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ESTIMATING INEFFICIENCY IN FISHCAGE CULTURE OPERATION VIA STOCHASTIC FRONTIER TOTAL COST FUNCTION: THE CASE OF SAMPALOC LAKE, PHILIPPINES

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I. INTRODUCTION

THIS paper is a follow-up of our two earlier papers written about the cage culture of tilapia in Sampaloc Lake. In the first paper [6], a bioeconomic analysis of the 1986 fishcage operation has been done. Being a less intensive feeding regime, biological or ecology-related factors were also included in the estimation of yield and some factors (e.g., externality and location variables) were found significant. Following a considerable increase in the number of cages in a span of four years and a shift to a more intensive feeding, a reinvestigation was carried out [11] [12]. Results showed that where the growth of fish relied less and less on the natural food of the lake, locational advantage and effects of overcrowding became less important. A very interesting result which also came out was the big discrepancy between the estimated optimum (367 fingerlings/m^2 or 73 fingerlings/m^3) and the actual average (17 fingerlings/m^2 or 4 fingerlings/m^3) stocking densities. This prompted us to check if this result accords with the biophysical potentials and limits of both the fish and the lake. Matching the water quality criteria of *Oreochromis niloticus* (the tilapia species of concern in this study) and the water quality (physicochemical) parameters of Sampaloc Lake, favorable growth of the said fish can be expected in the lake. Furthermore, compared to the stocking densities in other countries, the estimated optimum rate even turned out to be low. As an offshoot of the preliminary investigation, a peculiar relationship between cage size and stocking density surfaced, and is the focus of our attention in this paper.

The purpose of this study is to estimate the level of inefficiency of the fishcage farmers of Sampaloc Lake using a stochastic frontier analytical framework, and in turn determine the factors affecting the fishcage farmers' inefficiency. So far this is the first attempt to address the above issues from a more rigorous econometric point of view.[1]

This paper is organized as follows. Section II provides background information about the problem from which we drew our basic hypothesis. Section III discusses the methodology and data. Section IV sets forth and analyzes the empirical

[1] In Southeast Asia, even in the field of agriculture, only a meager number of studies exist which have applied the econometric analysis adopted in this paper [5] [7].

results. In the final section concluding remarks with special reference to policy recommendations on technology adoption are presented.

II. DEVELOPMENT AND STATEMENT OF HYPOTHESIS

The main hypothesis in this paper was developed from a cross-country comparison of stocking, harvesting, and growth data for the intensive cage culture of *O. niloticus*.[2] As shown in Table I, the fishcage farmers in the Philippines (Sampaloc Lake) use very large cages, very low stocking densities, stock relatively small fingerlings, and obtain very low yields compared to the practice in other countries of using small cages, very high stocking densities, bigger fingerlings, and harvesting very high yield. In China (Jindou Reservoir) an intensive cage culture of *O. niloticus* with a stocking density ranging from 53 to 496 fingerlings/m^3 and 28 per cent protein feed produced yields of 13–72 kg/m^3 in fishcages of size 8–38 m^3. In Ivory Coast (Lake Kossou), stocking density ranged mostly between 300–307 fingerlings/m^3 at 33–49 grams/fingerling producing yield of 56–76 kg/m^3 in only 1 m^3 cages. Similarly, Belgium (thermal effluent) and the Central African Republic (fertilized pond) utilized very small cages and yet yields were notably high due to very large stocking densities averaging 367 and 247 fingerlings/m^3 respectively, while in the Philippines (Sampaloc Lake), the average stocking density was only 4 fingerlings/m^3 yielding an average of about 0.5 kg/m^3. In addition to the contrast in stocking density and yield was the notably large cage sizes being used in the Philippines, averaging 1,669 m^3 and 868 m^3 in our two study periods (based on 1986 and 1990 cage inventories respectively). Considering that the other factors (i.e., daily feed ration, protein content of feed applied, and culture period) are just about the same in the Philippines and in the other countries, some very intriguing questions can be raised. That is, why do fishcage farmers of Sampaloc Lake prefer to invest more in cages rather than in fingerlings when the latter is relatively much cheaper? Is there a strong economic justification for the existing low stocking densities?

We also made a descriptive comparison of output and input quantities by cage size using Sampaloc Lake data (1986 and 1990), and in general smaller cages have higher yield, stocking density, and feeding rate.

Based on the above preliminary findings, we would like to test the following hypothesis: the inefficiency in the fishcage culture operation in Sampaloc Lake is primarily due to the adoption of relatively large cages and low stocking densities, ceteris paribus.

III. METHODOLOGY AND DATA

A. *Estimation Procedure and Assumptions*

At the outset we selected an econometric (stochastic) technique of estimating frontier and, consequently, inefficiency due to its ability to handle statistical noises.

[2] Cage size, stocking, and harvesting data were converted to per cubic meter for this purpose since the foreign data gathered were mostly expressed in this unit.

TABLE

COMPARATIVE SUMMARY OF STOCKING, HARVESTING, AND

Location	Average Cage Size (m^3)	kg	Ave. Wt. (g)
Philippines (Sampaloc Lake)	1,668.75	54.34	8
Philippines (Sampaloc Lake)	868.25	30.58	10
Ivory Coast (Lake Kossou)	1.00	10.13	33
Ivory Coast (Lake Kossou)	1.00	14.70	49
Central African Republic (fertilized pond)	1.00	10.62	43
Belgium (thermal effluent)	0.50	10.28	56
China (Jindou Reservoir)	37.50	147.94	75
China (Jindou Reservoir)	15.63	240.41	31
China (Jindou Reservoir)	8.00	155.95	73
China (Jindou Reservoir)	15.63	180.31	58

TABLE I

Location	Culture Period (Days)	Survival (%)	Growth Rate (g/day)
Philippines (Sampaloc Lake)	306	0.72	0.44
Philippines (Sampaloc Lake)	109	0.89	1.67
Ivory Coast (Lake Kossou)	130	0.87	1.41
Ivory Coast (Lake Kossou)	122	0.93	1.80
Central African Republic (fertilized pond)	56	0.84	0.81
Belgium (thermal effluent)	30	0.98	1.27
China (Jindou Reservoir)	104	0.70	2.75
China (Jindou Reservoir)	96	0.52	2.56
China (Jindou Reservoir)	104	0.75	2.32
China (Jindou Reservoir)	96	0.77	3.50

Note: China's values were derived from the original data (per m^2) of Xue et al. [13]
[a] NLT=not less than.

