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~~The~~ AGGREGATE BIOECONOMIC MODELS

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FISHING POWER FUNCTIONS IN AGGREGATE BIOECONOMIC MODELS

Timothy G. Taylor and Fred J. Prochaska[1]

INTRODUCTION

The necessity to manage ocean fisheries in accordance with the Fishery Conservation and Management Act of 1976 (PL94-265) has placed increased importance on the development of empirical models of fishery production. Such models have generally been specified in aggregate terms and are based on the biological surplus stock production concept [Shaefer, 1957; Pella and Tomlinson, 1969]. Fishing effort in these bioeconomic models has generally been represented by a single composite variable. This treatment of fishing effort appears to result from the nature of the types of sustainable yield functions used in fishery production models.

One of the primary assumptions of the surplus stock production models is that fishing effort be measured in homogeneous (standardized) terms. Standardization can sometimes be achieved by utilizing firm level data [Griffin, 1977]. For many fisheries, however, individual firm data is not available for a sufficient length of time for bioeconomic analysis. Consequently effort is defined in terms of a composite of several aggregate variables which serve to measure effort. Standardization is then often achieved by forming an effort index defined by the simple ratio of the composite value at each point in time to the value during a predetermined base period. While the use of such procedures enables a standardized measure of fishing effort to be easily obtained, significant errors in the measurement of effective fishing effort can result.

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The use of such an indexing procedure generally assumes that the contribution of each factor in the composite measure has the same effect on total effort and hence catch. This paper presents a method of disaggregating the composite measure of fishing effort into a nominal component and a fishing power component in the absence of individual firm data. Standardization of fishing effort is based on an index formed utilizing the fishing power function. The resulting index has the property that the contribution of each factor in determining fishing effort is determined by the data rather than *a priori*.

A review of the basic notion of fishing effort and the development of the fishing power function is contained in section one. The second section contains an empirical formulation of these notions. The third section of the paper presents an empirical example of the use of fishing power functions in standardizing fishing effort for the Gulf of Mexico Reef Fish Fishery (GMRFF). The final section summarizes the concepts presented in this paper.

FISHING EFFORT

Fishing effort, like the input capital in economic theory, is well understood conceptually, but difficult to measure. The correct measurement of fishing effort is extremely important when attempting to draw inferences concerning the status of a fish stock or management of a fishery. Rothchild [1977, p. 96] notes ". . . errors in stock assessment are most likely to arise from a misinterpretation of the magnitude of fishing effort applied to the stock." Such a statement could also be made with respect to the management of a fishery. Since fishery management measures frequently center on fishing effort as the primary management vehicle, correct measurement of fishing effort is essential for successful management.

Fishing effort, ideally should be measured in standardized (homogeneous) terms. Measured in this manner, changes in a given type of gear over time or differences in gear types are fully reflected in the standardized unit of effort. One such measure used by the biological discipline is defined as instantaneous fishing mortality (F). The fishing mortality coefficient can be expressed as

$$F = \frac{c}{N} \tag{1}$$

where c is the average catch attributable to fishing and N is the resource stock size. Equation (1) serves to define fishing mortality (effort) in terms the fraction of population taken by fishing. A unit of effort is thus defined as the amount of fishing activity required to harvest a given proportion of the stock. Fishing mortality however, is a highly abstract notion and of limited use in developing empirical models of fishery production. To remedy this, the concepts of nominal fishing effort and fishing power have been developed.

Nominal fishing effort serves to create a link between physical measures of fishing effort commonly used in fishery production models and fishing mortality. In simplist form, this relationship between fishing mortality and nominal fishing effort is given by

$$F = qf \tag{2}$$

where f denotes nominal fishing effort and q is defined as the catchability coefficient [Rothchild, 1977]. From equation (2) fishing mortality is seen to be proportional to nominal fishing effort. A more general form of equation (2) is given by

$$F = \phi(f,N,t) \tag{3}$$

with t defined as time and all other terms retaining their previous definition. Equation (3) implies that the relationship between nominal effort and fishing mortality may be nonlinear reflecting competition or saturation effects.

Physical measures corresponding to nominal fishing effort are generally rough measures of the magnitude of aggregate fishing activity. For example, nominal effort may be measured in terms of the total number of traps fished or the number of vessels engaged in a particular fishery. Such measures, however, are very heterogeneous with respect to their effect on the resource stock. Traps with different volume or construction, or vessels of different size almost certainly differ in their ability to catch fish (fishing power). Thus, to assign one unit of effort to each of these nominal measures would result in erroneous measures of fishing effort. Given this heterogeneity, it becomes apparent that decisions based on utilizing nominal fishing effort alone may be incorrect.

Fishing power provides a means by which nominal effort measures may be standardized to provide homogeneous measures of fishing effort. Standardization should ideally be based on factors such as the area over which the influence of a particular type of fishing gear extends and the proportion of fish caught in a given area [Gulland, 1964].

