STOCK ADJUSTMENT MODELS OF CANADA'S OFFSHORE GROUNDFISH FISHERIES

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1. Introduction[1]

The effects of man's exploitation of fisheries resources have been rather difficult to assess. The main reason for this is that the underlying resource, the fish population, is not known neither are its growth rates or natural mortality. Biologists have attempted models of this exploitation based on factors which are known and measurable, namely catch and fishing effort data. These models have provided the starting point of economic models where both supply and demand have been introduced. This paper will concentrate however on a bio-economic supply model since supply aspects are generally the most problematic and uncertain in fisheries economics.

The most popular biological model is the steady state model associated with Schaefer which assumes that the underlying population is in a steady state or in ecological equilibrium whereby sub tractions from that population caused by natural mortality, predation and man's fishing effort are balanced by additions to the population caused by the natural rate of reproduction. It is known however that populations are generally in transient rather than in steady states as a result of man's exploitation. Because of this, a stock adjustment model of fisheries based on the

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[1] I am greatly indebted to Professor Dagum, my supervisor, for his assistance and suggestions on this paper. I am also grateful to Miss Pauline Chung of the Social Science Research, Department of Environment, who did most of the computer work.

Houthakker-Taylor formulation (1970) was developed for fisheries. This model was tested in comparison with the steady state model and the standard stock adjustment model associated with koyck et al in specifying bio-economic supply models of Canada's offshore groundfish fisheries in the Northwest Atlantic.

11. Canada's Offshore Groundfish Fisheries North West Atlantic

Canada is one of the major countries in the North West Atlantic fisheries which has been managed by ICNAF, the International Commission for the North West Atlantic fisheries, since 1953. Canada's fisheries in this area consist of two major sectors based on technology and location: (1) an offshore sector and (2) an inshore sector. The inshore sector is confined to the coastal or territorial waters within Canadian jurisdiction and control while the offshore sector is the international fishery conducted outside these limits in the ICNAF Convention area.[1]

Offshore fishing in the Northwest Atlantic is mainly for groundfish carried out from large vessels (trawlers and draggers) generally over 50 gross tons.[2] Other species, i.e. pelagic and molluscs and crustaceans,

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[1] Not all offshore operations take place in ICNAF areas. Some are conducted in the Gulf of St. Lawrence and the Bay of Fundy which are under Canadian jurisdiction.

[2] Some vessels under 50 gross tons such as longliners also fish in offshore waters with the result that in Canadian Fisheries Statistics vessels over 25 gross tons are considered offshore vessels. The 50 gross tons and over classification, however, conforms to the ICNAF classification and will be used throughout this study.

are also fished but these are small except for herring, a pelagic species, in relation to groundfish species. Because of the large vessels used for groundfish and other species and the availability of these species throughout the year, offshore operations are carried out on a year round basis.

Growth in Output of Groundfish Landings

The many species of groundfish exploited by Canadian vessels are divided into three major species (1) cod (2) redfish and (3) flatfish. Landings of these species by offshore vessels for selected years during the period 1953-1971 are shown in Table 1.

Table 1. Canada's offshore groundfish landings
By major species - Selected years 1953-1971

	Cod		Redfish		Flatfish		Total Groundfish	
	Q Metric Tons	V ($'000 constant 1971) dollars	Q Metric Tons	V ($'000 constant 1971) dollars	Q Metric Tons	V ($'000 constant 1971) dollars	Q Metric Tons	V ($'000 constant 1971) dollars
1953	43,557	2,965	20,751	1,598	49,531	5,060	113,839	9,623
1956	51,326	3,529	24,789	1,812	93,740	8,471	169,855	13,812
1959	51,256	3,438	18,244	1,339	79,209	11,473	148,718	16,250
1962	48,566	3,980	24,306	1,910	110,463	11,476	183,335	17,276
1965	92,493	8,794	52,407	3,951	149,986	15,806	294,946	28,551
1968	111,285	9,452	82,903	5,794	156,195	16,389	350,383	31,635
1971	79,586	8,176	106,991	8,365	151,444	18,405	338,021	34,946

Sources: ICNAF, Statistical Bulletins Annuals (Dartmouth, Nova Scotia) Environment Canada, Annual Review of Canadian Fisheries, Vol 4 (Ottawa, 1972).

Offshore groundfish landings increased from 113 thousand metric tons, valued at $9.6 million in 1953 to 338 thousand metric tons valued at $34.9 million with a peak of 350 thousand metric tons in 1968. Most of this increase was attributable to flatfish and redfish landings.

The growth in offshore groundfish landings during the period was due to a substantial expansion in Canadian offshore fishing effort, characterized by increases in the number of vessels and days fished, from 1953 to 1968 but declined afterwards to 1971 (Table 2).

The number of offshore vessels increased from 105, valued at $12.3 million in 1953 to 558 valued at $149.6 million in 1968 but declined to 543 valued at $122.4 million by 1971. Groundfish vessels followed the same pattern increasing in number from 101 to 378 in 1968 and then dropping to 341 vessels in 1971. There was little apparent change in the size structure of the fleet judging from the average tonnage per vessel until about the mid 1960's when there was a trend towards larger and costlier vessels. This trend was to a large extent fostered by government programs of assistance, both Federal and Provincial, for vessel construction on the Atlantic coast (Mitchell and Frick, 1970).

Table 2. Factor inuputs, offshore fisheries, selected year 1953-1971

	Groundfish Vessels 1/	Total No. of Vessels	Tonnage	Value of Vessels 2/	Days Fished
				($'000 constant 1971 dollars)	
1953	101	105	13,335*	12,296	8,117
1956	124	136	17,272*	27,192	11,916
1959	192	211	26,742	19,805	10,768
1962	272	201	34,525	n.a.	22,225
1965	321	410	64,729	73,821	34,889
1968	378	558	113,536	149,566	45,898
1971	341	543	115,752	122,410	42,217

* Estimated

1/ These include trawlers (stern and side), dory vessels and longliners.

2/ Values not compatible for the whole period since prior to 1960, values given were for vessels 40 tons and over whereas offshore vessels given by ICNAF were vessels of 50 tons and over.

Sources: Environment Canada, Annual Statistical Review of Canadian Fisheries, Vols 1 to 4, (Ottawa) ICNAF, List of Fishing Vessels and Fishing Effort. Triannual publication, (Dartmouth, Nova Scotia).