I

GROWTH DATA FOR INTENSIVE CAGE CULTURE OF O. NILOTICUS

Stocking			Harvest				
Number (Fish)	No./m³	kg/m³	kg	Ave. Wt. (g)	Number (Fish)	No./m³	kg/m³
6,792	4	0.03	687.82	141.24	4,870	3	0.41
3,058	4	0.04	522.72	191.94	2,723	3	0.60
307	307	10.13	56.00	210.28	266	266	56.00
300	300	14.70	75.90	271.00	280	280	75.90
247	247	10.62	18.40	89.00	207	207	18.40
184	367	20.55	17.00	94.67	180	359	34.00
1,973	53	3.94	498.75	361.50	1,380	37	13.30
7,755	496	15.41	1,116.88	276.68	4,037	258	71.48
2,127	266	17.50	502.80	314.23	1,600	200	62.85
3,125	200	11.48	952.34	393.57	2,420	155	60.95

(Continued)

Daily Feed Ration (DFR) (% of Biomass)	Protein Content (%)	Feed Conversion Ratio (FCR)	Source and Remarks
—	—	0.58	Tan (1980) [10]
10 reducing to 3.6	NLT 27[a]	2.10	Tan and Higuchi (1990) [11]
4 to 6	24.7	3.14	Coche (1977) cited in Coche [3] Values are averages of seven 1 m cages.
4 to 6	24.7	3.30	Coche (1977) cited in Coche [3]
6	41	5.50	N'Zimasse (1979) cited in Coche [3]
7	46	2.77	Phillipart et al. (1979) cited in Coche [3] Values are averages of three 0.5 m cages.
3.5 to 4.5	28.1	2.70	Xue et al. [13] Values are averages of cages no. F2 & F4 in Table 7 (1986).
3.5 to 4.5	27.8	2.10	Xue et al. [13] Values are averages of cages no. SF1-SF5 in Table 7 (1987).
5	28.1	2.70	Xue et al. [13] Values are averages of cages no. B2-B4 in Table 6 (1986).
3.5 to 4.5	27.8	1.80	Xue et al. [13] Values are averages of cages no. NF4-NF6 in Table 6 (1987).

and were converted on a per m³ basis.

A transcendental logarithmic function was applied due to its flexibility, since the more flexible the parametric form, the closer it will envelop the data. The choice for estimating a cost frontier was based on the exogeneity assumption, i.e., output is exogenous [9]. Finally, the inherent advantage of estimating a system of equations (i.e., cost and cost-share equations) over a single equation in deriving more asymptotically efficient estimates of the technology led us to employ this estimation. Cowing et al. [4] did a comparison of alternative frontier cost function specifications, and their results showed that different assumptions for the error distributions made little difference in the parameter estimates while a great deal of difference came out between the estimation of the cost function solely and the whole system jointly.

The cost systems can be expressed as

$$\ln TC = \ln TC(P, Q) + \omega, \qquad \omega = v + u,$$
$$S_j = S_j(P, Q) + \varepsilon_j, \qquad j = L,\ FI, \text{ and } K,$$

where TC is observed total cost; $TC(\cdot)$ is the deterministic minimum total cost frontier; Q is output; P is an input price vector; v is a two-sided disturbance (statistical noise) and u is a one-sided disturbance (inefficiency); S_j is the observed share of the jth input; $S_j(\cdot)$ is the efficient share of the jth input; ε_j is the disturbance (composed of statistical noise and inefficiency) on the jth input share equation; and L, FI, and K are labor, fingerlings, and capital inputs respectively.

With respect to the disturbance terms, u is assumed to be distributed truncated normally with zero mode while v is assumed to be normally distributed and independent of u and ε_j. ε_j is assumed multinormally distributed and dependent of u. These assumptions can be illustrated as follows [7].

$$v \sim N(0, \sigma_v^2),$$
$$\begin{bmatrix} u \\ \varepsilon \end{bmatrix} \sim N(0, \Sigma),$$
$$u \geq 0,$$

where

$$\varepsilon' = (\varepsilon_L, \varepsilon_{FI}, \varepsilon_K),$$
$$\Sigma = \begin{bmatrix} \sigma_{uu} & \sigma_{uL} & \sigma_{uFI} & \sigma_{uK} \\ \sigma_{uL} & \sigma_{LL} & \sigma_{LFI} & \sigma_{LK} \\ \sigma_{uFI} & \sigma_{LFI} & \sigma_{FIFI} & \sigma_{FIK} \\ \sigma_{uK} & \sigma_{LK} & \sigma_{FIK} & \sigma_{KK} \end{bmatrix}.$$

(Σ is the variance-covariance matrix of the inefficiency disturbances of the cost and cost-share equations.)

The likelihood function for this system can be written as

$$\ln L = \sum_i \ln \lambda(\omega_i, \varepsilon_i)$$
$$= -\frac{N}{2} \ln(1 + \sigma_v^2 \sigma^{uu}) + \frac{N}{2}[\ln \sigma^{uu} + \ln \sigma^{LL}(u)$$
$$+ \ln \sigma^{FIFI}(L) + \ln \sigma^{KK}(FI)] + \sum_i \sum_j \ln f^*(z_{ji})$$

$$-\sum_i \ln[1-F^*(z_{bui})]+\sum_i \ln[1-F^*(A_i)], \qquad i=1,\ldots, N;\ j=L,\ FI, \text{ and } K,$$

where N is the number of observations; σ^{UU}, σ^{LL}, σ^{FIFI}, and σ^{KK} are elements of Σ^{-1} matrix; and f^* and F^* are standard normal and standard normal cumulative density functions. For the remaining parameters, we have provided all the formulas in the Appendix (see also [7]). Estimates of this model were calculated using the time series processor (TSP) program employing the maximum likelihood (ML) command and the Davidon-Fletcher-Powell method of updating the approximated value of the Hessian matrix at each iteration based on the gradient and parameter changes.

The inefficiency component can be estimated as follows:

$$EI_i=1-E[\exp(-u_i)\,|\,\omega_i,\ \varepsilon_i],$$

where

$$E[\exp(-u_i)|\omega_i,\ \varepsilon_i]=\frac{\exp\left[-\mu_i^*+\dfrac{(\sigma^*)^2}{2}\right]\cdot\left[1-F^*\left(\sigma^*-\dfrac{\mu_i^*}{\sigma^*}\right)\right]}{1-F^*\left(-\dfrac{\mu_i^*}{\sigma^*}\right)},$$

$$\mu_i^*=-\frac{-\omega_i+\sigma_v^2(\sigma^{uL}\cdot\varepsilon_{Li}+\sigma^{uFI}\cdot\varepsilon_{FIi}+\sigma^{uK}\cdot\varepsilon_{Ki})}{1+\sigma_v^2\cdot\sigma^{uu}}, \text{ and}$$

$$\sigma^*=\frac{\sigma_v}{\sqrt{1+\sigma_v^2\cdot\sigma^{uu}}}.$$

In the final analysis, the different determinants of inefficiency were estimated by methods of regression.

