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Microeconomics of Existing Aquaculture Production Systems: Basic Concepts and Definitions

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The main objective of this paper is to provide an introduction to the methodology used in the case studies that follow. The paper focuses on the role of relative prices in farmers' production behaviour and presents a model for explaining output variations among farmers. In the context of this production mode, the concepts of output elasticity, economies of scale, and technical and economic efficiency are explained using illustrative examples. The type of data used and the estimation techniques are briefly described and the distinction between average and frontier production functions is emphasized.

A typical aquaculture resource system (Fig. 1) has subsystems of procurement, transformation, and delivery (Ruddle and Grandstaff 1978). The procurement subsystem includes the factor markets for stocking materials (seed or fry) and other inputs, such as land, water, labour, feed, fertilizer, and managerial expertise. Many aquaculture systems are dependent upon wild fish stocks to provide fry for stocking in rearing enclosures, although hatcheries are becoming increasingly important for certain species. The transformation subsystem includes the production process by which seed stock is reared to marketable size. Finally, the delivery subsystem includes the various marketing intermediaries and consumers, both domestic and foreign.

The concepts and terminology to be discussed are drawn primarily from neoclassical production economics theory. In the case studies, attention will be directed to addressing such questions as: Which inputs are significant in explaining variation in output from various aquaculture producers? Are there economies of scale in aquaculture production? (If all inputs are doubled, will output also double, or more than double, or less than double?) Are producers making optimal use of inputs? Are they technically and economically efficient? What constraints inhibit increased productivity and profitability of existing aquaculture resource systems?

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The Underlying Biological/Economic Relationship in Production

Output from an aquaculture production system is a function of the inputs applied in the production process. The level of output depends upon environmental factors (soil pH, water salinity, etc.), stocking rates, supplementary inputs (feed, fertilizer, pesticide), labour (hired and family), managerial expertise, and the underlying technology used. The deep water pond system for rearing milkfish in Taiwan using the "plankton" method, for example, is a different technology from the shallower ponds of the Philippines that use the filamentous algae method. The relationship between inputs and output is commonly referred to as the production function, and much of production economics dwells on methods of determining this physical input-output relationship, adding an economic component, and interpreting producer behaviour based on the results.

Output, then, is a function of variable and fixed inputs. By examining progressively complex representations of this relationship, it is possible to establish the link between (and differences between) biological and economic considerations of aquaculture producers.

Let us begin with the simple unconstrained case (no capital constraint) of one output and a single variable input. This case can be illustrated in a two dimensional diagram (Fig. 2) where output (e.g., fish) is dependent upon the quantity

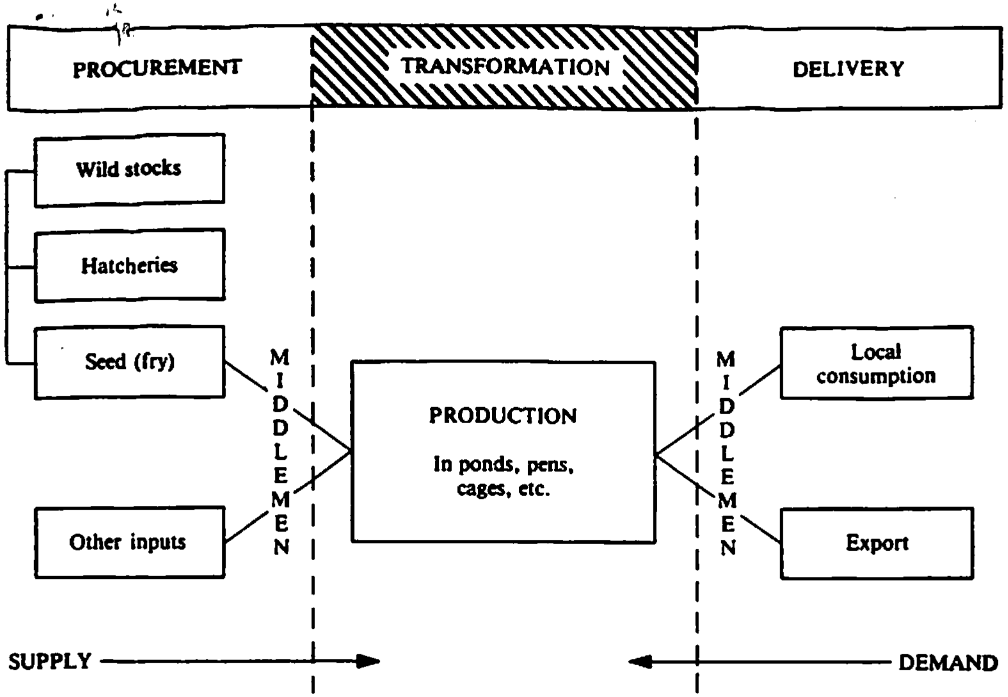

Fig. 1. A simplified aquaculture resource system.