The decline in the number of offshore fishing vessels have been the result of scarcity of offshore resources leading to increasing fishing costs and deteriorating economics returns to vessel operations (Table 3).

Table 3. Revenues & estimated costs, offshore groundfish fisheries, Selected years 1953-1971

Year	Estimated Costs	Revenues	Profit or Loss
	($'000, constant 1971 dollars)		
1953	8,757	9,623	866
1956	12,295	13,815	1,520
1959	15,438	16,250	812
1962	15,894	17,276	1,382
1965	28,322	28,551	229
1968	33,287	31,634	-1,653
1971	39,662	34,945	-4,717

Source: Based on costs and revenues from Proskie J and J.P. Charron Costs and Earning of Selected Fishing Enterprises Atlantic Provinces annuals, (Ottawa).

The table indicates that the offshore groundfish fisheries have in recent years been operating at levels where total costs exceed total revenues i.e. at an economic loss characterized by the absence of any economic rents. This conforms to the economic theory of fisheries exploitation which will be discussed later and indicates low returns to capital i.e. to vessels, in the offshore fisheries.

The absence of rent is however misleading since there might be accruing to plants, i.e. the secondary level, rather than vessels. This is because there is a high degree of vertical integration in the industry. Most of the offshore vessels are owned by large processing plants or companies. These companies control vessel prices to a great extent, keeping them low to their vessels since vessel operating losses can be recouped by profits from their processing operations.

Growth in the volume, value of offshore landings, and in the fishing fleet exploiting offshore resources during the period 1953-1971 resulted in growth in employment and per capita incomes (Table 4).

Table 4. Estimated per capita income offshore fishermen
Selected year 1953-1971

	No. of Fishermen	Gross Value of Output Per Fishermen	Net Income Per Fishermen
		(constant 1971 dollars)	
1953	5,210	1,846	722
1956	5,456	2,531	992
1959	4,910	3,309	1,542
1962	4,799	3,229	1,657
1965	6,011	4,787	2,209
1968	5,952	7,833	3,603
1971	5,122	9,686	4,456

* Based on Cope's (1967) estimates of returns to labour at 39 percent of gross output for the years up to 1957 and 46 percent thereafter.

Estimated per capita incomes for offshore fishermen increased from about $722 in 1953 to $4,456 by 1971. There is, however, quite a range in incomes for offshore fishermen depending on the level of skills required with the skippers, mates, and engineers in some of the larger and more technically sophisticated vessels receiving high incomes. Some skippers incomes were as high as $20,000 or more (Charron, 1972).

The secondary manufacturing or processing sector of the fishing industry will not be discussed here in detail since we are interested mainly in the primary sector. However, all the landings from the offshore fisheries are processed into semi-finished and finished products by many processing plants along the coast. These can be sub-divided into (1) food products and (2) reduction plants. The former utilize offshore groundfish landings for processing them into fillets, blocks, frozen round and dressed and canned goods; while the latter process mainly pelagic herring but also groundfish off all into fish meal and oil.

Processing operations add much to the value of fish landings: the value added by processing is generally equal to the value of the catch. Thus, in 1971 the marketed value of the products produced from offshore landings was probably in the vicinity of $70 million. Most of these products, about 65 per cent, are exported mainly to the United States where they compete with similar products from many other countries. Because of this, market prices for fisheries products are generally established in the United States market which can be considered one of the World's major fish markets.

111. Fisheries Exploitation: Bio-economic aspects

It was only since 1953 with a seminal article by Gordon[2] (1953) that the economics of fisheries exploitation began to receive some attention in the literature. In recent years a number of mathematical models have been developed for natural resources in general and fisheries in particular by Crutchfield-Zellner (1962) Quirk and Smith (1970) Burt and Cummings (1970) Fullenbaum et al (1971) and others. These models have to a large extent been based on biological models of fisheries population dynamics.

The Biological Foundation

Biologists distinguigh two types of models of fisheries population growth (a) a dynamic-pool model associated with Beverton and Holt and (2) a logistic growth model associated with Schaefer (1953)[1/]. The dynamic-pool model is characterized by a eumetric yield function which has no clearly demarcated maximum limit. The maximum in fact from the fishing standpoint is defined as a limit which can only be reached by an almost infinite fishing effort. This model has not been widely used by economists who have, with some exceptions, embraced the simpler logistic model by Schaefer. The biological theory underlying this model is called the theory of ecological equilibrium.

The theory of ecological equilibrium as described by Schaefer indicates that fisheries populations tend to remain in ecological equilibrium whereby losses due to natural mortality are on average offset by

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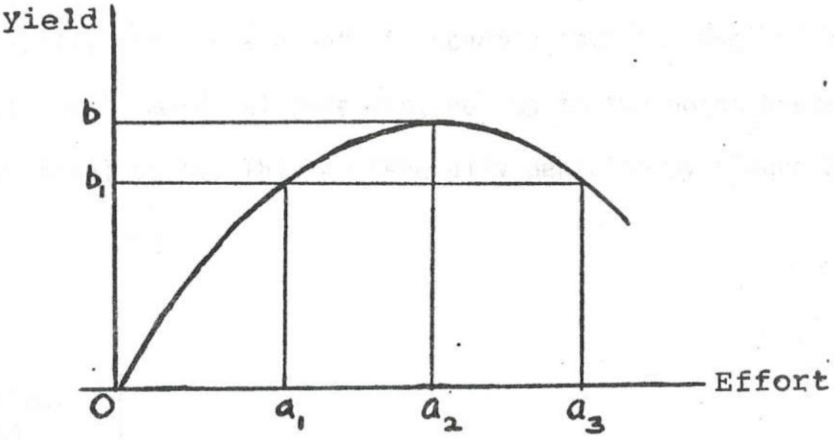
1/ For an extensive review of the biological models see Ricker (1958).

increments due to reproduction and growth.[1] Fishing operations by man disturb this equilibrium as losses due to mortality and fishing effort at first diminishes the population but these losses are in turn offset by increases in the rates of reproduction, since at a lower population density fish tend to reproduce, survive and grow better. Thus a new equilibrium level at a lower population level is attained.

