AN ANALYSIS OF THE UNITED STATES DEMAND FOR FISH MEAL

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ABSTRACT

As fishery management plans are developed under the Fishery Conservation and Management Act of 1976, economic evaluation of management procedures will be necessary. To adequately address the economics of optimum yield, for instance, research will be required in the traditional economic subjects of demand, production and costs, industrial organization, and international trade. This paper addresses the domestic demand for the primary industrial fishery product—fish meal. In developing the demand model the important points are: 1) choice of empirical variables for inclusion in the model, 2) determination of appropriate functional form of the demand equation, 3) treatment of the "simultaneity bias" problem, and 4) choice between a static (or equilibrium) model and a dynamic model. The paper presents maximum likelihood estimates of both the static and dynamic models. With either model the price elasticity of demand is high when fish meal price is low, and is low when price is high.

Analysis of prices and market demand relationships for fish is of increased importance since the enactment of the U.S. Fishery Conservation and Management Act of 1976 (FCMA[2]). The new law not only establishes a zone of Federal control over fisheries from 3 to 200 mi offshore, but it also establishes national standards for fishery management plans which include economic and social aspects. A key concept is that of "optimum yield"—that rate of annual catch "which will provide the greatest overall benefit to the Nation" (FCMA, Sec. 3(18)). Economic benefits to the nation accrue primarily through the consumption of fishery products which are sold in more-or-less free and competitive markets. Market prices can be expected to vary in response to changes in the annual yields permitted under fishery management plans. These price impacts, along with associated changes in real income, cannot be neglected in the development of appropriate management methods. The demand analysis presented in this paper will assist in the determination of optimum yield for fisheries which contribute to the U.S. fish meal supply.

Fish meal is a primary product of the Atlantic and Gulf of Mexico menhaden fisheries and the California anchovy fishery. It also appears as a byproduct of groundfish and tuna processing. It is used as a high protein supplement most commonly mixed with corn, soybean, or cottonseed meal; meat byproduct meal; and vitamins and minerals for feeding to broilers, layers, and turkeys. According to J. Vondruska,[3] fish meal is also used in feeds for mink and other fur-bearing animals, farmed fish, laboratory animals, livestock, and household pets. About 80% of fish meal consumed in the United States goes into poultry feed. A high level of metabolizable energy and such nutritional elements as riboflavin, pantothenic acid, niacin, choline, and several amino acids are contributed to animal feed by the addition of fish meal (Karrick 1963). Most of these constituents are available in high protein vegetable meals, but fish has a particularly high concentration of the amino acids lysine and methionine.

Because the lysine and methionine are necessary for fast growth in chicks, feed mixers generally seek to include between 2 and 8% fish meal in broiler rations. With >8% fish meal, the poultry tends to pick up a "fishy" flavor. With <2% fish meal, further substitution of vegetable protein meals for fish meal will result in slower growth because the fixed quantity of feed eaten per day per chick cannot contain the ideal mix of amino acids. When fish meal is extremely high priced or

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[2]Public Law 94-265, 94th Congress, 2d Session 13 April 1976, 16 USC 1801 et seq. (Suppl. 1977). Hereafter, FCMA.

[3]J. Vondruska. 1979. Postwar production, consumption, and prices of fish meal. Unpubl. manuscr., 66 p. National Marine Fisheries Service, 3300 Whitehaven St., N.W., Washington, DC 20235.

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unavailable, the lysine and methionine content of the feed can be augmented with synthetic proteins. Kolhonen (1974) described the development of synthetic methionine and lysine for use in feed formulas.

Linear programming has been widely adopted by formula feed manufacturers in the United States and western Europe (Kolhonen 1974). Least-cost combinations of feed constituents needed for adequate nutrition are quickly and accurately computed for any vector of constituent prices. Thus, the demand for feed ingredients is expected to exhibit great sensitivity to relative prices. In a recent examination of demand for agricultural feed ingredients, Meilke (1974) reported that price elasticities are generally >2 in absolute value. It is expected that the demand for fish meal will be elastic also, at least when available quantities allow the feed formula manufacturers to include between 2 and 8% fish meal in poultry rations. When the supply of fish meal is low enough to jeopardize the maintenance of at least 2% fish meal, the demand may become inelastic. Thus, one hypothesis to be tested is that the own price elasticity of demand for fish meal falls with increasing price and decreasing quantity.