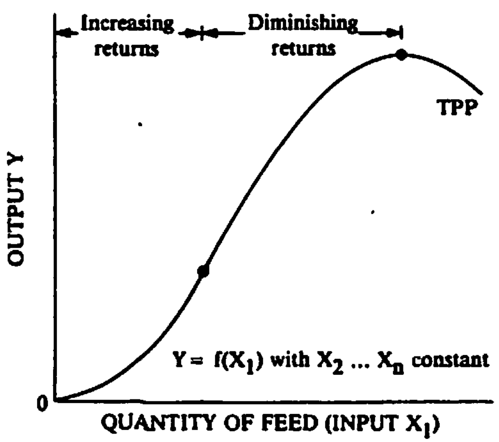

Fig. 2. Input/output with single variable input in short run (TPP = total physical product).

of input X_1 (e.g., feed) used. All other inputs have been held constant. As additional quantities of feed are applied, total physical product (TPP) as shown on the production response curve first increases at an increasing rate (increasing returns), then increases at a decreasing rate (diminishing returns), and finally, with excessive feeding, actually declines. This phenomenon of diminishing returns is best illustrated by the fact that if it did not exist, we could produce from a single small fishpond sufficient fish to feed the world. This single variable input case can also be expressed mathematically as:

$$Y = f(X_1) \text{ with } X_2 \ldots X_n \text{ constant}$$

where Y = output; X_1 = variable input; and $X_2 \ldots X_n$ are fixed inputs.

When two variable inputs (e.g., stocking rate and feed) are applied to the fishpond, we can represent the production response surface with a three-dimensional diagram (Fig. 3). This particular diagram shows diminishing returns over its full range. Three production isoquants, CC, DD, and EE, reflect the output attainable with various combinations of the two variable inputs. For example, 1000 kg of output can be attained with either high quantities of feed and low stocking rates or with lower quantities of feed and higher stocking rates. In other words, there is a certain degree of substitutability among inputs whereby output is not affected. This single output, two variable input case can be expressed mathematically as:

$$Y = f(X_1, X_2) \text{ with } X_3 \ldots X_n \text{ constant}$$

where Y = output; X_1, X_2 = variable inputs; and $X_3 \ldots X_n$ are fixed inputs.

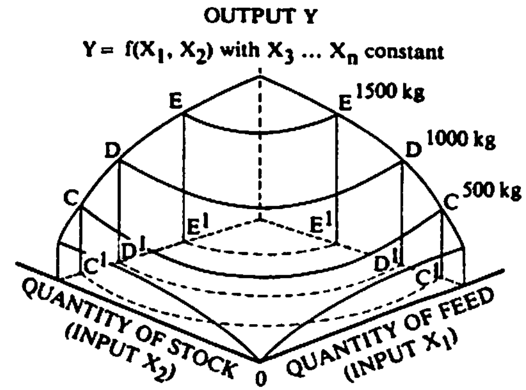

Fig. 3. Output as a function of two variable inputs (adapted from Hirshleifer 1976).

When three or more variable inputs are applied to the fishpond, it is no longer possible to depict the relationship between output and inputs using a diagram. Mathematically, however, we can express the relationship as:

$$Y = f(X_1, X_2, X_3 \ldots X_n)$$

where Y = output; and $X_1 \ldots X_n$ are variable inputs.

To this point we have been referring to output in terms of total physical product (TPP). The average physical product (APP) and the marginal physical product (MPP) curves, which are necessary to determine the rational range of input use and production for the aquaculture producer, can be derived from the production function. The relationships among these three curves are shown in Fig. 4. Point A is the point of diminishing returns (the inflection point) and thus the point at which MPP is at its maximum. Average physical product (APP) at this level of input application is, however, still increasing so it makes sense for the producer to increase the use of the variable input, at least to reach point B where APP is at its maximum. Point B thus defines the boundary between production area I and II, or the beginning of the area of rational economic production. With continued increase in use of the variable input, point C will eventually be reached where MPP reaches zero, and TPP begins to decline. Beyond this point is area III, an irrational area of production, because the same output can be achieved at lower levels of input use and cost. Area II is thus known as the area of rational economic production. To be able to determine the exact input level the producer should use, we need to introduce costs, returns, and profits to our theoretical model.