B. *Model Specification*

The stochastic frontier total cost function employing a translog functional form was adopted as the basic model.[3] The specification is as follows:

$$\begin{aligned}\ln\frac{TC_i}{P_{FEi}}=&\ \alpha_0+\alpha_1\ln\frac{P_{Li}}{P_{FEi}}+\frac{1}{2}\alpha_{11}\left(\ln\frac{P_{Li}}{P_{FEi}}\right)^2+\alpha_2\ln\frac{P_{FIi}}{P_{FEi}}\\&+\frac{1}{2}\alpha_{22}\left(\ln\frac{P_{FIi}}{P_{FEi}}\right)^2+\alpha_3\ln\frac{P_{Ki}}{P_{FEi}}+\frac{1}{2}\alpha_{33}\left(\ln\frac{P_{Ki}}{P_{FEi}}\right)^2\\&+\alpha_Q\ln Q_i+\frac{1}{2}\alpha_{QQ}(\ln Q_i)^2+\alpha_{12}\ln\frac{P_{Li}}{P_{FEi}}\ln\frac{P_{FIi}}{P_{FEi}}\\&+\alpha_{13}\ln\frac{P_{Li}}{P_{FEi}}\ln\frac{P_{Ki}}{P_{FEi}}+\alpha_{1Q}\ln\frac{P_{Li}}{P_{FEi}}\ln Q_i\\&+\alpha_{23}\ln\frac{P_{FIi}}{P_{FEi}}\ln\frac{P_{Ki}}{P_{FEi}}+\alpha_{2Q}\ln\frac{P_{FIi}}{P_{FEi}}\ln Q_i\\&+\alpha_{3Q}\ln\frac{P_{Ki}}{P_{FEi}}\ln Q_i+\omega_i,\end{aligned}$$

[3] See [1] [2] for further details.

where TC_i is the total cost of the ith sample; P_{Li}, P_{FIi}, P_{Ki}, and P_{FEi} are respectively the prices of labor, fingerlings, capital, and feed of the ith sample; Q_i is the output of the ith sample; and ω_i is the disturbance consisting of statistical noise (v_i) and inefficiency (u_i). All variables were normalized by dividing each by their respective means. As shown, the linear homogeneity in prices has been imposed by dividing TC_i, P_{Li}, P_{FIi}, and P_{Ki} by P_{FEi}. The choice of denominator was based on the result of correlation analysis of the transformed variables to avoid multicollinearity. The symmetry of parameters ($\alpha_{ij} = \alpha_{ji}$ and $\alpha_{iQ} = \alpha_{Qi}$) was also imposed.

The associated cost-share equations are as follows:

$$S_{Li} = \alpha_1 + \alpha_{11} \ln \frac{P_{Li}}{P_{FEi}} + \alpha_{12} \ln \frac{P_{FIi}}{P_{FEi}} + \alpha_{13} \frac{P_{Ki}}{P_{FEi}} + \alpha_{1Q} \ln Q_i + \varepsilon_{Li},$$

$$S_{FIi} = \alpha_2 + \alpha_{22} \ln \frac{P_{FIi}}{P_{FEi}} + \alpha_{12} \ln \frac{P_{Li}}{P_{FEi}} + \alpha_{23} \frac{P_{Ki}}{P_{FEi}} + \alpha_{2Q} \ln Q_i + \varepsilon_{FIi},$$

$$S_{Ki} = \alpha_3 + \alpha_{33} \ln \frac{P_{Ki}}{P_{FEi}} + \alpha_{13} \ln \frac{P_{Li}}{P_{FEi}} + \alpha_{23} \frac{P_{FIi}}{P_{FEi}} + \alpha_{3Q} \ln Q_i + \varepsilon_{Ki}.$$

C. *Variables*

The frontier total cost function contains six variables: total cost, prices of labor, fingerlings, feed, and capital, and output. Total cost is equal to the sum of expenditures for labor, fingerlings, feed, and imputed expenditures for capital services incurred in one culture period. Labor cost was estimated from the imputed owner-operator labor and the actual hired labor cost. The price index for labor was estimated from the shares of expenditures on specific activities (i.e., feeding, maintenance, guarding, and harvesting) on total labor cost and the activity-specific labor prices which were based on the wage rate adopted by the local cooperative of Sampaloc Lake.[4] The cost of fingerlings was based on the actual expenditure on this input. It is a common practice to give an additional 10 per cent of the actual number of fingerlings bought free of charge as an allowance for mortality. In this regard, some adjustments were made in calculating the price of fingerlings per unit. Further adjustments were also done for cases of indirect stocking (i.e., fries or fingerlings underwent a preculture period in nursery cages prior to grow-out cages). Feed cost consists of expenditures for three feed types applied at different culture stages (i.e., starter, grower, and

[4] The share for wage rate in the labor cost of a specific work activity as set by the local cooperative of Sampaloc Lake was derived using the Tornqvist-Theil-translog index procedure. In this study, the set wage has been adopted for evaluating the different work activities including that of family labor since there was no clear proof that warranted a different evaluation for it. In this case, mainly from the difference in the effort density of family and hired labor, the evaluation of a fishcage farmer's own labor may exceed the set individual activity wage. In checking for the effect of this bias, the optimum level of each factor was estimated. In particular, even if the set wage of family labor was estimated at twice its standard level, except for labor, the optimum level of the other factors practically did not change (cage size$=26$ m^2, fingerlings$=2{,}914$ pieces, and feed$=897.6$ kg).

finisher).[5] The price index for feed was estimated from the shares of the three feed types on total feed cost and their corresponding prices. Finally, the price of capital service (i.e., grow-out cages) was estimated following Jorgenson and Griliches's procedure [8, p. 256].[6]

D. *Data*

While the problem of cage congestion is not unique to Sampaloc Lake (104 hectares), being the largest of the seven lakes in San Pablo City (surface area ranging from 14.5 to 104 hectares) and the most accessible (situated within the city proper) with strong potential for other beneficial uses (e.g., for recreation and tourism), we selected this as our study site. (The familiarity and close affinity of the senior author to the study area also played a big role in the selection.) The choice of cage culture technology for tilapia is corollary to the choice of the study area and vice versa. That is, in the Philippines, cage culture technology is the main aquaculture technology adopted in relatively deep lakes or lakes of volcanic origin such as Sampaloc Lake. And the main fish species cultured in fishcages are tilapia.

Our data were obtained through cross-sectional surveys of tilapia fishcage farmers of Sampaloc Lake, Philippines, pertaining to their fishcage culture opera-

[5] The classification of feed is somewhat arbitrary as some fishcage farmers applied the same kind of feed throughout the culture period. On average, a starter feed was given over a period of 30 days (131 kg), a grower feed for a period of 47 days (455 kg), and a finisher feed for a period of 32 days (449 kg). In the feeding guidelines of the local cooperative of Sampaloc Lake, daily feeding is on average given at a ratio of 27:46:27, in the morning, noon, and afternoon respectively.

[6] Capital consists of cage frames, nets, and other equipment and accessories. By Jorgenson and Griliches's definition, $p_k = q_k(r + \delta_k - \dot{q}_k/q_k)$, where p is the price of kth capital, q_k is the price of the kth investment good, r is the rate of return on all capital (net value of output divided by the value of capital stock), δ_k is the rate of replacement of the kth investment, and $\dot{q}_k/q_k$ is the rate of capital gain on the kth investment (assumed zero in our calculation).

If the opportunity of utilizing funds for other uses (e.g., loanable funds) fully exists in perfect competition in an orderly manner, the corresponding opportunity cost of fixed capital is the market interest rate (r). However, in this study, the above condition does not hold, and market interest rate cannot be applied. For this reason, following the Jorgenson and Griliches's procedure, the r represents the rate of return on all capital and not the market interest rate. For each sample, we used the rate of return on all capital (0.74). This value is somehow stated implicitly in the recommended guidelines of the local cooperative of Sampaloc Lake and is being followed by its members. Of course, this is considerably high if we look at it as market interest rate. The optimal capital stock becomes underestimated. Provisionally, in this study the capital service market is perfectly competitive. The optimal capital stock (cage size) was estimated using a much lower value than the market interest rate (r). Based on the result, our assumption was clearly valid. In particular, in the case where $r=0.1$, while the estimated optimum cage size is large (96.3 m^2), it is still only about 55 per cent of the average cage size of 176 m^2. In the extreme case where r is set at zero, optimum cage size was found to be 120.2 m^2, a sufficiently large difference.

tions in 1986 and 1990 (Figure 1).[7] A stratified sampling procedure using the location-based (i.e., southwest [SW], southeast [SE], northeast [NE], and northwest [NW]) proportional allocation method was employed.