Markets for fish meal in the United States are, for obvious reasons, concentrated in the poultry-producing regions—California, Arkansas, and states in the Deep South. Domestic production of fish meal occurs mainly in California, the Gulf Coast States, and the South Atlantic States. In some years, however, much of the domestic supply is imported from major foreign producers such as Peru. Foreign meal is a perfect substitute for the domestic product, but the supply of foreign meal has undergone tremendous fluctuations due to variations in fish stocks (especially the Peruvian anchoveta, *Engraulis ringens*). Domestic supplies have also been strongly influenced by uncontrolled variations in domestic stocks (especially menhaden *Brevoortia tyannus* and *B. patronus*) and by administrative decisions of fishery management agencies (California's anchovy, *Engraulis mordax*, fishery, e.g., see Pacific Fishery Management Council 1978: 31660-31664). On the supply side of the domestic market, therefore, the major fluctuations are not price induced, but are due to exogeneous factors. On the demand side the poultry industry experienced a steady expansion starting in the early 1950's and continuing until about 1970.

DEVELOPMENT OF DEMAND MODEL

Demand and price analysis has been a cornerstone of applied economic research since the 1930's (Working 1927; Schultz 1938; Wold and Juréen 1953). Agricultural economists have been particularly active in developing demand models for commodities. Research on demand for fish is of more recent vintage but differs in few important respects from that for agricultural commodities. For an excellent review of the historical development of demand analysis, see Waugh and Norton (1969). Among the methodological issues addressed in applied demand studies are: 1) specification of the demand model, 2) development of appropriate functional forms, 3) treatment of simultaneity bias in market demand and supply function estimates, and 4) incorporation of dynamic response mechanisms in the demand model. These issues are discussed seriatim.

Specification

The specification of a demand model consists of the choice of dependent and independent variables. Annual quantity demanded, as measured by quantity purchased, should be the dependent variable. Purchased quantities are difficult to obtain, however, while production, import, and export statistics are well documented. Also, meals derived from different sources differ in protein content and sell at different prices. Both the quantities and the prices must be aggregated such that they represent a reasonably homogeneous commodity. Fish meal quantities (Table 1, columns 1-6) are converted to a protein equivalent basis by multiplying the quantity of each type of meal by the prevailing percentage of protein content. The total available domestic quantity, computed by summation of protein equivalent fish meals and subtraction of exports, is listed in Table 1, column 7. Similarly, since the prices of the various fish meal types (Table 2, columns 1-4) are based on protein content, each price is converted to a protein basis. The aggregate price of fish meal introduced as an independent variable in the demand model is the average price per unit protein for all meal supplied to the U.S. market (Table 2, column 5). Some specification error may enter the model because domestic supply rather than quantity purchased is used for the dependent variable, but this problem is unavoidable with available information.

TABLE 1.—United States fish meal supplies, 1955-76 (thousands of metric tons). (National Marine Fisheries Service 1975, 1977.)

Year	(1) Men-haden	(2) Tuna	(3) An-chovy	(4) Other[1]	(5) Im-ports	(6) Ex-ports	(7) Total supply protein basis[2]
1955	172.9	21.2	0.0	37.6	88.9	n.a.[3]	195.8
1956	191.1	23.9	0.0	44.1	82.0	n.a.	207.5
1957	156.4	23.3	0.0	51.3	73.7	n.a.	185.3
1958	143.4	23.0	0.0	50.2	91.1	n.a.	188.0
1959	203.1	23.0	0.0	43.1	120.6	n.a.	238.8
1960	198.1	24.0	0.0	33.1	119.4	n.a.	229.6
1961	224.6	19.2	0.0	28.8	197.6	n.a.	291.0
1962	217.5	24.1	0.0	31.5	228.9	n.a.	311.4
1963	167.1	24.5	0.0	33.4	341.4	n.a.	355.7
1964	145.4	19.1	0.0	39.6	398.3	n.a.	380.4
1965	159.7	23.0	0.0	37.3	245.5	n.a.	290.4
1966	122.5	23.0	4.1	42.9	406.2	n.a.	378.6
1967	108.1	23.1	5.1	46.5	591.0	n.a.	492.9
1968	129.9	26.1	2.5	47.4	775.9	n.a.	626.7
1969	144.7	24.4	10.3	42.1	325.1	n.a.	343.6
1970	171.1	24.2	14.7	23.2	227.8	4.3	284.9
1971	200.4	26.6	6.9	22.7	256.9	9.2	314.4
1972	175.6	39.2	10.1	23.8	355.6	9.5	373.2
1973	171.3	39.6	20.0	22.4	62.1	33.3	171.4
1974	185.0	43.7	12.8	23.0	62.0	50.3	167.2
1975	173.6	33.7	25.1	20.9	107.4	10.7	215.0
1976	192.9	36.4	19.9	22.0	127.4	30.0	226.7

[1]Primarily from offal, waste, and scrap from groundfish and herring.
[2]Converted to protein as follows: menhaden, exports, and other meal assumed to be 60% protein; anchovy and imports assumed to be 65% protein; tuna meal assumed to be 55% protein. Total supply is production plus imports minus exports.
[3]n.a. means data not available.

TABLE 2.—Annual average prices for various fish meals and average price per unit of protein in fish meal in the United States. (National Marine Fisheries Service 1975.)