So far we have been referring to a purely biological or technical relationship. The production function per se is devoid of economic meaning, but it is the basic building block for the economic analysis to follow. Incorporation of the economic element can best be illustrated by an example (see Table 1).

Let us assume that we are dealing with a small production system with a 0.1 ha pond where fish (in kg) is the only output and where the single variable input is feed (in bags of 20 kg each). All other inputs (land, labour, stocking rate, etc.) are assumed to be fixed, bags of feed are available in unlimited quantity, and the producer has no capital constraint. Feed is assumed to have a constant cost (P_x) of $8.00/bag, and the farmgate price (P_y) for fish is $2.00/kg. We assume that the output price does not change in response to increases in output from our small producer. The small producer is a price taker in a competitive market. The question the fish farmer is trying to answer is: "How many bags of feed should I apply to maximize my profits from fish production?"

Maximum profits ($40) are earned when five bags of feed are used. At lower levels of input use, the value of the marginal physical product (VMP or marginal revenue) obtained from each added input is greater than the marginal costs (P_x) of the added input. The marginal revenue from the sixth bag equals its marginal cost so the profit is unchanged. Beyond six bags of feed, the marginal

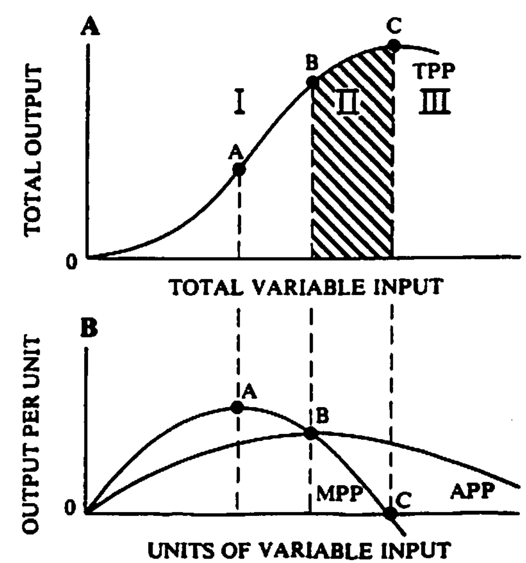

Fig. 4. The production function and some of its derivatives (from Snodgrass and Wallace 1970), where TPP = total physical product, APP = average physical product, and MPP = marginal physical product.

Table 1. Hypothetical data showing profit maximizing principle when inputs are unlimited.

Bags of feed	Total physical product (TPP)	Average physical product (APP)	Marginal physical product (MPP)	Value of the marginal physical product (VMP = MPP·Px)	Marginal cost (Px) ($)	Total revenue (TR) ($)	Total cost (TC) ($)	Profit (TR - TC) ($)
0	0	0				0	0	0
			6	12	8			
1	6	6				12	8	4
			7	14	8			
2	13	6.5				26	16	10
			(11)	22	8			
3	24	8				48	24	24
			10	20	8			
4	34	(8.5)				68	32	36
			6	12	8			
5	40	8				80	40	(40)
			4	8	8			
6	44	7.3				88	48	40
			1	2	8			
7	(45)	6.4				90	56	34
			-1	-2	8			
8	44	5.5				88	64	24
			-2	-4	8			
9	42	4.6				84	72	12

Note: Maximum values for TPP, APP, MPP, and profit are enclosed within parentheses. Adapted from a similar example in Snodgrass and Wallace (1970).

cost exceeds the marginal revenue. In other words, the producer should keep adding inputs as long as the additional revenue obtained exceeds the additional cost.

The same decision regarding optimal input use can be obtained graphically. Figure 5 illustrates this same example, and makes clear the relationship between the underlying production function and the economically determined level of optimum output and input use. Note that profits are maximized in the upper figure (a) when the difference between total revenue (TR) and total costs (TC) is at its maximum. As shown in the lower figure (b) this is achieved when the value of the marginal product (VMP) is equal to the input price (P_x), or the marginal cost of the added input.

Mathematically, this means that profits will be maximized when VMP = P_x and because VMP = MPP·P_y, one can determine the profit maximizing level of input use by equating the marginal physical product to the input/output price ratio: MPP = P_x/P_y.

There are several interrelated conclusions from this unconstrained case:

(1) *Maximizing production does not maximize profits.* In our example, maximum production is achieved with seven bags of feed, but profits are lower at $34 than the $40 obtained from using only five bags of feed. Maximum profits are, therefore, obtained at lower levels of output and input use than those that maximize production.

(2) *The profit maximizing decision rule is based on marginal principles.* A producer who bases his production decisions upon average or total production and revenue principles will earn less profit than a producer who uses the marginal analysis described above.

