflow water), based on work by Hailu (1998) and Hailu and Veeman (2000), and previous work by Coggins and Swinton (1996) and Färe et al. (1993). A modified Malmquist index is then used to evaluate productivity considering again the emission of pollutants (nitrogen and phosphorus loads in outflow water), using techniques developed by Hailu and Veeman (2001) and previous research by Caves et al. (1982) and Nishimizu and Page (1982). Although other possible undesirable outputs could be incorporated in the study (e.g., dissolved matter, other inorganic elements in water effluent, bacterial loads in discharges), the selection of nitrogen and phosphorus was based on the availability of the mass balances for their indirect estimation.

2. Materials and Methods

2.1 Primary-source information

Primary-source data of semi-intensive shrimp farms in the State of Sonora, Mexico is used, specifically an unbalanced panel of 11 farms for the years 1994, 1996-1998 and 2001-2003. This time period coincides with a "normal" year (1994) of operations with white shrimp (*L. vannamei*), a transition to a different technology (1996-1998) using a different species (blue shrimp *L. stylirostris*) after the viral outbreaks (1995) that forced farmers to introduce the new species commercially after several severe losses, and finally the return to white shrimp (2002-2003) when blue shrimp culture collapsed due again to viral diseases.

The primary information is provided on a per-pond basis detailing the quantity of input (feed, seed, labor, water) and output (shrimp harvested). Although in practice the production analysis is conducted day by day at pond level, which allows discussion of results on pond-basis, in this study the farm is selected as the basic Decision Making Unit (DMU) to facilitate discussion and comparison of results with other work reported in the literature. The information available per year is the following: farms per year is 7 (45 ponds), 8 (75 ponds), 9 (87 ponds) and 11 (92 ponds) for the years 1994, 1996, 1997-1998 & 2001-2003 respectively (575 ponds total). However, since the Malmquist Index approach demands comparison in time of the same production units, the productivity analysis is carried out for 7 farms only (number of farms in the first year: 1994). Changes reported in productivity are only due to improvements in the units studied, and the results may differ with different samples. Due to climatic conditions, only one production cycle was performed per year in each pond for the farms included in this study.

N and P contents in water discharges, considered in this study the undesirable outputs, are estimated by means of nutrients flow balances reported in the literature for semi-intensive shrimp farms in northwest Mexico (Páez-Osuna et al., 1997). While the disadvantages of calculating effluents indirectly using mass balances exist, these errors are minimized if the base is kept consistent by working with these balances rather than using others developed in other countries and under different production systems.

2.2 The Input Distance Function approach

Just as the production function defines the maximal output that can be produced from an exogenously given input vector, the direct input distance function describes how far an input vector is from the boundary of the

representative input set, given a fixed output vector.
Following Fare and Primont (1997), a vector of N inputs, denoted by $x=(x_1,\ldots,x_N)$, a vector of M outputs denoted by $y=(y_1,\ldots y_M)$, and a technology set $T = \{(x, y): x \in R_+^N, y \in R_+^M, x \ can \ \ produce \ \ y\}$ define a production function:

$$F : R_+^N \rightarrow R_+^M$$

$$F(x) = \max_y \{y : (x, y) \in T\} \tag{1}$$

If we define the input requirement set as:

$$L(y) = \{x: (x,y) \varepsilon T\} \tag{2}$$

where T is the set of all feasible input-output vectors, so that

$$T = \{(x,y) : x \varepsilon L(y), y \varepsilon R_+^M\} \tag{3}$$

the input distance function is given by:

$$D_i(y,x) = \sup_\lambda \left\{ \lambda > 0 : (\frac{x}{\lambda}) \in L(y) \right\} \ \forall y \in R_+^M \tag{4}$$

Equation 4 measures the maximal equi-proportionale contraction of all inputs consistent with keeping the output vector in the technology set. In other words, the input distance function is the largest radial contraction of the input vector for a given output vector, that is consistent within the production possibility set. The input distance function is non-increasing in the outputs y, non-decreasing in x, linearly homogeneous (degree one) and concave in x. If inputs are weakly disposable, then a complete characterization of the production technology exists. The disposal of an undesirable output would impose a cost in the form of a reduction in desirable outputs, and the treatment of the derivative properties for desirable and undesirable outputs has to distinguish between the two. Therefore, the input distance function is non-decreasing in undesirable outputs, because pollution abatement can also be achieved through the use of additional inputs, with desirable outputs constant. This condition embeds the assumption that a reduction in pollutant outputs requires the use of additional inputs for abatement, other inputs being held constant.