Year	(1) Men-haden	(2) Tuna	(3) Domestic anchovy	(4) Peruvian anchovy	(5) Average price per unit protein in fish meal: Actual[1]	Deflated[2]
	-------dollars per metric ton of meal-------					
1955	123.4	130.7	—	—	1.99	4.34
1956	121.7	121.7	—	—	1.97	4.16
1957	117.7	114.8	—	121.5	1.95	4.01
1958	125.0	124.8	—	128.2	2.01	4.19
1959	116.2	117.1	—	131.9	1.95	3.94
1960	84.4	86.0	—	86.1	1.39	2.80
1961	106.4	99.7	—	100.0	1.69	3.40
1962	112.6	109.5	—	111.2	1.81	3.64
1963	114.1	106.2	—	109.7	1.76	3.58
1964	119.3	115.8	—	119.7	1.88	3.81
1965	152.9	143.2	—	140.3	2.30	4.63
1966	146.1	134.4	137.3	141.9	2.23	4.33
1967	123.8	117.6	117.5	118.1	1.86	3.57
1968	131.8	114.2	110.7	118.8	1.88	3.53
1969	158.1	132.6	137.9	142.5	2.31	4.24
1970	167.4	155.4	156.0	176.4	2.72	4.72
1971	143.3	128.0	140.4	150.7	2.33	3.92
1972	168.3	141.4	154.1	162.6	2.59	4.15
1973	433.8	359.6	365.5	409.8	6.75	9.70
1974	250.5	245.5	270.3	260.6	4.15	4.99
1975	216.9	206.3	214.8	226.5	3.54	3.88
1976	314.3	347.8	247.5	309.9	4.92	5.15

[1]For each meal, price per unit protein equals price per ton divided by percent protein. Average price computed by weighting the price per unit protein for each meal by the proportion of U.S. fish meal protein supplied by that meal.
[2]Deflated by Wholesale Price Index, all commodities (January 1977 = 100).

In addition to the price of fish meal, the demand model should contain independent variables representing 1) the prices of close substitute products, 2) prices of complementary products, and 3) the level of production activity that governs the demand for fish meal. Several high protein meals (e.g., soybean, cottonseed, meat, and bone meals) are potential substitutes for fish meal in poultry rations. Soybean meal is the most common substitute, and its price is used as an independent variable in the demand model. The price of corn meal (Table 3, column 2) is introduced as a complementary product price. Demand for fish meal is expected to increase when the price of a substitute product increases, and is expected to decrease when the price of a complementary product increases. Finally, the overall production of poultry products would cause shifts in the level of demand for fish meal independently of the prices. The poultry and egg production index (Table 3, column 3) is adopted as the appropriate measure of this factor.

In summary, the fish meal demand model is specified as follows:

1) Quantity demanded, the independent variable, is represented by annual production plus net imports of protein-equivalent meal.
2) Annual price of fish meal is measured as the weighted average of the prices per unit protein for all domestically supplied meals.

TABLE 3.—Exogenous variables in the fish meal demand model.

Year	Price of domestic soybean meal[1]	Price of domestic corn[2]	Poultry and egg production index[3] (1976 = 100)
	-------dollars per metric ton------		
1955	51.6	2.24	58
1956	46.5	2.30	63
1957	42.7	2.06	64
1958	50.8	1.99	68
1959	51.3	1.94	70
1960	48.2	1.84	70
1961	57.3	1.80	75
1962	60.3	1 80	75
1963	65.8	2.00	77
1964	62.8	1.99	80
1965	64.9	2.07	83
1966	76.0	2.18	88
1967	69.4	2.06	92
1968	70.3	1.80	90
1969	67.6	1.96	92
1970	71.8	2.19	97
1971	70.7	2.15	98
1972	95.2	2.10	100
1973	216.3	3.57	97
1974	127.8	5.20	97
1975	112.6	4.71	94
1976	147.5	4.37	100

[1]Forty-four percent protein. Simple average price at Decatur, Ill., from National Marine Fisheries Service (1977).
[2]Price of No. 2 yellow corn, Chicago. USDA, ERS, Poultry and Egg Situation, PES-294, 1965-77.
[3]From Schultze et al. (1979).

3) Annual domestic price of corn and annual domestic price of soybean meal are introduced as complementary and substitute product prices.
4) The trend in aggregate demand over time is accounted for by the aggregate poultry and egg production in the United States.

All of the variables expressed in dollars are deflated by the Wholesale Price Index to eliminate spurious correlations caused by the inflationary trend.