(3) *The level of fixed costs does not influence the decision of the producer regarding optimal use of the variable input.* Note that the producer's decision is based upon a comparison of the marginal revenue and marginal cost of the variable input. Producers will continue to produce as long as they cover their variable costs.

The preceding example refers to an unconstrained case; that is where the producer has unlimited capital. In real life, of course, capital and other constraints usually do exist, and in the long run, producers have the option of using their limited resources for several alternative production processes. The marginal principle for maximizing profits, however, still applies. Fish farmers will maximize their profits if they use their limited resources (e.g., capital) in such a way that the marginal returns from the various activities are equal. In this way, the opportunity cost of their capital (i.e., the cost of the alternative foregone) does not exceed its value in the use chosen.

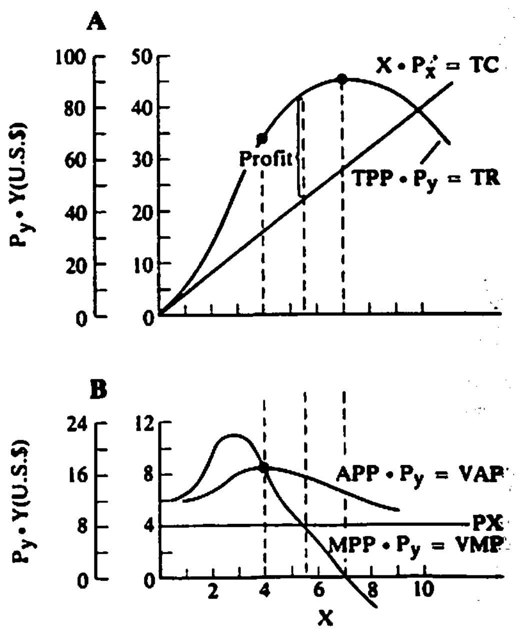

Fig. 5. Hypothetical revenue and cost curves (TPP = total physical product, APP = average physical product, MPP = marginal physical product, VAP = value of the average product, VMP = value of the marginal product, TC = total costs, and TR = total revenue).

Production Functions: Estimation and Interpretation

The approach to production economics described in the preceding section is known as the neoclassical approach. First, the physical relationship between inputs and outputs is estimated, and then marginal analysis is employed to evaluate producer behaviour. It is assumed that the production function is continuous; that is, the marginal physical product can be derived from the production function through differential calculus. There are four distinct steps in the neoclassical approach: specification, data collection, estimation, and interpretation.

Specification

Specification of the model chosen to describe the production process depends in great measure upon the researcher's assumptions about the underlying biological relationships in the production process. Decisions must be made regarding: (1) which explanatory variables to include: and (2) the appropriate function form.

The underlying production process in aquaculture systems is not in fact a direct input to output relationship. In milkfish ponds, for example, output is only indirectly related to certain inputs, such as fertilizer, because output is a function of algae growth, which is in turn a function of the fertilizer applied to the pond. In this case, the correct production function would relate functions to functions rather than things to things (Garrod and Aslam 1977). Other inputs, however, such as seed stock and supplementary feed, are directly related to output. Because it is difficult to accurately and easily measure algae growth in milkfish ponds during a survey, the most common procedure is to assume a direct relationship between fertilizer and output. In this paper, we will deal only with production functions that directly relate various inputs (the explanatory variables) to output (the dependent variable). One of our purposes is to explain, as much as possible, the variation in output observed from farm to farm.

In biological experiments it is customary to hold all variables constant, except the one for which the biologist is interested in determining the effect on output. In the social laboratory in which economists operate, however, such controlled experimentation is not possible. With no variables controlled, the production function must be estimated from a host of explanatory variables.

For aquaculture production functions, we may wish to consider including some or all of the following inputs or explanatory variables: stocking rates; fertilizer; feed; pesticide; labour; land (or rearing area); environmental factors (soil pH, water salinity); management (expertise of operator); and dummy variables (e.g., for location). However, this is not an exhaustive list.

We can then develop hypotheses regarding the significance of each of these variables (and all of them taken together) in explaining variation in output. It is common practice to standardize the explanatory variables to account for differences in farm size. For example, the explanatory variables could all be expressed in terms of input quantity per hectare (for ponds) or per cubic metre (for cages). Each variable must be homogeneous; that is, fertilizers of various qualities should not be combined in a single variable. There is no fixed formula, however, to guide the researcher in the choice of explanatory variables for inclusion in the model being specified. Biologists should be consulted for their opinions so that in a priori fashion, the explanatory variables can be selected.