One way to measure the extent of the input efficiency is to calculate the input distance function. The greater the value of the input distance function, the less efficient x is in producing y. If, instead, the reciprocal of the input distance function is computed, then an efficiency measure is obtained that lies between zero and one and that takes higher values the more efficient x is in producing y. The Debreu-Farrell input oriented measure of technical efficiency is simply:

$$TE_x(y,x) = \frac{1}{D(y,x)} \tag{5}$$

The input oriented measure of technical change is defined as the rate at which inputs can be proportionally decreased over time without changing output levels. This rate is equal to:

$$TCx(y,x) = \frac{\partial D(y,x)}{\partial t} \tag{6}$$

The "standard" properties of the input distance function when only desirable outputs are obtained must be distinguished from those used in this study where one desirable output (shrimp) and 2 undesirable ones (P and N discharges) are obtained.

2.3 Productivity measurement with undesirable outputs

The distance function (DF) approach used in the efficiency determination above can also be used in productivity analysis, since the distance functions can be employed as indexes of technological change, or differences in technologies across production units, assuming that production units were operated efficiently. In this research, the environmentally sensitive input-based measure of technical efficiency are defined as the reciprocal of the input distance function and rewards the producer who increases desirable outputs (since the distance function is non-increasing in desirable outputs) and decreases undesirable outputs (since DF is non-decreasing in undesirable outputs). Hence, the Malmquist index obtained using the DF estimations is defined as a composite of the technical efficiency and technical change, also credits producers in these two ways.

Caves, Christensen and Diewert (1982) generalized the Solow notion of technological change (or comparison) to the case of multiple outputs using distance functions. They treated this new Malmquist productivity index as a theoretical one and proved that the Tornqvist index can be derived from it. For 2 firms, *k* and *l* (can be the same firm at 2 different points in time) with output-input vectors (y^k, x^k) and (y^l,x^l) and production technologies given by the input distance functions $D^k(\cdot)$ and $D^l(\cdot)$, the input-based Malmquist productivity index that compares the productivity of l to k is:

$$M(x^l, x^k, y^l, y^k) = \left\{ \frac{D^k(y^k, x^k)}{D^k(y^l, x^l)} \quad \frac{D^l(y^k, x^k)}{D^l(y^l, x^l)} \right\}^{1/2} \tag{7}$$

M is a geometric mean of the two Malmquist input-based productivity indexes,

each defined with a different reference technology. On the right-hand side of the equality, the first term indicates the minimal input inflation factor such that the inflated input for firm *l* and output vector of firm *l* lie on the production surface of firm *k*. This term is greater than one only when *l* has a higher productivity level than firm *k*. The second part of the right-hand part of the equality measures the maximal input deflation factor such that the deflated input from *k* and the output vector of *k* lie on the production surface of *l*. This is also greater than one for *l* more productive than *k*.

The Malmquist index in equation 7 can be decomposed into the efficiency and technical change components following Färe et al., (1993):

$$M(x^l, x^k, y^l, y^k) = \frac{D^k(y^k, x^k)}{D^l(y^l, x^l)} \bullet \left\{ \frac{D^l(y^l, x^l)}{D^k(y^l, x^l)} \quad \frac{D^l(y^k, x^k)}{D^k(y^k, x^k)} \right\}^{1/2} \tag{8}$$