Data collection consisted of two phases in both survey periods. In the first phase complete inventories of all cage structures was done. Not all of the cage structures found in the lake were used for culturing tilapia, so it was necessary to classify all cages according to their uses (e.g., grow-out, nursery, and fishtrap). The classification however was arbitrary since the cages could be used for different purposes throughout their useful life. Cages whose recently concluded culture cycles culminated just shortly before the survey was conducted were included in the population for sampling. To be able to employ a stratified sampling procedure, we translated the information (e.g., actual sites of cages in the lake) we got from the first-phase interview questionnaires and from our reconnaissance of the whole lake area onto maps. From the maps we were able to classify the cages by location and, consequently, identify our respondents on the basis of ownership/caretakership. The second phase of data collection proceeded from this point. During this phase in-depth personal interviews of the owners or caretakers (whichever were more familiar with the culture operation) of the selected cages were conducted using sets of questionnaires.

In this particular study, due to the inherent difficulties in handling the 1986 data and its unsatisfactory results arising from insufficient information on prices of inputs, our analysis concentrated on the 1990 data. A total of fifty-seven samples were used in the analysis.

IV. EMPIRICAL RESULTS

A. *Theoretical Consistency*

At the point of approximation, the monotonicity condition can be investigated directly from the signs of the coefficients of input prices and output quantity (i.e., α_1, α_2, α_3, α_4, and α_Q), and their nonnegative values indicate that this condition has been satisfied (Table II).[8]

[7] Shown are the cage structures (i.e., grow-out, nursery, and hatchery) as of August 1986. From a total of 819 cages (total area of 20.27 hectares), this rose to 1,803 units (total area of 29.65 hectares) as of July 1990. Furthermore, the average cage size decreased by almost 50 per cent, from 333.75 m^2 (1986) to 176 m^2 (1990). (Given the limited space in this report for a map, the essential details would be lost, and for this reason we did not provide a 1990 map.)

[8] In general,

$$\alpha_{ij}=\frac{\partial^2 \ln TC}{\partial \ln P_i \partial \ln P_j}=\frac{\partial S_i}{\partial \ln P_j}=\frac{\partial S_j}{\partial \ln P_i}, \qquad i, j=L, FI, \text{ and } K,$$

$$\alpha_{iQ}=\frac{\partial^2 \ln TC}{\partial \ln P_i \partial \ln Q}=\frac{\partial S_i}{\partial \ln Q}, \qquad i=L, FI, \text{ and } K.$$

Consequently, the statistical insignificance of the parameter estimates α_{44}, α_{QQ}, α_{13}, α_{23}, α_{3Q}, and α_{4Q} can be explained as follows. First, the possibility of a change in feed cost share (S_{FE}) due to price of feed (P_{FE}) and output quantity (Q) is small. Second, the possibility

Fig. 1. Map of San Pablo City Showing the Seven Lakes and Highlighting Sampaloc Lake and Cage Structures