Dummy variables may also be included to account for differences (in location or climate for example) that cannot readily be quantified. A dummy variable takes the value of 1 or 0 depending upon whether the farm in question falls in the particular category or not. The presence of significant differences in output by climate type or location can then be tested for in a manner similar to that used for testing for the significance of the other quantifiable explanatory variables.

The management variable poses serious difficulties because it is hard to quantify the expertise of the aquaculture producer. One possible solution is to use a proxy variable, such as education level, as a measure of management expertise. Another solution is to treat the residual (the unexplained variation) after estimation of the production function as a measure of management. However, this is not entirely satisfactory because the residual or error term also includes the effects of all other variables not included in the model.

Once the researcher has chosen the relevant explanatory variables to include in the model, the next step is to specify the functional form to be used, that is, the form of the relationship between inputs and output. Four alternative functional forms are shown in Table 2. Of these four, the first two deserve only brief mention. The first, the linear form, is most commonly used in linear programing models and these are not discussed in this paper. The second form, the quadratic, shown as the special case where all but one explanatory variable are held constant, describes a parabola and is probably familiar to most biologists. The third and fourth functional forms, the Cobb-Douglas (C-D) and the constant elasticity of substitution (CES) functions, are those that have been traditionally favoured by production economists.

Table 2. Traditional forms of the production function.[a]

Linear

$$Y = A + \beta_1 X_1 + \beta_2 X_2 \ldots + \beta_n X_n$$

Quadratic (single input case)

$$Y = A + \beta_1 X_1 - \beta_2 (X_1)^2$$

Log-linear (Cobb-Douglas or C-D)

$$Y = A X_1^{\beta_1} X_2^{\beta_2} \ldots X_n^{\beta_n}$$

or

$$\log Y = \log A + \beta_1 \log X_1 + \beta_2 \log X_2 \ldots + \beta_n \log X_n$$

Constant elasticity of substitution (CES)

$$Y = \gamma[\delta X_1^{-p} + (1 - \delta) X_2^{-p}]^{-\frac{1}{p}} \qquad (p > -1)$$

[a]Y = output; X_i = inputs; β_i = factor (input) productivities; and A, γ, δ, p are constants. Error terms are omitted.

The C-D function, which is linear in its logarithmic form, has several advantages that have made it attractive. (1) The elasticities of production, which measure the responsiveness of output to increased units of input, are identical to the production coefficients (β_i). Consequently, a percentage change in output that is brought about by a given percentage change in input use can be easily determined. (2) The sum of the production coefficients ($\Sigma\beta_i$) can be interpreted as a measure of economies of scale.[2] If $\Sigma\beta_i > 1$, for example, positive economies of scale exist. This implies that a doubling of the use of all inputs will result in more than a doubling of output. (3) Unlike the linear and quadratic forms, which preordain the shape of the production surface, the unconstrained C-D form can describe a production surface that demonstrates increasing, unitary, or decreasing returns to scale, depending upon the data. (4) Input and output data can readily be used, without aggregation (as in the CES function) to estimate the parameters of the model. (5) Unlike the quadratic form, which uses up two degrees of freedom for each added variable, a C-D function that includes no interaction terms uses only one degree of freedom per explanatory variable.

The C-D production function is actually a special case of the CES function in that in the C-D function, the elasticity of substitution[3] among inputs is constrained to unity. In the CES function, the elasticity of substitution can be any constant value. Because this permits the empirical data to determine the degree of substitutability among inputs, some researchers (Miller et al., undated) have claimed that the CES production function is theoretically superior to the C-D formulation. In contrast, "in the C-D form, the relative input shares remain unchanged, even with a change in relative input prices and input ratios, because the elasticity of substitution between inputs is forced to unity" (Garrod and Aslam 1977, p. 21). Although the CES production function thus has some inherent theoretical advantages over the C-D, it is difficult to apply if more than two inputs are to be used. The usual technique is to aggregate all explanatory variables into the two inputs of capital (K) and labour (L).

The balance of the discussion in this paper is based upon the Cobb-Douglas production function.

[2]Assuming that the $\Sigma\beta_i$ is not constrained to unity as in the original Cobb-Douglas case where

$$Y = A X_1^{\beta_1} X_2^{(1-\beta_1)}$$

[3]The elasticity of substitution shows the proportional change in the capital-labour ratio induced by a given proportional change in the input (factor) price ratio (Ferguson 1972).