The effects of fishing effort on output from a fishery under the ecological equilibrium conditions mentioned above are shown in diagramatic form in Figure 1.

Fig. 1



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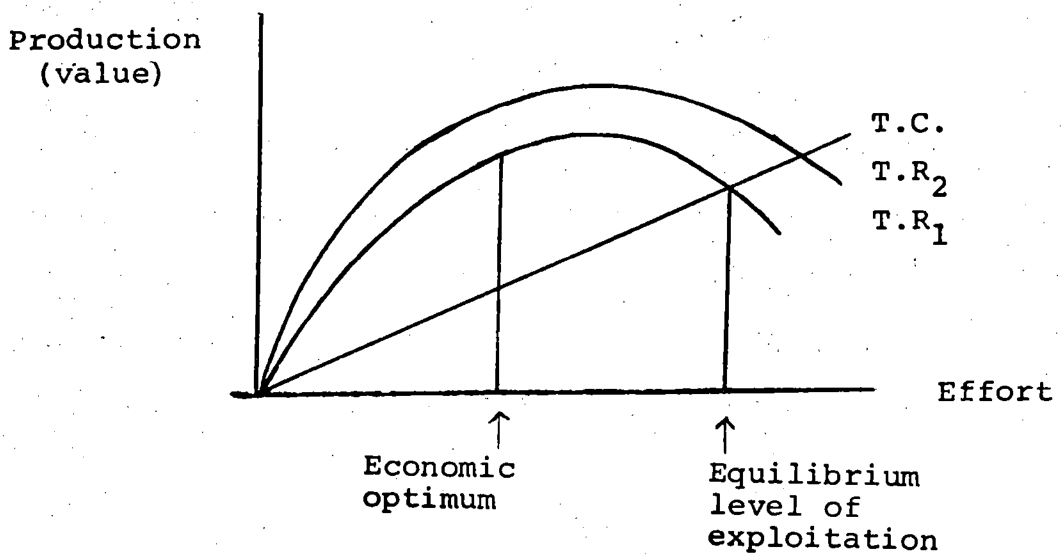
[1] For a mathematical exposition of this see Bell and Carlson (1970).

There is a sustainable yield from the fishery which can be low for both low and high rates of fishing effort, e.g., output at ob_1 at levels of effort oa_1 and oa_3 respectively. In between, there is some level of output ob where a maximum sustained physical yield can be obtained. This yield is not, however, the most economical or efficient since it does not take fishing revenue and costs of fishing effort into consideration. It was introducing the effects of economic factors, namely fishing costs and revenues, that an economic theory of fishery exploitation was developed.

The Economic Theory

The economic theory of fishery exploitation states that because fishery resources are common property, characterized by the free entry of capital and labour inputs (components of effort), exploitation of these resources generally takes place not at economic optimum levels i.e. where marginal costs equal marginal revenues, but up to the point where total revenues equal total costs. This is generally depicted by Figure 2.

Fig.2



In this diagram the biological production function is converted to a total revenue function by assuming constant prices. The total cost of fishing effort, i.e. both fixed and variable costs, is also assumed to increase linearly with effort. The economic optimum level of fishing is where MC=MR which occurs where $\frac{dR}{dt} / \frac{dC}{dt}$. However, it is argued that this level is generally surpassed with uncontrolled fishing resulting in a dissipation of any economic rent from the resource at an equilibrium situation where total revenues equal total costs. The assumptions of this model namely the price and cost assumptions are not realistic. Prices change because of supply demand relationships; and the total cost function probably curves upwards as effort increases. For example, if price increases, the total revenue curve will be pushed up to $T.R._2$ as shown in the diagram. As a result, this model has been criticized (Carlson, 1969) for being rather rigid and restrictive. But, although more general models have been developed taking both supply and demand into consideration these still support the basic thesis that in uncontrolled fisheries exploitation tends to take place at economic levels where all rents are dissipated. Besides, in these models supply rather than demand has proved to be the most problematic area with the result that interest here is centered on supply aspects.

IV. Bio-Economic Supply Models

Three bio-economic models were formulated based on the steady state model of Schaefer, and two stock adjustment models based on the Houthakker-Taylor stock adjustment formulation, and the more traditional stock adjustment (partial adjustment) associated with Koyck and others.

These models were specifed as follows:

Model 1. (Steady State)

$$C_t = b_1 E_t + b_2 E_t^2 + b_3 P_t + u_t$$

Model 11. (Houthakker-Taylor stock adjustment)

$$C_t = -A_0 + A_1 C_{t-1} + A_2 E_t - A_3 E_t + A_4 P_t - A_5 P_{t-1} + E_t$$

Model 111. (Traditional stock adjustment)

$$C_t = B_0 + B_1 C_{t-1} + B_2 E_t + B_3 P_t + V_t$$

Where C_t = catch

E_t = fishing effort

P_t = price or some other economic variable

Models 1 and 111 are relatively well known but the application of the Houthakker-Taylor formulation, Model 11, in a supply and fisheries context is unique.

<u>The Houthakker-Taylor Model in a fisheries context</u>

The Houthakker-Taylor model,though developed for consumer demand, seemed very applicable to fisheries from a supply standpoint. The aspect of this model which was most appealing is that it shows, based on the biological assumptions of fisheries population growth, that the underlying stock or population of fish can be eliminated from a regression equation comprised basically of catch and effort variables. An example of this model applied to fisheries is as follows:

(1) $C(t) = \alpha + \beta X(t) + \gamma E(t)$

where $C(t)$ = catch in time t

$X(t)$ = fish population or stock in time t

$E(t)$ = fishing effort in time t

α, β, γ = parameters

This shows that the catch from fishing is a function of the underlying fish population and fishing effort. Now the rate of growth of the fishery population when exploited by man is equal to the natural rate of growth of the stock minus the catch taken by man. This is expressed by the following identity:

(2) $\dot{X}(t) = W(t) - C(t)$

where $\dot{X}(t) = \frac{dX}{dt}$ = the rate of growth of population.

$W(t)$ = the natural rate of growth of stock.

This identity indicates that the fish population will grow if the catch taken by man is less than the natural rate of population increase and will decline if vice versa. The population will be in ecological equilibrium if $\dot{X}(t) = 0$ and $W(t) = C(t)$.