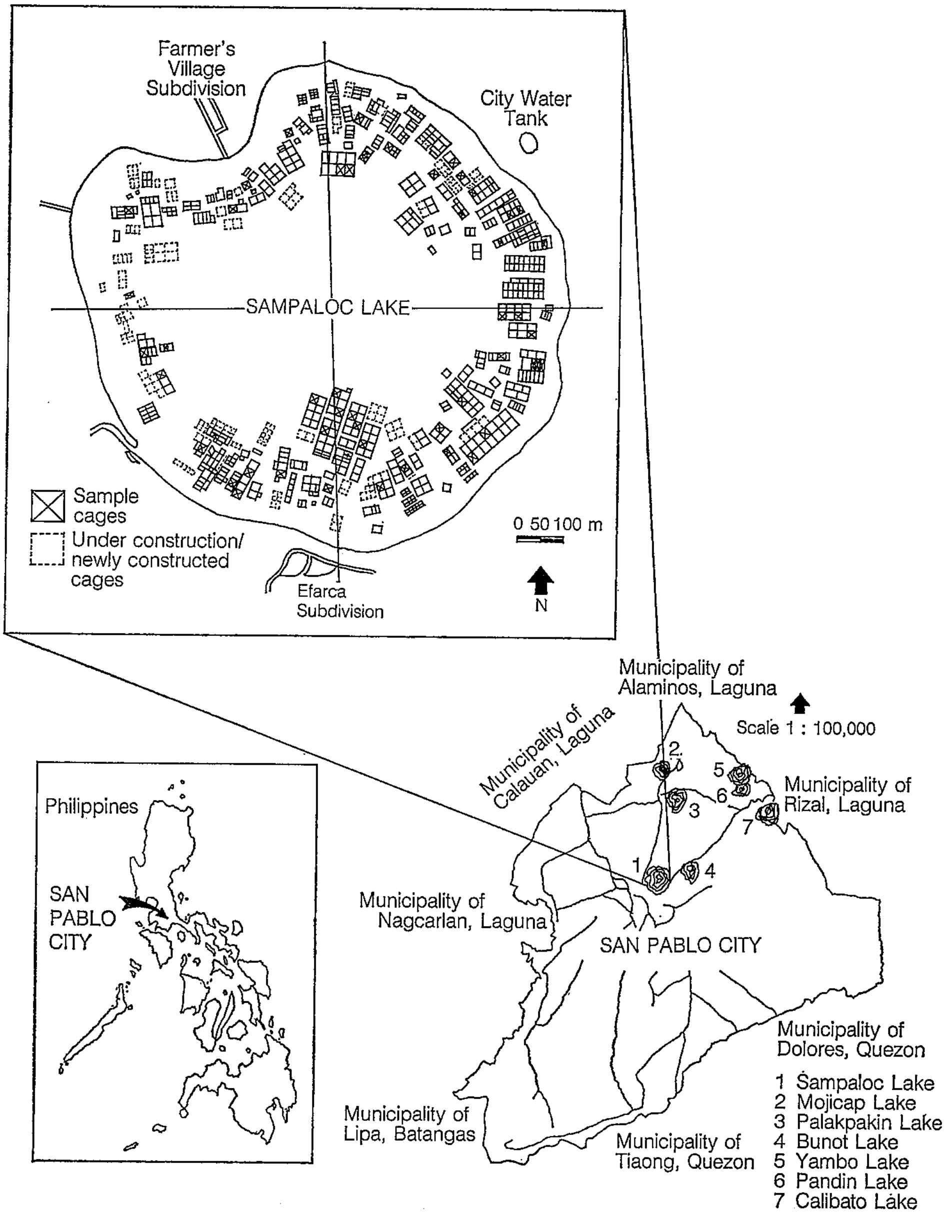


TABLE II

STOCHASTIC FRONTIER TOTAL COST FUNCTION PARAMETER ESTIMATES

Parameter	Variable	Estimate	Asymptotic t-value
α_0	Intercept	9.38738	221.802
α_1	Labor price (L)	0.17269	30.5156
α_2	Fingerling price (FI)	0.08129	31.8012
α_3	Capital service price (K)	0.07446	6.59275
α_4	Feed price (FE)	0.67156	47.7634
α_Q	Output quantity (Q)	0.63085	6.45099
α_{11}	$L \times L$	−0.04575	−2.51578
α_{22}	$FI \times FI$	0.05726	13.1092
α_{33}	$K \times K$	0.06857	1.91369
α_{44}	$FE \times FE$	0.02710	0.44691
α_{QQ}	$Q \times Q$	0.12118	0.40405
α_{12}	$L \times FI$	−0.01387	−2.28881
α_{13}	$L \times K$	−0.00582	−0.35937
α_{14}	$L \times FE$	0.06545	2.45570
α_{23}	$FI \times K$	−0.00679	−0.96661
α_{24}	$FI \times FE$	−0.03660	−3.49260
α_{34}	$K \times FE$	−0.05596	−1.30509
α_{1Q}	$L \times Q$	−0.02095	−1.49815
α_{2Q}	$FI \times Q$	0.00916	1.50624
α_{3Q}	$K \times Q$	−0.01510	−0.53278
α_{4Q}	$FE \times Q$	0.02689	0.77036
σ_v	Statistical noise	0.23832	9.61085
σ_{uu}	Inefficiency (I) $\times I$	0.02447	105.886
σ_{uL}	$I \times L$ cost share (LCS)	0.00126	194.569
σ_{uFI}	$I \times FI$ cost share ($FICS$)	−0.00144	−142.562
σ_{uK}	$I \times K$ cost share (KCS)	0.00198	114.879
σ_{LL}	$LCS \times LCS$	0.00053	127.361
σ_{LFI}	$LCS \times FICS$	-0.12498×10^{-5}	−5.94461
σ_{LK}	$LCS \times KCS$	−0.00023	−61.7418
σ_{FIFI}	$FICS \times FICS$	0.00011	124.983
σ_{FIK}	$FICS \times KCS$	0.00003	32.9817
σ_{KK}	$KCS \times KCS$	0.00228	108.783
Log of likelihood function=297.089			
Sample size=57			

Note: The maximum likelihood estimates were computed using the iterative Davidon-Fletcher-Powell algorithm.

of a change in labor cost share (S_L) due to capital service price (P_K) and output quantity (Q) is small. Third, the possibility of a change in capital service cost share (S_K) due to wage (P_L), price of fingerlings (P_{FI}), and output (Q) is small. Fourth, the possibility of change in fingerling cost share (S_{FI}) due to capital service price (P_K) is small.

Regarding $\alpha_{11}<0$, this means that an increase in wage (P_L) will lead to smaller labor cost share. As a result, with the increase in the relative wage price, labor will be substituted by other factors. Thus, a strong degree of substitution (elasticity of substitution is high) is depicted. Moreover, $\alpha_{14}>0$ means that labor cost share will increase due to an increase in capital service price (P_K). Or the capital service cost share (S_K) will increase due to an increase in wage (P_L). This can be interpreted as labor and capital having a strong substitution relationship.

TABLE III
SUMMARY OF HESSIAN CALCULATIONS

Parameter	Estimate	Asymptotic t-value
H_{11}	−0.18862	−10.5746
H_{22}	−0.01742	−3.92344
H_{33}	−0.00035	−0.00963
H_{44}	−0.19346	−3.22423
HH_2	0.00329	3.70004
HH_3	-0.17460×10^{-6}	−0.00147
HH_4	0.30536×10^{-7}	0.00147

Note: H_{11}, H_{22}, H_{33}, and H_{44} are the diagonal elements of the Hessian matrix of the second partials of total cost (TC) with respect to input prices (P_j). Since only the signs are of utmost importance for this purpose, all values were derived from the truncated form (second term on the right-hand side) of the original formulas, i.e., $H_{jj}=\alpha_j^2-\alpha_j+\alpha_{jj}$, where $j=1$ (labor), 2 (fingerlings), 3 (capital), and 4 (feed). The nondiagonal elements which are used to derive the principal minors of the Hessian matrix were computed as $H_{jh}=\alpha_j\alpha_h+\alpha_{jh}$. HH_2, HH_3, and HH_4 are the second, third, and fourth principal minors respectively.

The next condition (curvature) requires that the frontier total cost function must be concave in input prices. This has been satisfied by the nonpositive values of the diagonal elements of the symmetric Hessian matrix of the second partials of frontier total cost function with respect to input prices (i.e., H_{11}, H_{22}, H_{33}, and H_{44}) and the alternating signs of the principal minors starting with a nonpositive value (i.e., $H_{11}\leq 0$, $HH_2\geq 0$, $HH_3\leq 0$, and $HH_4\geq 0$, see Table III).

B. *Demand Elasticities and Elasticities of Substitution*

The own-price elasticities of labor, fingerlings, and feed were found to be significant (Table IV). Furthermore, the elasticities of substitution between labor and feed, and between fingerlings and feed were also significant. The own-price elasticity of feed is quite small relative to labor indicating that increases in the price of feed will lead to higher total cost. However, the elasticity of substitution between the two inputs is relatively large suggesting that there is a big opportunity of substituting labor for feed. If the relative price of labor will not increase significantly, the shift to a more labor-using technology could have a net effect of lowering the total cost. This possibility is based on two grounds. First, although there is no pertinent information to confirm the following, the substitutability relationship between labor and feed can be assumed to arise from higher feed losses at lower labor levels. Since feeding is done manually, a haphazard application and/or less efficient method may result from shorter time devoted to this activity, and loss can be further aggravated if not performed by the owner-operator himself.[9] Second, the proportion of total feed cost to total cost is relatively large (67 per cent) compared to that of hired labor (4 per cent). Apparently, minimizing feed losses could lead to a substantial reduction in total cost.

[9] Feeding was done by hired labor in twelve samples of the 1990 data.

TABLE IV

OWN-PRICE ELASTICITIES OF DEMAND AND ALLEN PARTIAL ELASTICITIES OF SUBSTITUTION

	Estimate	Asymptotic *t*-value
Own-price elasticities:[a]		
Labor	−1.09226	−10.0184
Fingerlings	−0.21432	−4.03080
Capital	−0.00465	−0.00963
Feed	−0.28808	−3.23756
Allen partial elasticities of substitution:[b]		
Labor-Fingerlings	0.01169	0.02642
Labor-Capital	0.54718	0.43095
Labor-Feed	1.56438	6.70563
Fingerlings-Capital	−0.12192	−0.10312
Fingerlings-Feed	0.32965	1.73428
Capital-Feed	−0.11902	−0.13993

[a] Computed as $DE_{jj}=\dfrac{\alpha_j^2-\alpha_j+\alpha_{jj}}{\alpha_j}$.

[b] Computed as $AES_{jh}=\dfrac{\alpha_{jh}+\alpha_j\alpha_h}{\alpha_j\alpha_h}$.