The biological treatment of fishing power in measuring total fishing power has been to define composite effort measures such as man-days-fished or vessel-ton-days [Segura, 1973]. Such measures may be adequate for stock assessment, but impose a very restrictive structure on the relationships between these factors and total effort when management strategies are being considered. Anderson [1976] apparently recognized this when he considered that vessels in a fishery could be considered to directly produce fishing effort rather than catch. Although Anderson did not explicitly discuss fishing power, his analysis serves to suggest that fishing power can be analyzed within the framework of economic production functions. This notion is expanded in the following treatment of fishing power in aggregate fishery production models.

A general function for the average fishing power of a nominal unit of effort can be given by

$$P_t = h(X_{it}, . . ., X_{nt}) \qquad (4)$$

where P_t denotes average fishing power in period t and the X_{it}, i = 1, . . ., n denote factors (inputs) which serve to determine the fishing power corresponding to each nominal unit of effort. Total effort in the fishery at any point in time is then given by the product of the nominal measure of aggregate fishing effort (f_t) and average fishing power as defined by equation (4)

$$E_t = f_t \cdot h(X_{it},. . ., X_{nt}) \qquad (5)$$

The definition of fishing effort as given by equation (5) offers two distinct advantages over the more conventional single composite variable representation of fishing effort. First, the fishing power function can be utilized to create a standardized measure of fishing effort, wherein the relative contribution of each factor determining fishing power and hence fishing effort is determined empirically rather than on an _a priori_ baiss. To see how this is accomplished, let h^* denote an estimated fishing power function. Fishing effort measured in standardized terms is then given by

$$E_t^* = f_t \cdot [\frac{h^*(X_{1t}, . . ., X_{nt})}{h^*(X1b, . . ., X_{nb})}] \qquad (6)$$

where the term in brackets corresponds to a fishing power index relative to the base factor levels X_{ib} i = 1, . . ., n. The h^* function in equation (6) merits further comment. Under a simple composite treatment of fishing power the h function is often assumed to be a product function.[1] The general treatment of fishing power (by means of h (·)), however, not only enables the relative contribution of factors affecting fishing power to be determined empirically, but also permits the validity of composite measures of fishing effort to be empirically tested.[2]

The second distinct advantage of generalized treatment of the fishing power function relates to management considerations. Management of fisheries often centers on the nominal fishing effort measure as the primary management vehicle. However, the management of only nominal effort may be insufficient for the attainment of management goals. The explicit inclusion of a general fishing power function with no or perhaps minimal *a priori* restrictions can greatly improve the ability of fishery managers to *effectively* control total fishing effort if necessary.

Empirical Considerations

Direct estimation of fishing power function such as given in equation (4) is not possible in that fishing power is not directly observable. However, parameter estimates can be obtained from an appropriately specified industry catch equation. A general expression for a fishery catch equation can be given by

$$C_t = g(E_t, N_t) \tag{7}$$

where C_t is catch in time t, E_t denotes total fishing effort and N_t is the resource stock size. Substitution of equation (5) into equation (7) for E_t yields

$$C_t = g(f_t \cdot h(X_{it}, \ldots, X_{nt}), N_t) \tag{8}$$

where all terms retain their original definitions. Catch is thus expressed as a function of nominal fishing effort, the factors which determine fishing power and the resource stock size. With the appropriate definition of the $g(\cdot)$ and $h(\cdot)$ functions in equation (8) the parameters of the fishing power function may be identified.

As an example, assume that the catch equation given in equation (7) takes the form

$$C_t = AE_t^{\beta_1}N_t^{\beta_2} \tag{9}$$

where all variables are defined as previously, and A, β_1, β_2 are constant parameters. In addition, let the fishing power function given in equation (4) take the form

$$P_t = X_{1t}^{\alpha_1}X_{2t}^{\alpha_2} \tag{10}$$

where P_t denotes the average fishing power of each nominal unit of effort and α_i, $i = 1,2$, are constant parameters.[3] Note that in equation (10), the α_i parameters are the output elasticities corresponding to each factor. When the fishing power index [equation (6)] is formed, the relative contribution to fishing power of each factor is then "weighted" by the corresponding elasticity. Thus, for the current example, it can be seen that the use of a simple composite measure of fishing power implicitly assumes that each factor in the fishing power function has a unitary output elasticity. Total effort is given by

$$E_t = f_t \cdot X_{1t}^{\alpha_1}X_{2t}^{\alpha_2} \tag{11}$$

which upon substitution into equation (9) yields

$$C_t = Af_t^{\beta_2}X_{1t}^{\pi_1}X_{2t}^{\pi_2}N_t^{\beta_2} \tag{12}$$

where $\pi_i = \alpha_i\beta_1, i=1,2$ and all other terms retain their previous definitions.