2.4 *Input distance function functional form and linear programming (LP) model*

A flexible functional form, specifically the flexible translog functional form, was selected to represent the production technology (input distance function) as follows:

$$\ln D(y, x, t) = \alpha_0 + \sum_{n=1}^{N} \alpha_n \cdot \ln x_n + \sum_{m=1}^{M} \beta_m \cdot \ln y_m + (0.5)\sum_{n=1}^{N} \sum_{n'=1}^{N} \alpha_{nn'} \cdot \ln x_n \cdot \ln x_{n'} + (0.5)\sum_{m=1}^{M} \sum_{m'=1}^{M} \beta_{mm'} \ln y_m \ln y_{m'} + (0.5)\sum_{n=1}^{N} \sum_{m=1}^{M} \gamma_{nm} \cdot \ln x_n \ln y_m + \alpha_t \cdot t + (0.5)\alpha_{tt} t^2 + \sum_{n=1}^{N} \alpha_{nt} \cdot t \cdot \ln x_n + \sum_{m=1}^{M} \beta_{mt} \cdot t \cdot \ln y_m \tag{9}$$

where:
N=production inputs: feed (n1), seed (n2), water (n3), labor (n4)
M=outputs: shrimp (m1), pollutant output N-outflow (m2), pollutant output P-outflow (m3)
α, β, γ= estimated parameter values of the translog Input Distance Function
t= time

Mathematical programming was used to estimate the parameters of the non-stochastic Input Distance Function in equation (9), this is, minimizing the sum of deviations of the values of the function from the unknown frontier that is being estimated (deviations from unity). Inequality restrictions are included to represent the asymmetric treatment of desirable and undesirable outputs, so that weak inequality restrictions on the first derivative of the input distance function are necessary. The objective of the problem is to choose the set of parameter estimates that minimize the sum of deviations of the logarithmic value of the distance function from zero. Monotonicity, homogeneity and symmetry are imposed:

$$Minimize_{(\alpha,\beta,\gamma)} \sum_{k=1}^{575} \ln D(y,x,t)$$

subject to the following constraints:

1) $\ln D\,(y,x,t) \geq 0, \quad t = 1,..4$

2) $$\frac{\partial \ln D(y,x,t)}{\partial y_m} \leq 0, \quad t = 1,...7 \quad m = 1$$

3) $$\frac{\partial \ln D(y,x,t)}{\partial y_m} \geq 0, \quad t = 1,...7 \quad m = 2,3$$

4) $$\frac{\partial \ln D(y,x,t)}{\partial x_n} \geq 0, \quad t = 1,...7 \quad n = 1,...4$$

5) $$\sum_{n=1}^{4} \alpha_n = 1$$

6) $$\sum_{n=1}^{4} \alpha_{nn'} = 0, \quad n' = 1,...4$$

7) $$\sum_{n=1}^{4} \gamma_{nm} = 0, \quad m = 1,...3$$

$$
8) \quad \begin{aligned}
&\sum_{n=1}^{4} \alpha_{nt} = 0, \\
&\alpha_{nn'} = \alpha_{n'n} \quad n, n' = 1,...4 \\
&\beta_{mm'} = \beta_{m'm} \quad m, m' = 1,...3
\end{aligned}
$$

where n and m were defined as in equation 14, and t is each of the seven years analyzed. The constraints ensure the followings: 1) the observation is within the technology frontier: feasible and with distance function value ≥ 1; 2) monotonicity condition: the distance function is non-decreasing in inputs; 3) the function is non-increasing in the marketable output (shrimp); 4) the input distance function is non-decreasing in the two pollutants or undesirable outputs; 5) linear homogeneity of the input distance function with respect to inputs; 6,7,8) symmetry conditions of the translog functional form. t is time (7 years of data) and k is each of the observations (= shrimp pond). A code for this problem was developed and solved using Mathematica® and MathOptimizer®.

According to the time period evaluated and what happened for the shrimp farming industry in the region during it, efficiency and productivity can be measured and the results can be analyzed in correspondence with four events:

1. use of white or blue shrimp in operations
2. the effect of experience of working with one species after many years (white shrimp), and to initiate a learning curve with a new species (blue shrimp) after 1996
3. the effect of the viral outbreak on production performance
4. the effect of Good Management Practices (GMPs), which have been incorporated into shrimp farming operations as a measure to diminish the risk of diseases outbreaks (years 2001-2003)

The environmentally-adjusted indicators are contrasted against "normal" ones (technical efficiency TE and total factor productivity TFP), this is, those that take in to account only shrimp production as the final output and ignore undesirable outputs.