Regarding feed and fingerlings, their own-price elasticities are equally low and the elasticity of substitution is relatively small. This means that price increases in both inputs will have about the same effect on total cost, thus there is not much incentive to substitute one for the other. Moreover there is little opportunity to do so.

C. *Returns to Scale*

The return to scale (RTS) has been computed as

$$RTS=\left[\frac{\partial \ln TC(P, Q)}{\partial \ln Q}\right]^{-1}.$$

As shown in Table V, at the mean value of output, RTS indicates an increasing returns to scale. Also shown are the resulting RTS as output level is varied. Economies of scale are exhausted at an output level which is about twenty times the existing average level.[10] This result proves that there is still much room for growth in the fishcage industry of Sampaloc Lake.

D. *Cost-Minimizing Input Levels*

The derivative property of the cost function, known as Shephard's lemma, is useful because a set of cost-minimizing input levels (given output level) can be obtained from a well-behaved cost function by differentiating cost with respect

[10] The scale economy index (RTS) in the domain above the samples' maximum output level (average × 2.28) is the value of the estimate based on the estimated model.

TABLE V
RETURNS TO SCALE BY LEVELS OF OUTPUT

Output Level	Returns to Scale	Standard Error
Sample mean ($Q=526$ kg)	1.58516	0.24572
$0.5\times Q$	1.82863	0.64646
$2.0\times Q$	1.39891	0.51098
$5.0\times Q$	1.21083	0.77346
$10.0\times Q$	1.09906	0.88568
$15.0\times Q$	1.04275	0.92860
$20.0\times Q$	1.00617	0.95150
$25.0\times Q$	0.97952	0.96570

Note: Computed as $RTS=\left[\frac{\partial \ln TC(P, Q)}{\partial \ln Q}\right]^{-1}$.

to input prices. We calculated this for fingerlings, feed, and capital, and the cost-minimizing levels for all the three inputs were found to be lower than their actual average levels (Table VI).[11] The most striking difference is between the cost-minimizing (26 m^2) and the existing mean (176 m^2) cage sizes. This is one of the significant findings which validates our hypothesis. Multiplying the cost-minimizing cage size by 5 meters (the average depth of cages in Sampaloc Lake) would be equal to 130 m^3. Looking again at Table I, the cost-minimizing cage size is still relatively large compared to that of the other countries.

The cost-minimizing quantity of fingerlings or stocking density (per cage) for the prevailing average output level is only about 5 per cent lower than the sample mean. Considering too the low share of this input to total cost (7.4 per cent), no significant decrease in total cost can be exploited from it. However, an interesting observation which can be pointed out here is that, on a per square meter basis, the cost-minimizing stocking density (2,908 fingerlings $\div$ 26 m^2 = 112 fingerlings/m^2) is considerably higher than the existing average (3,070 fingerlings $\div$ 176 m^2 = 17 fingerlings/m^2). This clearly illustrates that a reduction in cage size must be accompanied by an increase in stocking density (and vice versa). In part, this is what we meant by the "peculiar relationship between cage size and stocking density" which we stated in the introduction. (Campbell [1978], cited in Coche [3], writing on a related topic asserted that as the cage size decreases, the maximum carrying capacity of the cage increases.)[12] Nevertheless

[11] The cost-minimizing labor level can also be obtained but due to our failure to obtain good estimates of labor quantity for each activity, we opted not to offer any in-depth comment on this.

[12] Campbell has defined the maximum carrying capacity (MCC, in kg/m^3) for *Sarotherodon niloticus* (former generic name of *Oreochromis niloticus*) in well-oxygenated water with good circulation (at least 2 centimeters/second) as follows: with plastic netting of 25-millimeter mesh, 90 kg/m^3 for 1 m^3, 70 kg/m^3 for 6 m^3, and 40 kg/m^3 for 20 m^3; with nylon fiber netting of 40-millimeter mesh, MCC is also 40 kg/m^3 for 20 m^3. In practice, it is always safer to stock below the MCC as the risks of disease and mortality greatly increase as the MCC is approached [3]. For 1-cubic meter cages the recommended safe limit is about 73 kg (FAO [1976] cited in [3]).

TABLE VI
COST-MINIMIZING INPUT LEVEL

Input	Sample Mean	Cost-Minimizing Level
Fingerlings (pcs/cage)	3,070	2,908 (22.06)
Feed (kg/cage)	1,055	914 (21.19)
Capital (cage size in m²)	176	26 (6.33)

Notes: 1. Each jth input cost-minimizing level was calculated as

$$X_j^* = \frac{\partial TC(P, Q)}{\partial P_j},$$

where $TC(P, C)$ is the frontier total cost function; P_j is the jth input price.
2. Values in parentheses are asymptotic t-values.
3. Sample size=57.

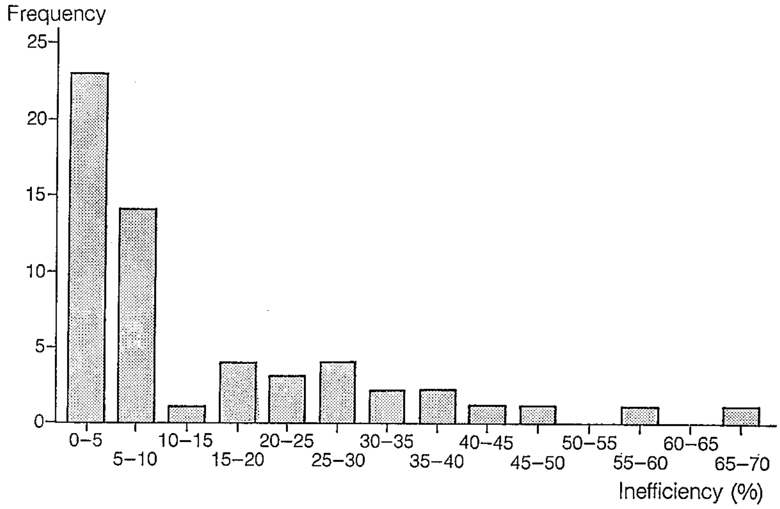
any recommendation of increasing the stocking density must take several other factors into consideration. One is that the existing mesh size of the nets used in Sampaloc Lake (23.44 millimeters) must be increased to promote good water circulation; however with larger mesh size, fingerling size at stocking must also be increased to prevent fish from escaping (from Table I it can be seen that Sampaloc Lake has the smallest fingerling size at stocking). With a larger mesh size, a larger number of fish and a smaller cage size, a more efficient method of feed application is necessary to avoid potential losses (feed could easily be washed out of the cage due to strong water movement created by the fish during feeding).

It should be emphasized that the cost-minimizing stocking density corresponds only to the existing average output level and it does not imply that this output level is optimal. To elucidate this point, the optimum stocking density, as computed from our previous paper, is about 367 fingerlings/m^2 which is associated with an output level (3,664 kg) that is about seven times higher than the existing average output level (535 kg).[13] This implies that the stocking density of 112 fingerlings/m^2 can still be increased further if the optimal output level is to be attained.