Data Collection

The explanation of output variation through a production function requires that data be collected from a sufficiently large number of farms to allow reliable estimation of parameters. A minimum sample size of 30 is often established, so that adequate degrees of freedom are maintained.[4] Data on inputs, output, prices, and costs can be obtained from: (1) many aquaculture farms for a single production cycle; (2) one farm over numerous production cycles; or (3) many farms over time. These data types are, respectively: cross-sectional data; time-series data; and time-series of cross-sections (Garrod and Aslam 1977). The last of these data types is the most desirable, but due to costs of obtaining a time-series of cross-sections, it is rarely available. Most common at the current stage of aquaculture economics research is cross-sectional data gathered from a (sometimes) randomly chosen sample of producers. Because so few producers have records to share with the researchers, the two most common methods of data collection are recall questionnaires and record-keeping forms. The former method is particularly susceptible to measurement errors in quantifying the input used and output attained. Other measurement errors can also occur if the interviewer or the fish farmer fails to correctly delineate one input from another, say differences in quality of various supplementary feeds. The decision of what data type (time-series or cross-section) and collection methods to use is most often determined by the limited budgets available to researchers.

Estimation

Production functions are usually estimated using standard multiple regression techniques, in particular the ordinary least squares (OLS) method. The OLS method fits a line to the data by minimizing $\Sigma (Y_i - Y_e)^2$, the sum of the squares of the distances from the observed data points to the fitted line (Fig. 6).

An important distinction must be made between a "frontier" production function and the "average" production function that is estimated using the OLS method (Garrod and Aslam 1977). As shown in Fig. 7, the "frontier" production function is derived by connecting the points of maximum output for each level of input. It thus represents the most technically efficient input-output combinations. The estimated production function, on the other hand, is an industry "average" function because it is derived by OLS methods that take into account all observed input-output combinations, not only the most technically efficient. Consequently, the average production function, though describing the average aquaculture firm in the system, does not represent the maximum possible output obtainable from a set of inputs. To determine the maximum productive capacity of aquaculture systems, a frontier production function should be used.

[4]Each additional explanatory variable included in the model reduces the degree of freedom by at least 1.

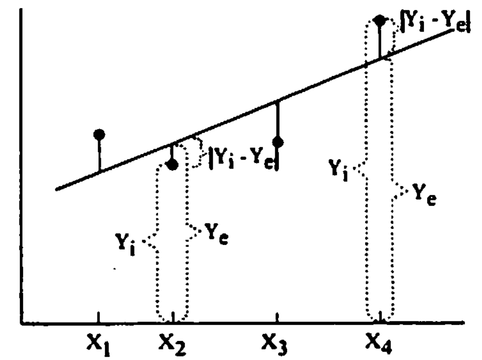

Fig. 6. Fitting a line using ordinary least squares (OLS) method (adapted from Alder and Roessler 1972).

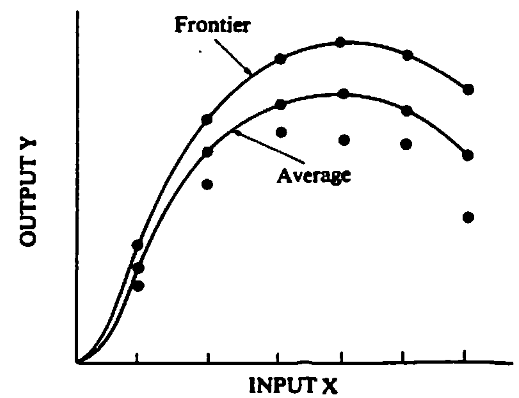

Fig. 7. Comparison between "frontier" and "average" production functions, single variable input case.

One specific estimation problem deserves particular mention. The problem of multicollinearity occurs when explanatory variables are highly correlated and produces biased estimates of the production parameters. Although some researchers (Rao and Miller 1971) claim that multicollinearity is more of a theoretical rather than an empirical problem, the applied researcher needs a decision-rule to decide if the degree of multicollinearity is serious enough to warrant discarding the specified model and starting again. One approach is to examine the simple correlations among the independent variables and eliminate from the model any that are highly linearly interrelated. A second approach is to plot the residuals (the difference between the observed Y_i and the estimated $\hat{Y}_i$) against the independent variables to look for any systematic distribution of the deviations around the regression line. However, despite some success with these approaches, no hard-and-fast rule seems to have been devised to deal with the potential multicollinearity problem. Fortunately, with larger sample sizes, the multicollinearity problem is reduced (but not eliminated).

Before leaving the topic of estimation, mention should be made of step-wise regression. This is a technique for entering the independent variables into the model in order of their contribution to the "explained" variation in the dependent variable. In this fashion, the most important explanatory variables are included first, and the researcher can then drop out of the model those explanatory variables that are less important. This approach is generally not recommended unless the researcher is working with a small sample. Each dropped variable will increase the degrees of freedom, an important consideration when sample size is small (e.g., < 30).