3. Results

3.1 Descriptive statistics of the data

Table 1 presents descriptive statistics of the variables included in the measurement of total factor productivity (TFP) as shown in equation 8, and technical efficiency (TE). Standard deviations are relatively high reflecting the somewhat diverse operating conditions of the four years under analysis.

Table 1 Seven-year descriptive statistics of variables included in the analysis (575 ponds)

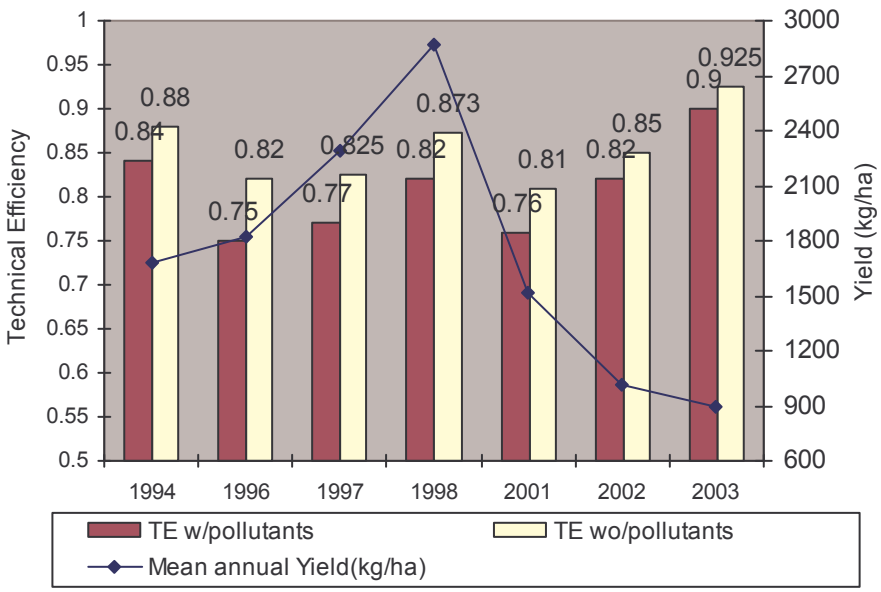
Variable (units)	Mean	Std.Dev.	Min.	Max.
Inputs				
Feed (kg/ha)	4,072	2,622	324	11,516
Seed (# postlarvae/ha)	98,096	63,702	40,777	493,431
Water (cubic meters/ha)	42,510	14,722	4,207	92,800
Labor ($/ha)	10,519	4,750	1,999	27,026
Outputs				
Desirable output				
Shrimp (kg/ha)	1,534	871	363.1	9,200
Undesirable outputs				
Nitrogen effluents (kg/ha)	94.8	52.1	8.75	409.59
Phosphorus effluents (kg/ha)	8.3	4.9	2	44.36

For the first period of study (1994,1996-1998) and compared to 1994, nutrient discharges increased annually. Annual yield grew simultaneously, which demonstrates that farm managers improved their productive performance (at least from the perspective of a traditional estimator: yield) with a simultaneous increase in discharge of nutrients. The effects of these two opposite results on traditional and environmentally-adjusted production performance will be properly tested later on in this paper, by means of TFP and TE. In 1994 farmers were very experienced rearing white shrimp (*L. vannamei*). However, beginning in 1996 both white and blue shrimp (*L. stylirostris*) are alternatively used in monoculture, until the transition is completed in 1998, first year of full blue shrimp operation. The nutrients discharge increases in 1997 and 1998. Working with the new species brings about higher feed conversion rates (FCR) and consequently increased nutrient discharges. The second period (2001-2003) corresponds again to white shrimp monoculture, since the industry returned to this species after high mortalities with blue shrimp in 1999 and 2000.