Regarding feed, the cost-minimizing level is lower than the sample mean by about 13 per cent. Considering the relatively large proportion of total feed cost to total cost (67 per cent), a 13 per cent reduction will definitely lead to a substantial decrease in total cost. This confirms our earlier conjecture that feed losses exist. On a per square meter basis, the cost-minimizing feeding rate ($914\text{ kg} \div 26\text{ m}^2 = 35.15\text{ kg/m}^2$) is about six times higher than the existing average rate ($1{,}055\text{ kg} \div 176\text{ m}^2 = 5.99\text{ kg/m}^2$) when the stocking density is increased by about seven times. In effect, the feeding rate per fish almost remains the same.

[13] Tan and Higuchi [11] calculated the optimum yield and input levels from the Cobb-Douglas productivity function, $Y = 0.24X_9^{0.7}X_{13}^{0.3}$, where Y is yield (kg/m^2); X_9 is stocking density (piece/m^2); and X_{13} is feeding rate (kg/m^2). The computed values were: 367 fingerlings/m^2 (optimum stocking density); 3.03 kg/m^2 (optimum feeding rate); and 20.82 kg/m^2 (optimum yield). The optimum output level, 3,664 kg, was derived by multiplying the optimum yield by the existing average cage size ($20.82\text{ kg/m}^2 \times 176\text{ m}^2$).

Fig. 2. Histogram of the Inefficiency Levels of Fishcage Farmers in Sampaloc Lake



That is, on a per fish basis, the cost-minimizing feeding rate (914 kg ÷ 2,908 fingerlings = 0.31 kg/piece) differs only slightly with the prevailing average feeding rate (1,055 kg ÷ 3,070 fingerlings = 0.34 kg/piece). And similar to the cost-minimizing stocking density, the cost-minimizing feeding rate corresponds only to the existing average output level. While the optimum feeding rate (3.03 kg/m^2, see footnote 13) which we have derived in our previous paper indicates that there is more room for further reduction in feed cost, we believe that this area requires further empirical study. Fish nutritionists are still looking for ways of reducing feed cost particularly in fish culture operations in lakes (or in open water in general). Particularly in the tropical regions fish have access to occasionally significant amounts of nutrient from natural sources which should be a good basis for employing a mixed feeding schedule (a combination of low and high protein feed) rather than a standard (high protein feed) feeding schedule.

E. *Inefficiency and Its Determinants*

To say that a fishcage farmer is incurring a cost which is 10 per cent more than what he should (given output level), we need to know what the minimum possible cost is. The percentage that fishcage farmers rise above the total cost frontier is the percentage of their inefficiency. The average inefficiency level was found to be about 14 per cent.[14] Figure 2 shows the histogram of the inefficiency

[14] For the purpose of capturing the degree of bias caused by the insignificance of the estimates of α_{44}, α_{QQ}, α_{13}, α_{23}, α_{3Q}, and α_{4Q} to the economic inefficiency estimate, these parameters were set to zero and the economic inefficiency was estimated and compared to that of the

TABLE VII

PARAMETER ESTIMATES OF INEFFICIENCY DETERMINANTS

Determinants	Estimate	t-value
Intercept	−2.86635	−1.57954
Fish size at harvest (pcs/kg)	−0.47958	−1.33664
Fishfarmers' experience in cage culture operation (year)	−0.00954	−0.10746
Farm size (m^2)	0.11412	1.16365
Hired labor cost / total labor cost (P)	0.34642	3.46980
Cage size (m^2)	2.49281	10.29070
Culture period (day)	2.50748	10.00620
Feed (kg)	1.24372	6.16402
Fingerlings (pcs/cage)	−3.44767	−11.70280
$R^2=0.83$		

Note: Parameters were estimated using the log-linear (Cobb-Douglas) function. Sample size=57.

levels of the fishcage farmers, and about 35 per cent of the sample operators have inefficiencies above the 10 per cent level.

We regressed inefficiency on several possible explanatory variables, and after several testings, the log-linear function provided a better fit over the multiple linear function. Five explanatory variables were found highly significant with stable coefficients: hired labor share, cage size, culture period, feed, and fingerlings (Table VII). Cage size, fingerlings, and culture period affected inefficiency the most and at almost the same level of magnitude (i.e., the value of coefficients and t-values are about equal). The negative coefficient of fingerlings means that stocking density must be increased. These verify our hypothesis.

We also made a comparison of inefficiency by cage size and stocking density (i.e., samples were divided on the bases of actual cage size and stocking density distribution). In general, inefficiency increases by about 7 per cent for every 100 m^2 increase in cage size, and inefficiency decreases by about 6 per cent for every ten fingerlings increase in stocking density.

Regarding the culture period, one might consider the trade-off between the additional cost incurred and the possible gain in fish weight for every additional day in the culture period. However, while cost is already taken to increase arithmetically per day, the biological growth in fish follows the pattern of diminishing returns. In other words, the initial exponential growth rate cannot proceed indefinitely even with continuous increases in input application. And as far as the cost of capital service is concerned, the longer the fish are kept inside the cage, the higher the cost that will accrue on the particular culture period. Further-

non-zero case. The average economic inefficiency index [(actual cost − frontier cost) ÷ actual cost] of the zero-parameter value case was 13.65, while that of the non-zero case was 13.97. Both differences were small. Clearly the insignificance of these parameters did not produce a bias in the estimation of economic inefficiency.

more, considering the relatively short life span of cages (averaging two years), potential revenues from the next culture periods will also be restrained.

The positive contribution of hired labor (cost share in total labor cost) to inefficiency further strengthens our supposition that feed losses arise from the inefficient method of application due to the less enthusiastic attitude of hired laborers compared to that of the risk-taking owners.[15] However we do not ignore the possibility that the method of feed application in general may be inefficient, be it done by hired labor or by the fishcage owners themselves.

The positive coefficient of feed means that there is overutilization of this input relative to the quantity of fish raised. The results of including fish size at harvest (as a management decision variable) in the regression function provide important insights into the art of tilapia cultivation. Two points will clarify this statement: first, its negative coefficient implies that inefficiency could be reduced by having more fish per kilogram harvested (smaller fish). If we talk about yield per se, given stocking density, the only way we can achieve higher yield is by having larger fish which means fewer fish per kilogram. However, if we take cost into account, it is better not to maximize yield, which is often the case. One logical way of doing this is by reducing the culture period, ceteris paribus, which is very much in accord with the effect of culture period on inefficiency. The only problem is how to determine the optimum time at which to harvest the fish. Related to this is the second point we want to raise which is the extent that fish can be harvested while still smaller in size. A fishcage farmer who is engaged in a restaurant business commented that based on his observation, the people who eat in his place prefer tilapia weighing about 250 grams each (four fish per kilogram) or less but not more than eight pieces per kilogram. This means that the weight or size of the fish matters. Since the existing average number of fish harvested per kilogram is already about five pieces, based on the size preference of the buyers, there will be less room for minimizing inefficiency through fish size reduction unless more efficient growth is achieved over a shorter culture period.

The experience of fishcage farmers (in years) was also studied, and it turned out to be insignificant implying that the technology can easily be transferred to anyone interested in it. The total farm size (total area of cages owned) of the fishcage farmers was also considered, and this likewise turned out to be insignificant.