Functional Form

Demand studies typically utilize least squares regression methodology with either a linear or a log-linear equation. As noted by Chang (1977), however, there is no a priori reason to choose one of these forms. Each form imposes some fairly strict conditions upon the characteristics of the demand function which may contradict theoretical considerations or actual experience. Linear equations imply that the elasticity of demand with respect to any independent variable is a decreasing function of that variable; a log-linear equation implies constant elasticities. Chang suggests that the income elasticity of demand for meat should fall with rising income. A similar consideration applies to fish meal demand. At low prices, feed manufacturers would use near maximum amounts of fish meal allowable and could easily substitute soybean meal for fish meal. With relatively high fish meal prices, feed manufacturers would use a smaller proportion of fish meal, but as price rises further it would be increasingly difficult to maintain desired quantities of lysine and methionine by substitution of soybean meal. Thus it is clearly unwarranted to rule out increasing price elasticity through a priori choice of functional form.

The function to be fitted by regression analysis can be chosen by determining the appropriate transformation of variables for the linear least squares procedure. The log-linear transformation is a special case of a parametric family of transformations introduced by Box and Cox (1964). The parameter defines the transformation

$$x^* = (x^\lambda - 1)/\lambda. \qquad (1)$$

Equation (1) is linear for $\lambda = 1$, and becomes logarithmic as λ approaches zero. The demand function is expressed as

$$q^* = b_0 + b_1 x_1^* + \ldots + b_k x_k^* + u \qquad (2)$$

where q is the quantity demanded, the x's are the independent variables affecting demand, u_t is a stochastic error term, and the b_i and λ are parameters to be determined. The superscript * indicates that the variable has been transformed as in Equation (1).

Price elasticity of demand is defined as the absolute value of the ratio of percentage change in quantity demanded to percentage change in price. Assuming that the first independent variable is the price, $E = \left|\frac{\partial q}{\partial x}\right| \cdot \left(\frac{x_1}{q}\right)$. From Equation (2) we get

$$E = |b_1| (q/x_1)^{-\lambda}. \qquad (3)$$

The elasticity defined in Equation (3) is an increasing function of x_1 when $\lambda > 0$, and is a decreasing function of x_1 when $\lambda < 0$. Thus the estimate of the transformation parameter λ provides a test of whether the price elasticity increases, decreases, or remains fixed along the demand curve.

Simultaneity Bias

In economic theory, the supply and demand curves interact to determine the market price. Over a period of time, shifts in both supply and demand factors cause the market price and observed quantities of products to vary. Without these shifts, only one price and quantity would be observed, making it impossible to estimate a demand or supply curve. When the demand curve remains stable, the observed price-quantity pairs "trace out" the demand curve with, of course, some stochastic error, and a regression analysis will result in a demand curve estimate. When the supply curve remains stable, the observed data will fall along the supply curve, and a regression analysis of the price-quantity relationship results in a supply curve estimate. If shifts in both demand and supply occur, the resulting data will not unambiguously identify either of these two curves, and an ordinary least squares regression will generally result in a set of parameters reflecting neither the supply curve nor the demand curve. In this case the estimated parameters are said to suffer from simultaneity bias.

The general statistical problems associated with estimation of individual structural relationships in a simultaneous equation system were first examined by Haavelmo (1943). Development of appropriate statistical methods for estimating simultaneous equation systems has been a major area of research for econometricians over the last two decades (Kmenta 1971). In estimating the demand curve for fish meal, however, direct regression estimates seem appropriate, because most of the observed variations in annual fish meal supplies are due to exogeneous shifts rather than price-induced movements along a stable supply curve. Production of fish meal is subject to wide fluctuations due to uncontrolled variations in the fish stocks exploited (Kolhonen 1974). At the same time, formula feed and poultry industries have remained relatively stable during the last 20 yr except for the secular growth accounted for in the analysis. Under conditions in which the random shifts in supply are much greater than the corresponding shifts in demand, the ordinary least squares procedure results in no significant simultaneity bias (Rao and Miller 1971).

Lagged Response Mechanisms

The use of annual price and quantity data for estimating the demand function requires that the response to a change in price occurs rather rapidly, at least within a period of time much shorter than a year. Since most domestic formula feed manufacturers employ professional nutritionists and cost-minimizing computer routines in calculating formulas, the response to changes in the vector of prices is probably rapid. If so, each annual quantity consumed may be assumed to represent at least approximately an equilibrium demand response to the set of independent variables. The assumption of rapid response and equilibrium approximation, however, has not been directly verified. In the interests of rigor it is useful, therefore, to consider alternative assumptions.

A lagged response to a change in price may occur due to rigidities in mixing procedures or personnel, inventory management problems, or time lags in renegotiating contracts for supply of input or sales of products. If any of these factors results in a sluggish response in the substitution between fish meal and other protein meals, the effect of a price change may be drawn out over several periods of time. A fairly simple model for representing a lagged response is the "partial adjustment model" originally developed by Nerlove (1958). Corresponding to any given level of the independent variable, p, there is an optimal or desired level of the dependent variable q. For a demand function with one independent variable, the level of demand fully adjusted to input prices by formula manufacturers represents the desired level of fish meal usage:

$$q_t^d = b\, p_t + u_t \tag{4}$$

where the superscript d signifies desired level.