3.2 Technical efficiency (TE) of farms

Using the whole data set of 575 ponds, seven series of mean annual technical efficiency (TE) scores for farms operating in each year were obtained according to seven individual frontiers (one frontier per year). These seven series are asymmetric because ponds (and farms) were not established all at the same time and also because after the viral diseases, ponds returned to operations at different times. Figure 1 summarizes the results per year, contrasting annual average TE scores against a traditional performance measurement: yield. Interpretation of the TE without undesirable outputs in 1994, for example, is that a reduction in inputs use in the order of 12% could be used to obtain the same amount of output (shrimp).

Fig.1 Comparison of average technical efficiency by year, with and without undesirable outputs, and yield (kg/ha).



The most important result shown in Fig. 1 is the fact that, although in recent years (2001-2003) yields dropped significantly, farmers are as efficient as they were when yields were at double or triple figures nine years before, and even in year 2003 the highest values in the time series of both TE (0.925) and EATE (0.9) were achieved, when annual yields are at their historical minimum. This means that use of inputs (mainly feed and water) is improved in this second period compared to the first one. The industry has learned to obtain the most of input use, i.e. be more efficient, correctly reducing inputs as adjustments to mortalities by disease. Specifically feed management (a Good Management Practice GMP) plays a very critical role in these days, but also the production systems are leaning towards a very small exchange of pond water every day. It is considered that this proves the experience of the farmers, and the TE and EATE figures capture it. This was certainly not the case when viral diseases

first hit the industry in the 90's, when feed conversion rates were higher but also daily water exchange rates of 15-20% were common.

On the other hand, the environmentally-adjusted technical efficiencies are always lower than the traditional ones, since the score is reduced for the use of inputs in generating the undesirable outputs. In the best years (1994, 2002 and 2003) the difference between both TE scores is very small, showing that farmers were almost equally successful not only in producing the target output but when technical efficiency is penalized for the simultaneous generation of undesirable by-products (N and P outflows), they were able to maintain their relative distance to the frontier.

3.3 Malmquist Total Factor Productivity (TFP) of farms

As discussed, the Malmquist Index approach provides a comparison across time of the same production units. Therefore, the same DMUs must be present in the sample each year. This reduces the number of observations to 49 and the results from the TFP evaluation reflects this data subsample.

An important decision when developing TFP evaluations using the Malmquist Index is the choice of the base of reference, that is, what year is considered t_0 and the successive annual evaluations will be compared against this year. In this study the analysis is more interesting if it centers on discerning productivity change from an initial state of relatively efficient and high production as in 1994. Therefore, focusing on the analysis of the viral outbreak and the transition through a new technology, the base year is kept as the initial year of 1994. Estimated annual TFP Malmquist Productivity Indexes are shown in Tables 2 and 3, for the performance measurement with and without undesirable outputs. The tables include mean technical efficiency (TE) and technical change (TC) components for comparative analysis.

Table 2 Mean annual Malmquist Productivity Index (1994=1.00), TE and TC with (W) undesirable outputs.

Comparison	Malmquist Index	TE	TC
1994/1996	0.835	0.971	0.86
1994/1997	0.821	0.947	0.866
1994/1998	0.85	0.942	0.902
1994/2001	0.81	0.893	0.909
1994/2002	0.962	0.984	0.98
1994/2003	1.12	1.2	0.931

Table 3 Mean annual Malmquist Productivity Index (1994=1.00), TE and TC without (WO) undesirable outputs.