The population increase is a function of the fish population which can be expressed by δX where δ represents the combination of factors such as the rate of recruitment, rate of growth of stock, and natural mortality per unit time where unit time is τ. Thus

$$(3) \quad W(t) = \delta X(t)$$

is a constant rate of growth proportional to the population.

(2) and (3) can therefore be combined into:

$$(4) \quad \dot{X}(t) = \delta X(t) - C(t)$$

$X(t)$ can be eliminated from (4) by using (1) to obtain:

$$(5) \quad \dot{X}(t) = \frac{\delta}{\beta}\Big[(C(t) - \alpha - \gamma E(t))\Big] - C(t)$$

Differentiating (1) with respect to (t) and substituting (2.5) for $X(t)$ result in:

$$(6) \quad \dot{C}(t) = \beta\left\{\frac{\delta}{\beta}\Big[C(t) - \alpha - \gamma E(t)\Big] - C(t)\right\} + \gamma\dot{E}(t)$$

which, on simplifying becomes a first order differential equation involving only the observable quantities of catch and effort, that is:

$$(7) \quad \dot{C}(t) = -\alpha\delta + (\delta - \beta)C(t) + \gamma\dot{E}(t) - \gamma\delta E(t).$$

The parameters, α, β, γ and δ in the continuous model were estimated by obtaining the discrete anologue of this model. This discrete analogue, obtained through a method of estimation using continuous differences and transformation, was:

$$(8) \quad C_t = -\frac{\alpha\delta}{1 - \frac{1}{2}(\delta-\beta)} + \frac{1 + \frac{1}{2}(\delta-\beta)}{1 - \frac{1}{2}(\delta-\beta)} C_{t-1} + \frac{\gamma\left(1 - \frac{\delta}{2}\right)}{1 - \frac{1}{2}(\delta-\beta)} \Delta E_t - \frac{\gamma\delta}{1 - \frac{1}{2}(\delta-\beta)} E_{t-1}$$

This equation, which is the one actually used for estimation, can be expressed as follows:

$$(9)\quad C = -A_0 + A_1 C_{t-1} + A_2 \Delta E_t - A_3 E_{t-1}$$

It can be verified, apart from estimating errors, that:

$$(10)\quad \alpha = \frac{2A_0(A_2 + \frac{1}{2}A_3)}{A_3(A_1 + 1)}$$

$$(11)\quad \beta = \frac{A_3}{A_2 + \frac{1}{2}A_3} - \frac{2(A_1 - 1)}{A_1 + 1}$$

$$(12)\quad \gamma = \frac{2(A_2 + \frac{1}{2}A_3)}{A_1 + 1}$$

$$(13)\quad \delta = \frac{A_3}{A_2 + \frac{1}{2}A_3}$$

The Houthakker-Taylor approach has been criticized by Dagum (1970) as being unnecessarily sophisticated since a discrete time formulation would allow directly and in a more simple way the deduction of the reduced form. As a result of this a discrete time formulation of the model was developed.

A Discrete Time Formulation[1/]

Equations (1) and (2) can be put into discrete time with each time interval being one year. We therefore have:

(2.1) $C_n = \alpha + \beta X_n + \gamma E_n$ and

[1/] I am indebted to Professor N.G.F. Sancho of the Department of Mathematics, McGill University, for this formulation.

(2.2) $X_{n+1} - X_n = \delta X_n - C_n = \delta X_n - \alpha - \beta X_n - \gamma E_n$

where X_n = Average population over year

C_n = Total catch for year

E_n = Total fishing effort for year

substituting for X_n and X_{n+1} from (2.1) into (2.2) results in:

(2.3) $\frac{1}{\beta}\left(C_{n+1} - \alpha - \gamma E_{n+1}\right) = \frac{(1 + \delta - \beta)(C_n - \alpha - \gamma E_n)}{\beta} - \alpha - \gamma E_n$ and

(2.4) $C_{n+1} - \alpha - \gamma E_{n+1} = (1 + \delta - \beta)(C_n - \alpha - \gamma E_n) - \alpha\beta - \gamma\beta E_n$ or

(2.5) $C_{n+1} = \alpha - \alpha(1 + \delta - \beta) - \alpha\beta + \gamma E_{n+1} - \gamma\beta E_n + (1 + \delta - \beta)(C_n - \gamma E_n)$

i.e.

(2.6) $C_{n+1} = - \alpha\delta + (1 + \delta - \beta)C_n + \gamma E_{n+1} - (1 + \delta)\gamma E_n$

now $E_{n+1} - E_n = \Delta E_{n+1}$ therefore:

(2.7) $C_{n+1} = - \alpha\delta + (1 + \delta - \beta)C_n + \gamma\Delta E_{n+1} - \gamma\delta E_n$

This agrees with Houthakker-Taylor's equation (8) to a first degree approximation and can be expressed as:

(2.8) $C_{n+1} = A_0 + A_1 C_n + A_2 \Delta E_{n+1} - A_3 E_n$ and

(2.9) $C_n = A_0 + A_1 C_{n-1} + A_2 E_n - A_3 E_{n-1}$

where the reduced form and structual coefficients are as follows:

(2.10) $A_0 = -\alpha\delta$

(2.11) $A_1 = 1 + \delta - \beta$

(2.12) $A_2 = \gamma$

(2.13) $A_3 = \gamma\delta$

(2.14) $\delta = A_3/A_2$

(2.15) $\beta = 1 + \delta - A_1 = 1 + A_3/A_2 - A_1$

This model, therefore, results in essentially the same estimating equation as the continuous model.

A bio-economic Formulation

The Houthakker-Taylor model formulation for fisheries was made into a bio-economic model by introducing an economic variable, price P, since fisheries exploitation takes place mainly for economic reasons. The basic equation with this variable included is as follows:

$$(3.1)\quad C(t) = \alpha + \beta X(t) + \gamma E(t) + nP(t) + u_t$$

with the estimating equation of Model 11 i.e.

$$(3.2)\quad C = A_0 + A_1 C_{t-1} + A_2 \Delta E_{t-1} + A_4 \Delta P_t - A_5 P_{t-1} + V_t$$

The inclusion of this other variable results in problems of identification and correlation which stem from the fact the two different estimates of the structual parameter δ are available from the reduced form coefficients A_4 and A_5 and it appears that the error term is auto-correlated[1]. As a result the H-T type model is susceptible in its extended form to problems of estimation. This is common, however, to most stock adjustment models and techniques have been developed to combat this (Johnston, 1972, 318-320). Houthakker and Taylor used an iterative technique for arriving at a single estimate of δ and the three-pass least squares where necessary to combat the auto-correlation problem. However a simpler method of estimating δ was used by Dobell et al (1972, 187) and this will be used in this paper[2].