Because purchasers of meal cannot immediately adjust to this desired level of usage, the demand Equation (4) is not directly observable. By assuming a simple structure to the adjustment process, however, an estimable equation is obtained. The partial model assumes that a fixed percentage of the adjustment to desired level is made each year. This introduces the difference equation

$$q_t - q_{t-1} = \gamma(q_t^d - q_{t-1}). \tag{5}$$

Solving this for q_t and substituting from Equation (4) yields

$$q_t = b\,\gamma\, p_t + (1-\gamma)q_{t-1} + \gamma u_t. \tag{6}$$

The adjustment parameter, γ, must be a positive number ≤ 1. Larger values of γ imply more rapid adjustment to changes in the independent variable. The impact of a unit change in p_t is distributed over time in an exponentially decaying fashion with successive annual changes in q being equal to $b\gamma$, $b\gamma(1-\gamma)$, $b\gamma(1-\gamma)^2$, and so forth. The ultimate change in q due to a change in p is

$$\Delta q = b\Delta p \sum_{j=0}^{\infty} \gamma(1-\gamma)^j = b\Delta p \tag{7}$$

where j = lag. The elements in the sequence under the summation sign are all positive fractions, and sum to one, so that the sequence can be treated like a probability distribution. Each element represents the percentage of the total effect occuring in year t, and the mean of the distribution, $(1-\gamma)/\gamma$, represents the mean lag in the adjustment process. Distributed lag models like that in Equation (4) result from other conceptual models such as models of expectations formation or habit formation. And the exponentially distributed lag is but one of a large class of more complex lag models (Griliches 1967; Kmenta 1971; Rao and Miller 1971).

Application of the partial adjustment model to the demand Equation (2) results in the following:

$$q^*_t = a_0 + \sum_{i=1}^{4} a_i x_i^* + a_5 q_{t-1}^* + u_t \qquad (8)$$

where the coefficients a_i can be interpreted in terms of the coefficients of Equation (2) as follows:

$$a_0 = \gamma b_0$$
$$a_i = \gamma b_i;\ i = 1, \ldots 4$$
$$a_5 = (1 - \gamma).$$

STATISTICAL PROCEDURES

For a given value of the transformation parameter, λ, the coefficients of either the equilibrium model [Equation (2)] or the partial Adjustment model [Equation (8)] can be estimated by the ordinary least squares method. Two statistical issues requiring further development, however, are the selection of the "best" value for λ, and the test for significance of the lagged adjustment parameter. An appropriate procedure for estimation of λ was first suggested by Box and Cox (1964). The procedure is more clearly explained in the linear regression context by Kmenta (1971) and is reviewed by Chang (1977). For a fixed value of λ, the linear regression procedure yields an estimate of the error variance $\hat{\sigma}^2$. Box and Cox showed that the maximized log likelihood is, except for a constant,

$$L_{\max}(\lambda) = -(N/2) \log \hat{\sigma}^2(\lambda) + (\lambda - 1) \Sigma \log q_i. \quad (9)$$

A maximum likelihood estimate of λ can, therefore, be found by searching through successive values of λ to maximize Equation (9). The use of this likelihood function implies, of course, that the error terms conform to full normal theory assumptions, i.e., that the u_t are independently normally distributed with zero mean and constant variance. An approximate 100% $(1 - \alpha)$ confidence region for λ is defined by

$$L_{\max}(\hat{\lambda}) - L_{\max}(\lambda) < \tfrac{1}{2} \chi_1^{\,2}(\alpha) \qquad (10)$$

where $\chi_1^{\,2}(\alpha)$ represents the value of the chi-square distribution with 1 df (Box and Cox 1964).

Serial correlation in the errors of the regression model raises problems in the interpretation of the test statistics for the nonlagged variables and the lagged adjustment parameter, and contradicts the assumptions of the log likelihood function. Careful examination of the hypotheses and statistics regarding the residuals of the regression equation is clearly necessary. Existence of serial correlation in the errors of the static demand model can be tested with the Durbin-Watson statistic. If no serial correlation is apparent in the residuals, then neither the distributed lag model nor the serial correlation model need be considered. If serial correlation is present in the residuals of the static model, then the problem is to distinguish between the distributed lag model and the serial correlation model.

Griliches (1967) showed that the serial correlation and lagged adjustment models cannot be distinguished by a simple t-test on the adjustment parameter. For example, if errors generated by a first order Markov process, i.e., $e_t = se_{t-1} + u_t$, occur in a regression equation, the coefficients of the lagged variables may be judged significant by the usual t-test even though there is no real lagged response in the underlying structural relationship. Similarly, it can be shown that serially correlated residuals will occur if a nonlagged model is mistakenly fit to data from an inherently dynamic process.