V. CONCLUSION

Amid the growing concern over the actual and perceived effects of overcrowding in Sampaloc Lake's fishcage operations, we have substantiated with strong evidences that such overcrowding can be remedied without necessarily reducing the number of existing fishcage farmers while at the same time significantly improving

[15] The share of hired labor was expressed relative to total labor cost, total variable cost, and total cost, and there were no significant differences between the three in terms of their effects on inefficiency and the other explanatory variables.

their yield and their income. Our analytical approach concluded that the above could be done through significant cage size reduction and utilizing higher stocking densities. Raising productivity in accordance with both economic theory and the biophysical potentials and limits of the lake ecosystem while also ensuring the "security of expectation" of the fishcage farmers are considered good bases of conservation policy for Sampaloc Lake.

Nevertheless, experience will tell that bold ideas based on our findings will not easily gain acceptance from the immediate parties concerned (e.g., the fishcage farmers, particularly the members of the local cooperative, and the Laguna Lake Development Authority staff). One reason is that this is the first time (to our knowledge) that fishcage culture operation in a volcanic lake has been analyzed much beyond the usual descriptive cost and return analysis. Also, this study is the first attempt to measure the level of inefficiency of the individual fishcage farmer and, consequently, the application of stochastic frontier total cost function based on translog functional form. Being a pioneering study, we have no other information with which to compare our results. While there is no doubt of the appropriateness and superiority of the analytical approach we have applied in this paper to the still relatively meager economic studies on this subject matter, the seemingly radical changes needed to carry out our propositions would certainly trigger much controversy and skepticism among the concerned parties, especially among the fishcage farmers whose livelihood is at stake, and the Laguna Lake Development Authority since our findings run counter to their Fishery Zoning Plan to reduce the total area of cages in the lake while maintaining the prevailing cage sizes and keeping the stocking density at fifteen fingerlings/m^2. Much time will be needed to test our results, and the big challenge will be to convince the fishcage farmers to give up a big part of their cherished space in the lake. Furthermore, granted that this could be done, the next challenge will be how to keep them (and other potential investors) from constructing more units of cages considering that investment per cage will be lower. While the former is a matter of technology adoption, the latter concerns the crucial role of the government in enforcing operating guidelines and in protecting property rights.

Sampaloc Lake represents only 0.05 per cent (104 hectares) of the total lake area (200,000 hectares) in the Philippines, a large part of which is now experiencing the same problem of cage/pen congestion. In San Pablo City alone, the six other lakes in the area are suffering very much the same problems as those of Sampaloc Lake. We hope that in due time our findings will find their way into the fishcage operations of these lakes (considering the geographical advantage) and be used in the manner we have conceived them. Our predications might be regarded as exceptions rather than the norms to be followed for the time being. However, given the dilemma at hand and the inevitable tragedy confronting the current situation, in the absence of a better strategy, we deem it worth the try.

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APPENDIX

DISTURBANCE STRUCTURE SPECIFICATIONS

The joint density function of the cost and cost-share disturbances is

$$\lambda(\omega,\ \varepsilon)=\frac{\sqrt{\sigma^{uu}\cdot\sigma^{LL}(u)\cdot\sigma^{FIFI}(L)\cdot\sigma^{KK}(FI)}\cdot[1-F^*(A)]}{\sqrt{1+\sigma_v^2\cdot\sigma^{uu}}\cdot[1-F^*(z_{bu})]}\cdot\Pi_j f^*(z_j),$$

$j=u,\ L,\ FI,$ and $K,$

where

$$\Sigma^{-1}=\begin{bmatrix} \sigma^{uu}, & \sigma^{uL}, & \sigma^{uFI}, & \sigma^{uK} \\ \sigma^{uL}, & \sigma^{LL}, & \sigma^{LFI}, & \sigma^{LK} \\ \sigma^{uFI}, & \sigma^{LFI}, & \sigma^{FIFI}, & \sigma^{FIK} \\ \sigma^{uK}, & \sigma^{LK}, & \sigma^{FIK}, & \sigma^{KK} \end{bmatrix},$$

$$\sigma^{LL}(u)=\sigma^{LL}-\frac{(\sigma^{uL})^2}{\sigma^{uu}},\quad \sigma^{LFI}(u)=\sigma^{LFI}-\frac{\sigma^{uL}\cdot\sigma^{uFI}}{\sigma^{uu}},$$

$$\sigma^{LK}(u)=\sigma^{LK}-\frac{\sigma^{uL}\cdot\sigma^{uK}}{\sigma^{uu}},\quad \sigma^{FIFI}(u)=\sigma^{FIFI}-\frac{(\sigma^{uFI})^2}{\sigma^{uu}},$$

$$\sigma^{FIK}(u)=\sigma^{FIK}-\frac{\sigma^{uFI}\cdot\sigma^{uK}}{\sigma^{uu}},\quad \sigma^{KK}(u)=\sigma^{KK}-\frac{(\sigma^{uK})^2}{\sigma^{uu}},$$

$$\sigma^{FIFI}(L)=\sigma^{FIFI}(u)-\frac{[\sigma^{LFI}(u)]^2}{\sigma^{LL}(u)},$$

$$\sigma^{FIK}(L)=\sigma^{FIK}(u)-\frac{\sigma^{LFI}(u)\cdot\sigma^{LK}(u)}{\sigma^{LL}(u)},$$

$$\sigma^{KK}(L)=\sigma^{KK}(u)-\frac{[\sigma^{LK}(u)]^2}{\sigma^{LL}(u)},$$

$$\sigma^{KK}(FI)=\sigma^{KK}(L)-\frac{[\sigma^{FIK}(L)]^2}{\sigma^{FIFI}(L)},$$

$$z_u=\sqrt{\frac{\sigma^{uu}}{1+\sigma_v^2\cdot\sigma^{uu}}}\left(\omega+\frac{\sigma^{uL}\cdot\varepsilon_L+\sigma^{uFI}\cdot\varepsilon_{FI}+\sigma^{uK}\cdot\varepsilon_K}{\sigma^{uu}}\right),$$

$$z_L=\sqrt{\sigma^{LL}(u)}\left[\varepsilon_L+\frac{\sigma^{LFI}(u)\cdot\varepsilon_{FI}+\sigma^{LK}(u)\cdot\varepsilon_K}{\sigma^{LL}(u)}\right],$$

$$z_{FI}=\sqrt{\sigma^{FIFI}(L)}\left[\varepsilon_{FI}+\frac{\sigma^{FIK}(L)\cdot\varepsilon_{FI}}{\sigma^{FIFI}(L)}\right],$$

$$z_K=\sqrt{\sigma^{KK}(FI)}\cdot\varepsilon_K,$$

$$z_{bu}=\sqrt{\sigma^{uu}}\left(\frac{\sigma^{uL}\cdot\varepsilon_L+\sigma^{uFI}\cdot\varepsilon_{FI}+\sigma^{uK}\cdot\varepsilon_K}{\sigma^{uu}}\right),\ \text{and}$$

$$A=\frac{-\dfrac{\omega}{\sigma_v^2}+\sigma^{uL}\cdot\varepsilon_L+\sigma^{uFI}\cdot\varepsilon_{FI}+\sigma^{uK}\cdot\varepsilon_K}{\sqrt{\dfrac{1}{\sigma_v^2}+\sigma^{uu}}}.$$