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[1] Since δ is also equal to $\dfrac{A_5}{A_4 + \frac{1}{2} A_5}$

and, the error term v_t defined by:

$$v_t = \frac{(1-\frac{\delta}{2})u_t - (1-\frac{\delta}{2})u_{t-1}}{1-\frac{1}{2}(\delta- \quad)}$$

[2] This is based on the weighted average of the two estimates of δ, the weights being the inverses of the t-ratios of A_3 and A_5 (Footnote 18,187)

The Traditional Stock adjustment Model, a fisheries context

The traditional stock adjustment model was considered as a special case by Houthakker-Taylor where present values are preferable to lagged dependent variables. For fisheries, the present level of fishing effort might be more significant than the lagged effort or period (one year) changes in effort i.e., E_{t-1} and ΔE_t. This model can be applied to fisheries in the following way:

(4.1) Let $C_t^* = \alpha + \beta E_t + \varepsilon P_t$

where C_t^* = The optimal catch as a function of fishing effort and price

the growth in catch from t-1 to t is:

(4.2) $C_t - C_{t-1} = \gamma(C^*_t - C_{t-1}) + u \qquad o<\gamma<1$

therefore:

(4.3) $C_t - C_{t-1} = \gamma(\alpha + \beta E_t + \varepsilon P_t - C_{t-1}) + u_t$ and

(4.4) $C_t = \alpha\gamma + (1-\gamma)C_{t-1} + \beta\gamma E_t + \varepsilon\gamma P_t + u_t$

which is expressed in reduced form by Model 111 i.e.

(4.5) $C_t = B_o + B_1 C_{t-1} + B_2 E_t + B_3 P_t + V_t$

The reduced form coefficients of this model are as follows:

(4.6) $B_o = \alpha\gamma$

(4.7) $B_1 = (1-\gamma)$

(4.8) $B_2 = \beta\gamma$

(4.9) $B_3 = \varepsilon\gamma$

Parameter Estimates and Their Uses

The parameter coefficients of both the structual and reduced forms of the two stock adjustment models provide valuable information on the relationships between the dependent and independent variables. In the models the coefficients of the structual form show the relationship between the dependent variables, the catch, with the underlying stock and also on effort and price or income variables.

The stock coefficients in Model 11 are δ and β. δ measures the natural rate of growth and β its stock adjustment due to fishing effort. Thus this indicates that if:

$\delta > \beta$ there is population growth

$\delta = \beta$ zero growth or steady state and

$\delta < \beta$ stock depletion or overexploitation

In Model 111 the stocks adjustment coefficient is γ. The closer this is to unity the greater is the adjustment made.

The coefficients of the other variables give the short term or instantaneous change of these variables with respect to catch, before the state variables have time to adjust. The long term coefficients during which adjustment takes place can also be derived for the two models as follows:

	Model II (The H-T Model)		Model III (the traditional stock adjustment)	
	Short Run	Long Run	Short Run	Long Run
Effort	γ	$\gamma' = \frac{\gamma\delta}{(\delta-\beta)}$	$\beta\gamma$	β
Price or Income	η	$\eta' = \frac{\eta\delta}{(\delta-\beta)}$	$\varepsilon\gamma$	ε

From the short and long term coefficients the short and long term elasticities of prices or incomes can be obtained (Dagum, 1971, pp 1406 - 1408).

V. Application of Models and Results

The three bio-economic models described earlier were tested by applying them to Canada's groundfish fisheries in the Northwest Atlantic for cod, redfish and other groundfish. It was assumed that fisheries resources in the Northwest Atlantic were evenly distributed throughout the areas fished, that fishing effort was highly mobile between areas, and that landings were proportional to fishing effort.This effort was measured by the total tonnage of vessels times the days spent at sea.

The Results

The list of variables used in the models were as follows:

Table 5. List of Variables

C_{21} = Canadian east coast offshore cod landings

C_{22} = Canadian east coast offshore redfish landings

C_{23} = Canadian east coast offshore other groundfish landings

E_{21} = Canadian offshore fishing effort for cod

E_{22} = Canadian offshore fishing effort for redfish

E_{23} = Canadian offshore fishing effort for other groundfish

P_{21} = Wholesale price index (constant prices) U.S. market for cod

P_{22} = Wholesale price index (constant prices) U.S. market for redfish

P_{23} = Wholesale price index (constant prices) U.S. market for other groundfish

Y_t[1] = Per capita income (constant dollars) Canada

The wholesale price index in the United States for cod, redfish and other groundfish was chosen as the price variable instead of ex-vessel prices since this proved to be more significant in regression equations using both. This supports the contention that, because of vertical integration in the industry and its pricing policy for vessels, market prices exert a greater influence on fishing effort than ex-vessel prices.

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[1] G.N.P., Disposable income and disposable income per capita all in constant dollars were tried but results were not as good as with G.N.P. per capita.

The best results from a variable or specification standpoint of the models for the three species given were as follows:

Canada's Offshore Cod

(I.1) Model 1 (Steady State)

$$C_{21} = 114.01 + 1.136E_{21} - .0028E_{21}^{2} + 2.665Y_{t}$$

(4.81) (5.19) (.2.42) (-3.02)

((23.70)) ((21.91)) ((11.38)) ((8.80))

R^2=.95 $\bar{R}^2$=.94 S.E.E.=5.59 D.W.=2.06

(II.1) Model 11 (Houthakker-Taylor Stock Adjustment)

$$C_{21} = 81.443 + .339C_{\substack{21\\t-1}} + .647\Delta E_{21} + .487E_{\substack{21\\t-1}} + .117\Delta Y_{t} - 1.96Y_{t-1}$$

(2.50) (1.58) (6.64) (2.68) (0.07) (-1.85)

((32.5)) ((.251)) ((.097)) ((.181)) ((16.53)) ((10.60))