Although there is no fully satisfactory method for determining which model is the truth, Griliches (1967) developed a provisional test. Briefly, the serial correlation model is

$$q_t = a_0 + \sum_i a_i x_{it} + e_t \qquad (11a)$$

$$e_t = se_{t-1} + u_t \qquad (11b)$$

where s is a positive fraction and u_t is a nonserially correlated error term. From Equation (11a), $e_{t-1} = q_{t-1} - a_0 - \Sigma_i a_i x_{it-1}$; so that $e_t = s(q_{t-1} - a_0 - \Sigma_i a_i x_{it-1}) + u_t$. Substituting this into Equation (11a) yields

$$q_t = (1 - s)a_0 + \sum_i (a_i x_{it} - b_i x_{it-1}) + s\, q_{t-1} + u_t. \quad (12)$$

When Equation (12) is computed, the serial correlation model implies that $a_i s = -b_i$ for each i. Griliches suggested that the first-order serial correlation model be rejected if these four equalities do not appear to hold. Thus, there are four hypotheses of the following form:

$$H_0\colon (b_i + sa_i) = 0. \tag{13}$$

An approximate sample variance for $(b_i + sa_i)$ is computed by the "delta method" described by Seber (1973). The expression for approximate variance of a function of a vector of random variables, $G(x)$, is

$$\mathrm{v}[G(x)] = \Sigma v(x_i)\left(\frac{\partial G}{\partial x_i}\right)^2$$

$$+\,2\sum_{i<j}\sum \operatorname{cov}(x_i\,x_j)\left(\frac{\partial G}{\partial x_i}\right)\left(\frac{\partial G}{\partial x_j}\right). \tag{14}$$

Assuming that the estimate of $(b_i + sa_i)$ from the regression equation is approximately normally distributed, the following ratio will be approximately distributed as an F-statistic with 1 and $(n - r)$ df (where r is the number of regression parameters estimated):

$$(b_i + sa_i)^2/\mathrm{v}[b_i + sa_i] \approx F(1, n - r). \tag{15}$$

Since the serial correlation model requires each of the four hypotheses to hold, a definite rejection of one or more of the hypotheses may be taken as evidence against the serial correlation model and in support of the partial adjustment model. Because of the lack of rigor in the suggested testing procedure, however, caution must be exercised in drawing conclusions.

RESULTS

Ordinary least squares estimates of the static demand Equation (2) were computed for a range of values for the transformation parameter λ. The regression coefficients and statistics of most interest are listed in Table 4. A value of $\lambda = -0.55$ maximizes the log likelihood function, but the 95% confidence interval for λ is 0.2 to -1.4. The interval includes the logarithmic transformation ($\lambda = 0$), but not the linear transformation ($\lambda = 1$). The negative value of λ, which implies a price elasticity of demand that decreases as quantity decreases, conforms to expectations. The signs of all the coefficients are also consistent with prior expectations; demand is diminished by increasing price of fish meal or corn meal, and is increased by increasing price of soybean meal and by expanding poultry and egg production. Application of t-tests to the coefficients of the equation with $\lambda = -0.55$ indicates statistical significance with 99% confidence for the coefficients of fish meal price and corn meal price, and with 90% confidence for the coefficient of soybean meal price. The poultry and egg production index appears to be an insignificant influence on fish meal demand by the t-test. But this is insufficient reason for eliminating a theoretically important variable from the equation.

The squared multiple correlation coefficient, $r^2 = 0.73$, indicates a reasonably "good fit" for a demand equation estimate from time-series data.

TABLE 4.—Regressions for determining maximum log-likelihood of static demand function. P_f = price of fish meal, P_s = price of soybean meal, P_c = price of corn feed, Q_p = poultry and egg production index. Superscript * indicates Box-Cox transformation expressed in Equation (1).

Transformation parameter (λ)	Intercept	Coefficient P_f^*	P_s^*	P_c^*	Q_p^*	R^2	D-W[1]	$L\max(\lambda)$
0.5	44.184	−10.144	9.588	−8.597	0.816	0.695	0.754	−91.21
[2]0.2	12.499	−2.620	2.174	−2.532	0.545	0.714	0.716	−89.70
0.0	6.054	−1.064	0.812	−1.125	0.413	0.722	0.704	−88.97
−0.20	3.324	−0.432	0.305	−0.501	0.311	0.727	0.705	−88.48
−0.50	1.731	−0.112	0.071	−0.150	0.199	0.730	0.725	−88.14
[3]−0.55	1.592	−0.089	0.056	−0.123	0.184	0.730	0.731	−88.13
	(5.108)	(−2.602)	(1.864)	(−3.489)	(0.976)			
−0.60	1.474	−0.071	0.044	−0.100	0.171	0.730	0.735	−88.14
−0.70	1.282	−0.455	0.027	−0.067	0.146	0.729	0.751	−88.18
−1.0	0.929	−0.012	0.007	−0.020	0.088	0.724	0.801	−88.56
−1.2	0.789	−0.005	0.003	−0.009	0.061	0.719	0.839	−89.02
[2]−1.4	0.687	−0.002	0.001	−0.004	0.042	0.711	0.879	−89.61

[1]D-W stands for Durbin-Watson statistic.
[2]Indicates approximate 90% confidence interval for λ.
[3]Indicates maximum likelihood estimate (t-values in parenthesis).