Interpretation of Results

Before interpreting the results obtained from the estimated production function, it is necessary to examine the function for its ability to "explain" output variation. Two interrelated measures of "goodness of fit" are known as the correlation coefficient (R), and the coefficient of determination (R^2). The maximum possible value for R^2 is 1.0, which implies that 100% of the output variation is explained by the estimated function. In applied research using cross-sectional data, one would not expect to find such a high value for R^2. The F-test is usually used to test the overall significance of the independent variables chosen for inclusion in the model. The sign test can also be applied to determine if each of the production coefficients (β_i) has the expected positive or negative sign. Finally, t-tests are used to test the significance of the individual production coefficients.

Let us examine a hypothetical example of a C-D production function to interpret the results. A three input case is shown in Table 3. The variables are defined as follows, with mean values and prices as shown:

Variable	Mean value	Price ($)
X_1 = stocking rate (thousands/ha)	5	30.00
X_2 = feed (bags/ha)	6	25.00
X_3 = labour (man-days/ha)	9	2.00
Y = fish output (kg/ha)	367	2.00

The mean value for output (367 kg/ha) is calculated by substituting the mean input values into the production function and solving for Y.

In Table 3, the R^2 value is 0.8; therefore, 80% of the variation in output is explained by the three independent variables. All coefficients (β_i) have the expected positive sign. The coefficients of two of them (X_1 and X_2) are significantly different from zero at the 1% level according to the t-test.[5] The coefficient of the last input (X_3) is not significantly different from zero. The output or production elasticities are 0.3, 0.2, and 0.5, respectively. A 10% increase in input X_1, for instance, will produce a 3% increase in output, and so on. Because the sum of the coefficients equal 1.0, unitary economies of scale exist; a doubling of all three inputs will double output.

An important question yet to be answered is: "Are producers, on average, economically efficient?" In other words: "Is their use of inputs optimal in terms of maximizing their profits?" To answer this question it is necessary to calculate the marginal physical product of each of the variable inputs and compare it with the input-output price ratio:

$$MPP_{X_i} \gtrless \frac{P_{X_i}}{P_y}$$

If MPP is greater than the price ratio, use of the input should be increased. If MPP is less than the price ratio, use of that input should be reduced. Equality implies producers, on average, are economically efficient. To calculate the MPP of each input from the production function, partial differentiation is used with all variables, except the one being differentiated, entered into the production function at their geometric mean.

[5] H_o: $\beta_1 = 0$ and H_o: $\beta_2 = 0$ are rejected. H_o: $\beta_3 = 0$ is not rejected.

Table 3. Hypothetical Cobb-Douglas production function.[a]

$Y = 50X_1^{0.3}X_2^{0.2}X_3^{0.5}$			$R^2 = 0.80$; $F = 35.00^b$
log Y = log 50 + 0.3 log X_1 + 0.2 log X_2 + 0.5 log X_3			
s.e.	(0.10)	(0.05)	(0.30)
$t = \beta_i$/s.e.	3.00^b	4.00^b	1.67
Output elasticities	0.3	0.2	0.5
Economies of scale = $\Sigma\beta_i = 0.3 + 0.2 + 0.5 = 1.0$			

[a] X_1 = stocking rate; X_2 = feed; X_3 = labour; and Y = output.
[b] Significant at 1% level.

In the example of Table 3, the MPP of input X_1, for example, would be calculated as follows:

$$\begin{aligned} Y &= 50\, X_1^{0.3}\, X_2^{0.2}\, X_3^{0.5} \\ \partial Y/\partial X_1 &= 50(0.3)X_1^{-0.7}\, X_2^{0.2}\, X_3^{0.5} \\ &= 50(0.3)\,(5)^{-0.7}\,(6)^{0.2}\,(9)^{0.5} \\ &= 50(0.3)\,(0.32)\,(1.43)\,(3.0) \\ &= 20.59 = \text{MPP of input } X_1 \end{aligned}$$

$$\text{The price ratio } P_{x_1}/P_y = \frac{30.00}{2.00} = 15$$

Because MPP $> P_{x_1}/P_y$ (e.g., $20.59 > 15$), the use of input X_1 on the "average" farm should be increased. This can also be concluded from the fact that the value of the marginal product (VMP = MPP·P_y = \$41.18) is greater than the marginal cost (P_{x_1} = \$30.00) of the additional unit of input. Marginal physical products for the other two inputs would be calculated in a similar manner, and their use either increased or decreased depending upon the relationship between the MPP and the respective price ratio.

The preceding discussion has focused on the Cobb-Douglas production function and its interpretation. There are numerous other functional forms that can be used to analyze production, costs, and profits. As in agricultural economics, these somewhat more sophisticated approaches will undoubtedly find favour with aquaculture economists in the years to come.