Comparison	Malmquist Index	TE	TC
1994/1996	0.86	0.966	0.891
1994/1997	0.873	0.987	0.881
1994/1998	0.872	0.948	0.918
1994/2001	0.83	0.943	0.882
1994/2002	1.02	1.03	0.993
1994/2003	1.16	1.22	0.706

Discussion

The separation of the TE effect from the technological change (TC) in the Malmquist TFP Index is an important distinction for the analysis of results. What happened to the industry in both periods analyzed is contrasting: in the first period (1994, 1996-1998) there is a change of species, forced by the high mortalities in white shrimp. TFP scores decrease after the viral diseases, both traditional and environmentally-adjusted. The first TFP regression (in 1996, compared against the base year of 1994) is a direct indication of the viral diseases, and is the biggest reduction in TFP in the 4 years analyzed. Since TE is very uniform across the 3 periods (always close to 1, which reflects that on average most of the ponds maintained or even reduced their distance to the respective annual frontier), the productivity changes have their origin in the negative impact of the sudden change in technology (TC) as consequence of the viral outbreaks, which forced producers to introduce a new shrimp species in their operations. In this paper the change in species is considered a technological change since the production technology using blue shrimp is more input-intensive compared to white shrimp.

The second period (2001-2003) depicts the return to white shrimp culture and 2003 the extensive implementation of Good Management Practices (GMP) in Mexico. Since viral diseases have not been eliminated, the farmer strategy to compete or keep in business is reduction of input use. As mentioned, pond management has become critical, and there are important achievements in feed management and reductions of water exchange rates. The Malmquist indexes for the second period show that the high productivities achieved are a result of higher technical efficiency of the farms, rather than a technological change. But in absolute terms, the production results of farmers after 2000 are mixed: yields and total production have dropped drastically, even forcing farmers in several areas out of business. On the other hand, in achieving these smaller productions, farmers are very efficient: low stocking densities, low FCRs, low water exchange rates.

As expected, productivity and efficiency scores always fall following disease impacts. This result and conclusion is consistent with the findings of Tveteras and Heshmati (1998) in their productivity analysis of the Norwegian salmon

farming industry. They also concluded that productivity growth is negatively correlated with economic losses due to diseases and weather changes. For the first period of study, the magnitude of the TC decay, resultant from a disease outbreak, brings down TFP in 1996 and 1997, despite positive and uniform TE of ponds. Therefore, the main source for negative TFP growth rates is a technical regress where farmers were using more units of inputs to obtain the same amount of output with a new technology (following the input orientation of this study).

The efficiency effect (in this case an improvement) is the main influence for the growth in TFP in the second period. It is a shift in the production frontier (inwards, according to the input orientation of the study) that makes it possible to use less inputs to generate a fixed amount of outputs. Since feed is better managed, nutrients discharged registered its lower values in the second period, mainly in 2003. Actually in 2003 farmers decided to change their risk-seeker behaviour and to stock ponds at much lower stocking densities. These two elements, seed and feed, together with reduced water exchange rates, are the primary influence for the measurements of environmental production performance. But as expected, environmentally-adjusted TFP is smaller than the traditional score.

The analysis of TFP values with undesirable outputs is complemented with the use of the mean annual N and P discharges for the seven years: mean discharges of N and P dramatically increased in 1997 and 1998. However, in the second period the discharges fall in 2002 and 2003. Under the "fair" environmentally-adjusted TFP Index, which rewards producers not only for inputs used to generate the desirable product but also for those not directed towards the production of undesirable outputs, farmers have lower productivity and efficiency scores in both periods of study. However, in 2003 both EATE and TE, and EATFP and TFP are very close.

Comparative results between traditional and environmentally-adjusted indicators differ in this study to the ones reported by Hailu and Veeman (2000) in their analysis of the Canadian pulp and paper industry. They found that environmentally-adjusted productivity is higher than traditional one, because the pulp and paper industry in Canada has been successful in reducing average annual rates of pollutants emissions, so the adjusted performance measure rewards the producer or industry for this achievement. That might be the case of the shrimp farming industry in Mexico before the viral diseases of 1995, as shown by the only year analyzed where operations were "normal" (in 1994 conventional mean TE is 0.88 vs 0.84 of environmentally-adjusted TE). In this year the ponds and farms on average are almost equally efficient when considering all outputs produced and under conventional TE estimations.