R^2=.95 $\bar{R}^2$=.93 S.E.E.=6.11 D.W.=1.30

(III.1) Model 111 (Traditional Stock Adjustment)

$$C_{21} = 90.34 + .185C_{\substack{21\\t-1}} + .616E_{21} - 1.918Y_{t}$$

(3.82) (1.15) (6.33) (2.07)

((23.6)) ((.159)) ((.097)) ((.092))

R^2=.94 $\bar{R}^2$=.92 S.E.E.=6.36 D.W.=1.20

Canada's Offshore Redfish

Model 1 (Steady State)

$$C_{22} = -5.539 + .903E_{22} - .0019E_{22}^{2} + .219P_{22} \tag{I.2}$$

(0.54) (9.82) (-2.52) (2.23)

((10.20)) ((9.18)) ((7.77)) ((.098))

R^2=.99 $\bar{R}^2$=.99 S.E.E.=3.74 D.W.= 1.56

Model 11 (Houthakker-Taylor)

$$C_{22} = -14.39 + .315C_{\substack{22\\t-1}} + .764\Delta E_{22} + .427E_{\substack{22\\t-1}} + .268P_{t} \tag{II.2}$$

(-0.96) (1.18) (6.17) (2.18) (2.21)

((14.88)) ((.267)) ((.123)) ((.195)) ((.120))

R^2=.99 $\bar{R}^2$=.98 S.E.E.=4.24 D.W.= 1.93

Model 111 (Traditional Stock Adjustment)

$$C_{22} = .469 - .027C_{\substack{22\\t-1}} + .693E_{22} + .185P_{22} \tag{III.2}$$

(0.04) (-0.11) (5.59) (1.58)

((12.78)) ((.189)) ((.124)) ((.117))

R^2=.98 $\bar{R}^2$=.98 S.E.E.=4.50 D.W.= 1.45

Canada's Offshore Other Groundfish

Model 1 (Steady State)

$$(I.3) \quad C_{23} = 106.20 + 1.184E_{23} - .0034E_{23}^{2} - .442P_{23}$$

(5.78) (7.01) (-4.08) (-2.38)

((18.35)) ((16.87)) ((8.38)) ((.185))

R^2 .94 $\bar{R}^2$ .93 S.E.E. 9.12 D.W. 1.75

Model 11 (Houthakker-Taylor)

$$(II.3) \quad C_{23} = -4.375 + .402C_{\substack{23\\t-1}} + .550\Delta E_{23} + .065E_{\substack{23\\t-1}} + 5.176\Delta Y_{t} + 1.913Y_{t-1}$$

(0.07) (1.80) (2.77) (0.34) (1.69) (0.88)

((60.88)) ((.222)) ((.198)) ((.188)) ((30.52)) ((21.54))

R^2=.93 $\bar{R}^2$=.91 S.E.E.=10.52 D.W.=2.14

Model 111 (Traditional Stock Adjustment)

$$(III.3) \quad C_{23} = 82.14 + .476C_{\substack{23\\t-1}} + .267E_{23} - .374P_{23}$$

(2.61) (1.89) (1.89) (-1.51)

((31.46)) ((.251)) ((.141)) ((.247))

R^2=.90 $\bar{R}^2$=.88 S.E.E.=12.0 D.W.=1.60

Good results were obtained from all the models with Model 1, the steady state model, giving the best results in terms of high $\bar{R}^s$, low standard errors and good Durbin Watson statistics. The stock adjustment models results were as good with the Houthakker-Taylor model, Model 11, being slightly better than Model 111, the traditional stock adjustment model.

The Houthakker-Taylor Model 111 results were quite satisfactory, all equations gave good fits (Fig. 3). Judging from t-values at the 5 percent level, most of the variables were significant with effort variables (changes in fishing effort and lagged effort) as the most significant. The wholesale United States price index and income variables were also significant in most cases.

The Durbin Watson statistic was in the inconclusive range for (II.1) and (II.2). From (II.1) it is possible that auto-correlation is present and the new test suggested by Durbin (1970) for this broke down. However for II.2 and II.3 it indicated that the hypothesis of zero auto-correlation at the 5 percent level could be rejected.

The coefficients of the structual form of Models 11 and 111 are given in Table 6. The coefficients of Model 11 are obtained from the discrete form of the model since it was found that there were little differences in estimating them from the continuous or discrete formulations.

FIGURE 3

ESTIMATED AND ACTUAL LANDINGS, MAJOR SPECIES, CANADA'S EAST COAST OFFSHORE FISHERIES

(Thousand Metric Tons)