The Durbin-Watson statistic (0.731) is below the lower critical value (d_l = 0.86 for 21 observations and 4 parameter estimates), indicating significant serial correlation in the errors of the demand model. As suggested above, this serial correlation may be caused by incorrect specification of a static model when a dynamic adjustment model would be more appropriate, or it may reflect true serial correlation in the errors which may in turn be due to some other source of misspecification.

Following the suggestion by Griliches (1967), a regression equation with lagged dependent and independent variables was computed (Table 5). The F-statistics for the four hypotheses associated with the serial correlation model range from 0.119 to 6.516. The critical value for each hypothesis (with $P<0.05$ and for 1 and 11 df) is 4.84. Clearly, only one of the four hypotheses, the one associated with the soybean price, can be rejected with great confidence. Even this may be misleading, because the probability of wrongly rejecting at least one of four hypotheses at the 5% level is 0.183[4]. Due to the provisional nature of the test procedure and the inconclusiveness of the result, it is useful to consider both the static and distributed lag models as plausible representations.

The distributed lag model [Equation (8)] was estimated by ordinary least squares for several values of the transformation parameter λ. Regression coefficients and pertinent statistics for the distributed lag model are listed in Table 6. The log-likelihood function is greatest for λ = −0.3, and the approximate 95% confidence interval for λ is −1.0 to 0.22. As in the earlier nonlagged model, the coefficients of the independent variables have the appropriate signs. Since the coefficient of the lagged dependent variable can be interpreted via Equation (5) as one minus the rate of adjustment parameter, the partial adjustment parameter is 0.503. This implies an average lag of slightly less than one. As expected, buyers of fish meal generally adjust to changing conditions and prices within a year.

[4]The probability of type 1 error in a single test is 0.05. If four tests are made the probability of making at least one type 1 error is one minus the probability of making no type 1 errors, i.e., $1 - (0.95)^4$.

TABLE 5.—Estimates for demand function parameters with all variables lagged.[1] Transformation parameter, λ, equals −0.55; and all symbols are as explained in Table 4. R^2 = 0.855.

Variable	Estimated coefficient	SE	F-statistic[2]
$P_f^*(t)$	−0.07521	0.03208	0.455
$P_f^*(t-1)$	0.01861	0.03258	
$P_s^*(t)$	0.07498	0.0297	6.516
$P_s^*(t-1)$	0.03765	0.03609	
$P_c^*(t)$	−0.2059	0.07897	0.119
$P_c^*(t-1)$	0.1159	0.04239	
$Q_p^*(t)$	1.3352	0.5497	4.006
$Q_p^*(t-1)$	−1.5422	0.5309	
$q^*(t-1)$	˙0.5164	0.1979	—

[1]$q^*(t) = a_0 + a_1P_f^*(t) + b_1P_f^*(t-1) + a_2P_s^*(t) + b_2P_s^*(t-1) + a_3P_c^*(t) + b_3P_c^*(t-1) + a_4Q_p^*(t) + b_4Q_p^*(t-1) + a_5q^*(t-1)$.

[2]The hypothesis to be tested is $(b_i + a_i a_s) = 0$; and the corresponding F-statistic is $F_i = (b_i + a_i a_s)^2/\mathrm{Var}(b_i + a_i a_s)$.

DISCUSSION

Both the static demand model and the partial adjustment model provide reasonable levels of statistical fit to the historical data series and the signs and magnitudes of the regression

TABLE 6.—Regression equations for determining maximum log-likelihood of distributed lag form of demand function. P_f = price of fish meal, P_s = price of soybean meal, P_c = price of corn feed, Q_p = poultry and egg production index, q_{t-1} = quantity of fish meal, lagged. Superscript * indicates Box-Cox transformation expressed in Equation (1).

Transformation parameter (λ)	Intercept	Coefficient P_f^*	P_s^*	P_c^*	Q_p^*	q_{t-1}^*	R^2	$L_{max}(\lambda)$
1.0	297.904	−103.141	105.367	−21.018	0.694	0.468	0.766	−81.133
0.6	40.639	−16.897	13.097	−3.821	0.537	0.485	0.800	−83.953
0.1	4.122	−1.792	0.902	−0.482	0.389	0.498	0.822	−81.507
0	2.761	−1.147	0.522	−0.323	0.363	0.499	0.824	−81.259
−0.2	1.373	−0.470	0.170	−0.147	0.314	0.498	0.825	−81.014
[1]−0.3	1.030	−0.301	0.098	−0.100	0.291	0.497	0.824	−81.013
	(1.396)	(−3.567)	(1.161)	(−0.840)	(1.189)	(2.907)		
−0.4	0.809	−0.193	0.056	−0.068	0.268	0.494	0.822	−81.090
−0.5	0.665	−0.124	0.031	−0.047	0.247	0.491	0.819	−81.239
−1.0	0.404	−0.013	0.002	−0.008	0.153	0.458	0.795	−82.853