Reinhard et. al. (2000) in their analysis of the Dutch dairy farms found that conventional technical efficiency scores are higher than environmental ones,

where environmental efficiency is defined as the ratio of minimum feasible to observed use of environmentally detrimental inputs, conditional on observed levels of the desirable output and conventional inputs. Reinhard et al. modelled the pollutants as inputs in the production technology. Finally, in his study of the agricultural sector of the Netherlands, Oskam (1991) also found that the inclusion of the environmental effects reduces total and net factor productivity scores, with respect to traditional TFP. Oskam calls the performance measurement adjusted by environmental effects and the one which is not, "social" and "private" productivity and productivity change, respectively.

Economists commonly use partial productivity ratios such as output per worker and output per hectare to compare productivity of production enterprises. However, they have also recognized the inadequacy of these partial productivity ratios which can provide a misleading picture of productive performance and have subsequently developed a more comprehensive concept (Total Factor Productivity Indexes), which compares outputs with the combined use of all inputs (resources). The relevance of measuring and analyzing other production performance indicators in addition to yield (which is a partial productivity ratio) is clear from Figure 1 and Tables 2 and 3. While yields were always increasing in the first period analyzed (1994, 1996-1998), TE and TFP show that farms were less successful in transforming inputs to a fixed amount of output (including pollutants) in the two years that followed the disease problems. The year when the transition to blue shrimp started (1997) had lower efficiency and negative productivity growth that continued when blue shrimp became the main species (1998). The contrast is bigger in the second period analyzed (2001-2003), when yields dropped to historical lower values, but efficiency and productivity scores improved, even surpassing the levels of 1994 for TFP and EATFP.

The joint analysis of yields and production performance measurements, including environmentally-adjusted ones, indicates that in the first period, although farmers were always able to increase annual yields, the managerial tool behind this achievement changed as a consequence of the diseases and the ensuing adjustments, in addition to the learning-by-doing they were performing with the new technology and species. After the disease outbreaks, the increased yields was achieved with increased use of inputs, mainly feed and water. This result is opposite in the second period, when farmers decided to reduce losses by reducing input use.

The lower TFP scores found in this study, corresponding to the years of transition and adjustments after viral diseases, were certainly expected. The consequences from the viral diseases were strong for the industry in general.
The decomposition of productivity into its constituent parts (TE and TC) provides valuable information for strategic decisions, again, both at farm and planning levels. If a lack of growth occurs due to technological regress (for example technological obsolescence) the situation could be corrected with

more research in new technologies. On the other hand, if a lack in productivity growth is due to low TE, then the managerial incompetence of producers should become the focus. Training and education plays an important role so that those farms with lower TE values ("laggers") can "catch-up" with more efficient ones.

At the heart of this study are the policy implications of measuring production performance. The result that the regression in productivity as a result of the first viral outbreak (1995) took primarily the form of a technological regress is interesting. Although farmers were not too far from the annual frontier, the technological change required more inputs to get the same level of output. The capability for transmission of knowledge about the new production technology (with blue shrimp) is a key factor for a fast recovery in production performance. Therefore, training in the new technology know-how must be expedited to cope with the problem. The environmentally-adjusted estimators further evidence the need for a rapid transition period. The uniform and high TE scores indicate that farms in this region share and exchange information and that can be a competitive advantage of the industry.

This kind of methodology is currently being applied by the authors to evaluate the whole shrimp farming industry in the northwestern States of Mexico, where 90% of the shrimp by aquaculture is produced. The federal government by means of the National Commission for Fisheries and Aquaculture (CONAPESCA) is supporting this research. It is clear to both government and industry that it is time to evaluate the performance of the individual enterprises and the industry as a whole, not only by the production of the desired output (shrimp, using an indicator like yields), but paying attention to how this output is obtained in terms of input use, and mainly how much by-products or wastes are generated in the process. Governments at State and federal levels, business and academic communities would benefit from periodical reports of economic/environmental indicators highlighting the relevant economic and environmental issues related to the industry's development. However, it would be informative in future research to evaluate the robustness of this simple Distance Function methodology with other approaches reported in the literature. Finally, extension of this methodology to incorporate risks and uncertainty as inherent to most aquacultural production would certainly enhance the measurements at hand.

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