Marketing Subsystems

Brief mention should be made also of some basic aquaculture marketing concepts. Just as in production economics, there are numerous alternative approaches to analyzing marketing or delivery subsystems. Four major approaches are known as: (1) functional approach; (2) institutional approach; (3) organizational approach; and (4) price-efficiency approach.[6] The functional approach examines the important marketing functions of exchange (buying and selling), physical handling (storage, transportation, and processing), and facilitation (standardization, financing, risk bearing, market intelligence). The institutional approach studies the various agencies and intermediaries that perform the marketing process. Both of these approaches are essentially descriptive. The organizational approach attempts to link the structure of the market (concentration ratios, barriers to entry, product differentiation) to the conduct of intermediaries (price determination and competition) and the performance of the subsystem (profit margins, technical efficiency, progressiveness). This approach has most often been used in comparisons among various industrial marketing systems. Finally, the price-efficiency approach examines the role of prices and their allocative functions in terms of space, time, and form.

It is useful to mention the major principles and definitions. In Fig. 8 a very simple marketing or delivery subsystem is shown. The output from aquaculture producers moves through marketing channels, representing product flows, first to wholesalers, then to retailers, and finally to consumers.

The prevailing price at the farmgate (P_f) is related to the consumer price (P_c) by the marketing costs of intermediaries. Under conditions of perfect competition, the difference between the consumer and farmgate prices, known as the marketing margin, should over time on average equal the sum of all the marketing costs involved. Marketing costs include not only direct costs but also implicit costs, such as opportunity costs of the marketing inputs and a reasonable return to marketing intermediaries for their risk and management expertise. Arbitrage among various trading regions should keep the marketing costs roughly equal to the price differential as long as conditions approximating perfect competition (freedom of entry and exit, perfect information about supply and demand) exist. Analysis of marketing subsystems frequently focuses upon assessing departures from the norms of perfect competition.

[6] For discussion of the first and second see Kohls and Downey (1972); of the third see Bain (1968); and of the fourth see Bressler and King (1970).

$$P_f + \text{Marketing costs of middleman} = P_c$$

$$P_c - P_f = \text{Markup/Margin}$$

Fig. 8. Basic marketing concepts. Under perfect competition, differential between farmgate price (P_f) and the retail price (P_c) should equal the marketing costs of all middlemen, including a reasonable profit.

Conclusion

The production economics methodologies outlined in the preceding sections lead to conclusions that are primarily of interest to the policymaker. It would be unwise for a researcher to use the estimated production function to advise an individual farmer on optimum input levels because what is needed is location-specific advice. More than just ecological differences (soil, climate, etc.) are involved. A technology package may make sense in one area where input/output prices reveal marginal returns greater than marginal costs; in another area where the prevailing input/output prices are different, profits of producers may even be lowered by adopting the new technology. It is these location-specific differences that make technology packaging so very difficult and adaptation to locally prevailing conditions so expensive. However, progress can be made if biologists can determine the production response of different technologies and economists can evaluate the effect on producer profits. The need for this kind of teamwork is a strong argument in favour of interdisciplinary approaches to aquaculture research and development.

Analyses of existing aquaculture systems help us to understand the technical and socioeconomic environment in which producers operate and into which improved technologies are to be introduced. Depending upon the stratification of the sample, important differences between groups of producers can also be identified. Moreover, if through a production economics study, a group of existing producers are shown to be economically efficient, given the prevailing prices, it is hardly surprising that they do not adopt a new, allegedly superior technology. Production economics studies may then force us to discard our often held view that producers are somehow "irrational."

In the introduction to this paper, it was stated that producers respond to relative economics of various production alternatives, given their available resources. A production economics study of a specific aquaculture system is only the first step in revealing these relative economics and the producers' response. What are needed are similar studies of the alternative systems (for other aquaculture species, for example) or even of alternative use of the land (for grain production, for example).

Aquaculture economists are following in the footsteps of agricultural economists who have faced many of the same questions regarding efficiency, optimum farm size, and technology transfer that we are currently grappling with. It would not be inaccurate to characterize current aquaculture economics work as experimental in that we are still testing methodologies that have been used extensively in agriculture. Further refinements, particularly along the lines of cost and perhaps profit functions, and whole systems analysis would be very worthwhile undertakings. It would be unfortunate if we do not relate our efforts to the experience and insights of those who have gone before. The writings of Theodore W. Schultz, distinguished agricultural economist and Nobel prize winner, should be required reading for everyone interested in technological change. (See, for example, Schultz 1966.)

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