[1]Indicates maximum likelihood estimate (t-values in parentheses).

coefficients satisfy prior expectations. Because it yields a significantly higher r^2, and because the test for serial correlation suggested by Griliches (1967) lends it support, I tend to favor the distributed lag model. But the evidence is not really conclusive. For one thing, the "Griliches test" looks only for first-order serial correlation, and it will probably fail to give correct guidance when more complex residual generating processes are present. Another difficulty is the lower precision of the regression coefficients in the distributed lag model. The importance of this depends upon how the demand function is to be used. In fisheries management applications the most important use of the demand model will be for predicting price effects resulting from changes in annual production.

To compare the two demand models, the equations are transformed to give quantity demanded in natural units (tons of fish meal proteins) and the 1976 values of independent variables other than fish meal price are inserted. The resulting relationships between price and quantity are

TABLE 7.—Demand predictions ($\hat{q}$) and price elasticities (E) for static demand ($\lambda = -0.55$) and partial adjustment ($\lambda = -0.3$) models.

Price of fish meal protein (P_f)	Static demand model		Partial adjustment model	
	$\hat{q}$	E	$\hat{q}$	E
2	852.5	2.49	4,971.0	6.26
4	295.2	0.95	372.3	2.34
6	215.1	0.64	168.8	1.63
8	182.8	0.50	110.7	1.32
10	165.0	0.42	84.2	1.14

for the dynamic demand model. Quantities predicted by Equations (15) and (16) and price elasticities of demand for a range of prices are listed in Table 7. From the Table and Figure 1 it is clear that the two demand models are grossly similar. At low supply levels (less than about 250 t), however, the predicted price responses are greatly different, as are the quantities demanded when prices are low (<\$4 per unit protein). Thus, any conclusions reached on the basis of this demand analysis will be sensitive to the specification of the demand function.

$$q_t = \left[-0.00389 + 0.04916\left(\frac{P_f^{-0.55} - 1}{-0.55}\right)\right]^{\frac{1}{-0.55}} \qquad (16)$$

for the static demand model, and

$$q_t = \left[-0.03486 + 0.18001\left(\frac{P_f^{-0.3} - 1}{-0.3}\right)\right]^{\frac{1}{-0.3}} \qquad (17)$$

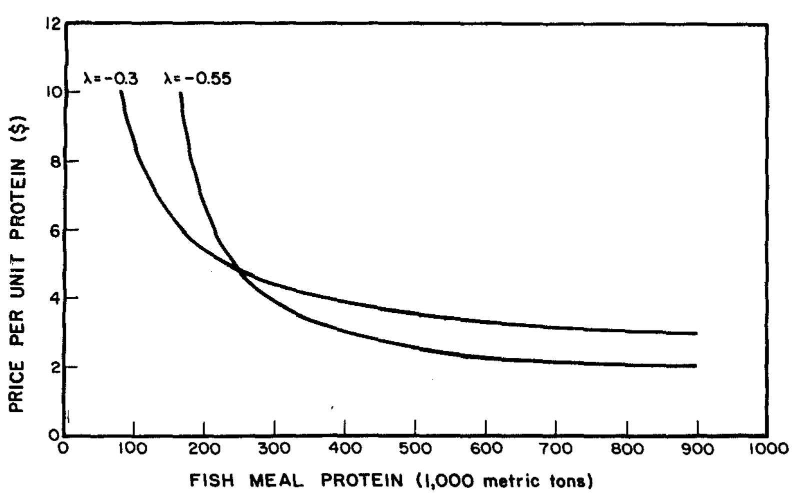

FIGURE 1.—Fish meal demand curves based upon the maximum likelihood estimates of the static demand model ($\lambda = -0.55$) and the partial adjustment model ($\lambda = -0.3$).

Most economic models of fishery management have ignored the influence of landings on the price of fish or fishery products. The assumption of fixed price is a particularly attractive one, because with fixed prices the harvest quantity is proportional to the total revenue. Only the relationship between costs and landings must be added to the model in order to derive economic critertia for optimization. When management programs control landings which are large relative to the market demand, however, the price is likely to become a variable rather than a fixed parameter. The use of demand relationships, such as the one estimated above, will undoubtedly become important as more control is exercised over more fisheries in the United States. The means for incorporating demand analysis into fishery management models is explained by Anderson (1973) and Clark (1976, chapter 5). More extensive use of these complex models which include variable prices will proceed only as fast as the development of solid, empirical demand studies.

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