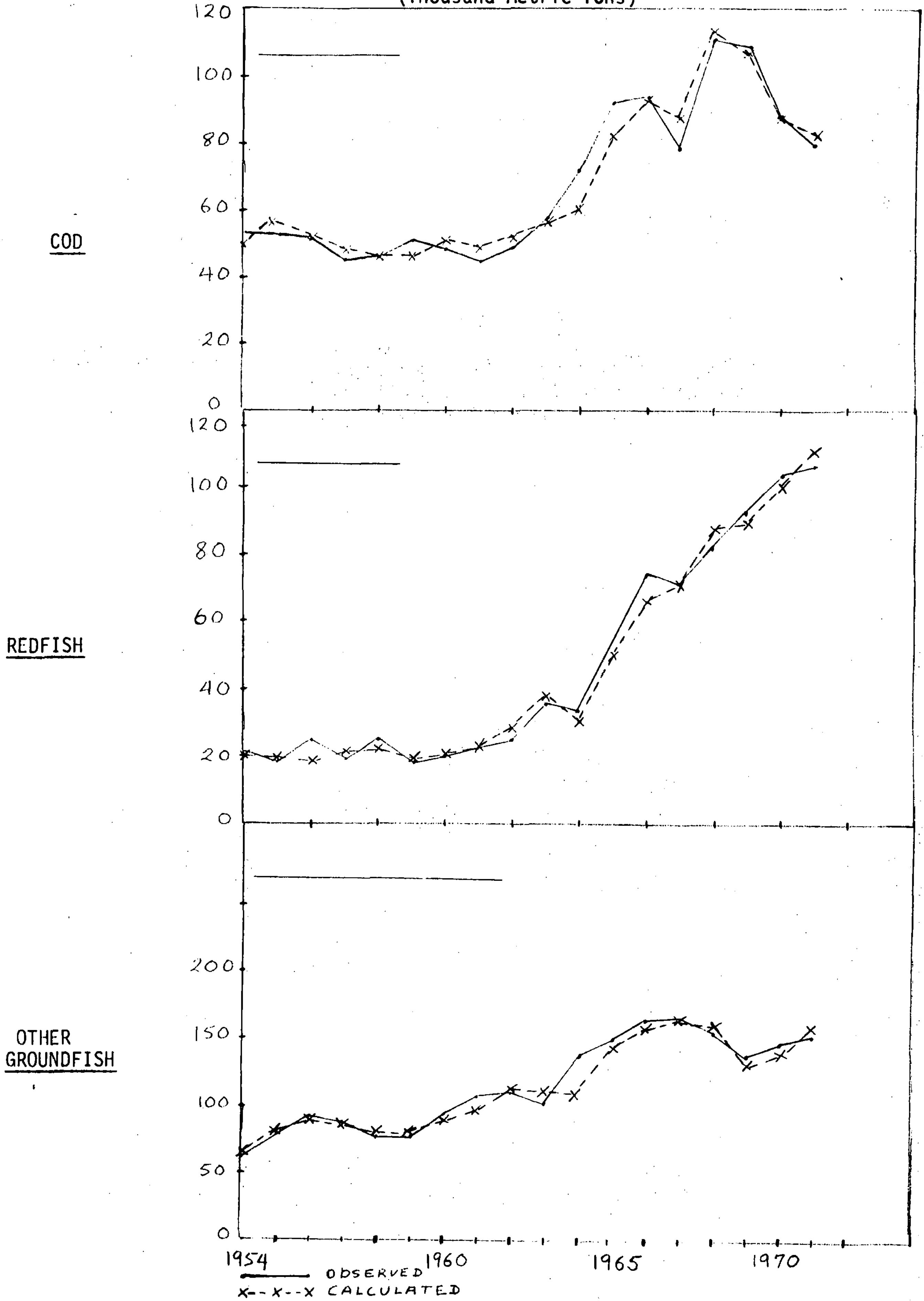

Table 6. Structual Coefficients, Models 11 and 111

Model 11

	β_2	δ_2	γ_2	γ'_2	η_2	η'_2
(II.1)	1.353	.752 *	.647	.818	.117(Y)	-3.18(Y)
(II.2)	1.243	.558	.764	.623	.268(P)	.217(P)
(II.3)	.920	.322	.550	.108	5.17(Y)	3.198(Y)

Model 111

	γ_3	β_3	ε_3
(III.1)	.815	.756	-2.35(Y)
(III.2)	1.027	.675	.180(P)
(III.3)	.524	.509	-.713(P)

Although it might not be apparent at first glance there are similarities between the coefficients of Models 11 and 111 in the equations with the same variables (1) and (2). The structual coefficients of Model 11 provide more information in that it has a stock adjustment coefficient due to fishing effort β_2 and δ_2 which is the natural rate of growth of stock

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* Implausible results were obtained by the method advocated by Dobell et al (1972) due to a high negative δ from A_5. As a result δ was estimated from $\frac{A_3}{A_2}$ which were more significant variables than $\frac{A_5}{A_4}$.

adjustment coefficient. The long run effort and price and income coefficients in Model 11 are of the same relative magnitudes as those in Model 111.

The information on stocks show considerable stock adjustment for the three major species. However in Model 11, the natural rate of growth of these stocks δ is less than the stock adjustment due to fishing effort indicating that the underlying stocks are declining. This supports the findings of ICNAF scientists that the resources are being exploited at levels higher than their reproductive capabilities can bear. The coefficients of fishing effort, in the short and long run, are positive and less than 1 in both models indicating decreasing returns to fishing effort, particularly for redfish and flatfish (other groundfish).

The prices and income coefficients were used to obtain short and long run elasticities from both models for 1971. There were as follows:

Table 7. Short and Long Term Elasticities 1971

Models		Short Run Elasticities	Long Run Elasticities
(II.1)	Income	.055	1.50
(II.2)	Price	-.284	-.230
(II.3)	Income	14.11	8.73
(III.1)	Income	-.90	1.10
(III.2)	Price	-.196	-.190
(III.3)	Price	-.471	-.898

The results indicated that fish species tend to be inelastic in respect to price in both the short and long run, and elastic in respect to income per capita in the long run.

Conclusion: The Policy Implications

The utility of models depends on their effectiveness in the decision making process, i.e. in policy formulation. In this respect models can be helpful both from their explanatory and predictive qualities. The models examined here have for example provided valuable insights into the major factors affecting the exploitation and supply of groundfish species. From the results obtained, the models should also be useful for making short term predictions. This aspect will not however be examined in any detail. The main reason for this is that for predictions to be made with any reliability there should be structural permanence and this certainly is not the case since ICNAF has from 1969 progressively extended its quotas until they now cover all groundfish species in the northwest Atlantic. As a result, the use of the models for predictive purposes is strictly limited.

Despite the limitations of the models for predictive purposes some short term predictions were made using Model 11. These were based on a small reduction in fishing effort since 1971. This seems to have been the case because the number of vessels in the offshore fleet declined between 1971 and 1972[1/] and in 1973 the government temporarily stopped its vessel

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[1/] From data obtained from the Economics Intelligence Branch, Fisheries & Marine Service, Department of Environment.

subsidy program in an attempt to bring Canadian fishing effort more in line with resource availability. The forecasts made on the basis of this assumption and on actual prices and incomes data were as follows:

Table 8. Short Term Projections Model 11

	1972	1973	1974
Cod (Actual)*	(78.2)	(53.1)	
(Predicted)	68.2	54.6	50.6 **
Redfish (Actual)	(109.9)	(156.0)	
(Predicted)	127.7	148.6	145.3
Other Groundfish (Actual)	(162.1)	(167.0)	
(Predicted)	160.7	170.7	173.5

* Preliminary

** The projection for 1974 was made on the basis of no change in cod fishing effort between 1973 and 1974.

The models predictions were not too good but no tests were made of the results. The predictions did indicate however decreased cod landings throughout the predictive period, and increases in redfish and other groundfish landings up to 1973 with some declines in 1974. Cummulative monthly landings up to June 1974 by Statistics Canada support this finding since these landings were far below cummulative landings for the same period last year.

Despite the limitations of the models for predictive purposes they can be used to assess the changes in effort necessary to catch the established quotas. This can be done by making effort the dependent variable in the regression equation results. For example in the case of Model 11 the change in effort required to take a certain catch or quota will be given by the following:

$$\Delta E_t = \frac{C_t + A_0 - A_1 C_{t-1} + A_3 E_{t-1} - A_4 \Delta P_t + A_5 P_{t-1}}{A_2} \qquad \text{(V.1)}$$

As a result, the models can be used to determine effort levels for obtaining desired levels of landings. This is an important policy consideration in the quota regime under which Canada's offshore fisheries in the northwest Atlantic now operate.

To conclude, the stock adjustment models 11 and 111 examined were not superior in their empirical testing to the steady state model when applied to Canada's offshore fisheries in the northwest Atlantic. Model 11, the Houthakker-Taylor model, gave slightly better results than the traditional stock adjustment model, Model 111.

APPENDIX

COMPARATIVE RESULTS OF THE MODELS

Table 1-1 Cod Results With Wholesale Prices (U.S.) As Available

Model 1

$$\begin{array}{lllll} C_{21} = & 66.581 & + .885\text{-}E_{21} & - .0025E_{21}^{2} & - 0.279P_{21} \\ & (\ 6.68) & (\ 5.00) & (-2.05) & (-2.50) \\ & ((\ 9.96)) & ((17.70)) & ((12.0\ )) & ((\ .111)) \\ & R^{2}=.944 & \bar{R}^{2}=.932 & \text{S.E.E.}=5.98 & \text{D.W.}=1.66 \end{array}$$

Model 11

$$\begin{array}{llllll} C_{21} = & 37.03 & + .442C_{21_{t-1}} & + .569\Delta E_{21} & + .296E_{21_{t-1}} & - .125P_{21} \\ & (\ 2.23) & (\ 1.71) & (\ 6.36) & (\ 2.08) & (-1.16) \\ & ((15.84)) & ((\ .258)) & ((\ .089)) & ((\ .142)) & ((\ .107)) \\ & R^{2}=.941 & \bar{R}^{2}=.923 & \text{S.E.E.}=6.37 & \text{D.W.}=1.48 & \end{array}$$

Model 111

$$\begin{array}{lllll} C_{21} = & 56.22 & + .109C_{t-1} & + .488E_{21} & - .172P_{21} \\ & (\ 5.62) & (\ 0.70) & (\ 6.31) & (-1.58) \\ & ((10.68)) & ((\ .157)) & ((\ .077)) & ((\ .108)) \\ & R^{2}=.930 & \bar{R}^{2}=.915 & \text{S.E.E.}=6.70 & \text{D.W.}=1.14 \end{array}$$

Table 1-2 Redfish Results With Wholesale Prices (U.S.) As A Variable

Model I

$$\begin{array}{lcccc}
C_{22} = & -5.539 & + .903E_{22} & - .0019E_{22}^{2} & + .219P_{22} \\
 & (-0.54) & (9.82) & (-2.52) & (2.23) \\
 & ((16.20)) & ((9.18)) & ((7.77)) & ((.098)) \\
 & R^{2}=.988 & \bar{R}^{2}=.986 & S.E.E.=3.74 & D.W.=1.56
\end{array}$$

Model II

$$\begin{array}{lcccccc}
C_{22} = & -14.998 & + .386C_{22_{t-1}} & + .759\Delta E_{22} & + .377E_{22_{t-1}} & + .306\Delta P_{22} & + .260P_{22_{t-1}} \\
 & (0.96) & (1.05) & (5.84) & (1.42) & (1.71) & (2.03) \\
 & ((15.57)) & ((.368)) & ((.129)) & ((.265)) & ((.179)) & ((.128)) \\
 & R^{2}=.987 & \bar{R}^{2}=.981 & S.E.E.=4.39 & D.W.=1.99 & &
\end{array}$$

Model III

$$\begin{array}{lcccc}
C_{22} = & .469 & - .027C_{22_{t-1}} & + .693E_{22} & + .185P_{22} \\
 & (0.04) & (0.11) & (5.59) & (1.58) \\
 & ((12.78)) & ((.189)) & ((.124)) & ((.117)) \\
 & R^{2}=.983 & \bar{R}^{2}=.980 & S.E.E.=4.50 & D.W.=1.45
\end{array}$$

Table 1-3 Other Groundfish Results With Wholesale Prices (U.S.) As A Variable

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Model 1

$$\begin{array}{llllll}
C_{23} = & 106.20 + & 1.184E_{23} - & .0034E_{22}^{2} - & .442P_{23} \\
 & (\ 5.78) & (\ 7.01) & (-4.08) & (-2.38) \\
 & ((18.35)) & ((16.87)) & ((\ 8.38)) & ((\ .185)) \\
 & R^2=.942 & \bar{R}^2=.930 & \text{S.E.E.}=9.12 & \text{D.W.}=1.75
\end{array}$$

Model 11

$$\begin{array}{lllllll}
C_{23} = & 39.73 + & .470C_{\substack{23\\t-1}} + & .604\Delta E_{\substack{23\\t-1}} + & .184E_{\substack{23\\t-1}} + & .057P_{23} \\
 & (\ 1.03) & (\ 1.99) & (\ 2.57) & (\ 1.31) & (\ 0.16) \\
 & ((38.26)) & ((\ .235)) & ((\ .235)) & ((\ .140)) & ((\ .339)) \\
 & R^2=.918 & \bar{R}^2=.893 & \text{S.E.E.}=11.3 & \text{D.W.}=2.21 &
\end{array}$$

Model 111

$$\begin{array}{llllll}
C_{23} = & 82.14 + & .476C_{\substack{23\\t-1}} + & .267E_{23} - & .374P_{23} \\
 & (\ 2.61) & (\ 1.89) & (\ 1.89) & (-1.51) \\
 & ((31.46)) & ((\ .251)) & ((\ .141)) & ((\ .247)) \\
 & R^2=.899 & \bar{R}^2=.878 & \text{S.E.E.}=12.0 & \text{D.W.}=1.60
\end{array}$$

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