Equation (12) is presented in deterministic form. Although continuous data on the resource stock size is seldom available, an equation similar to (12) may be estimated. Furthermore, with the appropriate stochastic specifications, the estimated version of equation (12) can be utilized to obtain a derived equilibrium equation [Taylor, 1980].[4]

The hypothesis concerning the validity of the use of a simple composite measure of total fishing effort can now be tested utilizing the estimated coefficients β_1, π_1 and π_2 from equation (12). The appropriate tests are $\alpha_i \equiv \frac{\pi_i}{\beta_1}$ $i = 1,2$ equal to one against the alternatives of not equal to one. A rejection of at least one of these hypotheses would imply that the use of a simple composite measure of fishing effort is not an appropriate specification.

Fishing Effort in the Gulf of Mexico Reef Fish Fishery

The GMRFF is a multi-species, multi-state hook-and-line fishery. All of the Gulf of Mexico coastal states[5] participate in the fishery. The primary species taken are red snapper (*Lutjanus campechanus*), black grouper (*Mycteroperca bonacii*) and a red grouper (*Epinephelus morio*).

A catch equation similar to equation (12) was estimated for each state in the fishery utilizing annual data obtained from annual issues of *Fishery Statistics of the United States* (U.S. NMFS, 1957-76) for the years 1957-75. Nominal fishing effort was defined as the number of vessels (V) reported fishing out of each state. Fishing power was expressed as a function of the average crew size (CS) and average vessel size (VS).[5] The choice of these measures in determining fishing power are harmonious with the biological notions of fishing power.

The GMRFF is a hook-and-line fishery with each crewman generally operating only one fishing line. Given this, average crew size provides a reasonable measure of the "gear contact" with the resource stock. Vessel size provides an adequate measure of the area of influence over which the gear extends. The reasoning behind this is that larger vessels have the potential to fish a larger area than smaller vessels. Furthermore, given that weather and sea conditions can impair or prevent fishing from being undertaken, vessel size provides a rough measure of these factors' influences on catch.

The State catch equations were characterized as a system of seemingly unrelated regression equations with autoregressive disturbances and cross equation parameter restrictions. The catch equation for the ith state in double log form is given by

$$\ln C_{it} = A_i + B_1 \ln V_{it} + B_1\alpha_1 \ln CS_{it} + B_1\alpha_2 \ln VS_{it} + U_{it} \qquad (13)$$

where V_{it} denotes number of vessels, CS_{it} is average crew size, VS_{it} is average vessel size (gross registered tons) and U_{it} is a disturbance term. A complete discussion of the specification and estimation of the GMRFF catch equations is contained in Taylor [1980].

The cross-equation parameter restrictions on the catch equations imply that the fishing power function was the same for all states. The estimated fishing power function [see equation (10)] is given by

$$\ln P_{it} = \underset{(.2592)}{.9635} \ln CS_{it} + \underset{(.2697)}{.4601} \ln VS_{it} \qquad (14)$$

where all terms retain their previous definitions and asymptotic standard errors are in parentheses. The hypotheses of unitary output elasticities for crew size and vessel size were tested. The elasticity of crew size was not found to be statistically less than one at the .05 level of significance. The same test when applied to the elasticity estimate corresponding to vessel size, however, was rejected at the .05 level of significance. Thus, it appears that the use of a simple composite effort measure constitutes an erroneous specification.

The fishing power function in equation (14) was used to estimate fishing power indices for each state in this GMRFF (Table 1).[6] Table 1 illustrates that considerable adjustments in nominal effort (vessels) result when effort is standardized on the basis of fishing power. Examination of the unitary output elasticity index shows that the use of this type of index would greatly overstate measured fishing effort.

Summary and Conclusions

The preponderance of theoretical and empirical models of the fishery to date have emphasized the attainment of an equilibrium relationship between catch and sustainable yield. Very little attention has been directed toward the issue of an "empirically correct" measurement of fishing effort when individual firm data is not available. This is a serious shortcoming in that fishing effort is a pillar upon which the concepts of sustainable yield rest.

The disaggregation of the usual composite measure of fishing effort into a nominal component and fishing power component has been shown to be a superior method of fishing effort. In the example of the Gulf of Mexico Reef Fish Fishery, the composite measure of fishing effort was shown to be an inappropriate means of measuring effort. Fishing effort was greatly overestimated when the simple composite measure was utilized. This potentially could lead to an inference of overfishing when such is not the case. Management regulations imposed on the basis of inaccurate conclusions resulting from the erroneous measurement of fishing effort will not achieve the desired increases in economic efficiency and could possibly bring about unnecessary economic and social costs on the users of the fishery.

Table 1. A comparison of estimated fishing power indices by state, 1957-75

Year	Florida West Coast		Alabama		Mississippi		Louisiana		Texas	
	I[a]	II[b]	I	II	I	II	I	II	I	II
1957	1.064	1.338	2.271	3.752	1.210	1.321	1.315	1.290	0.970	1.470
1958	1.176	1.415	2.361	4.085	1.297	1.650	1.281	1.391	1.154	1.776
1959	0.932	1.191	2.468	4.440	1.514	2.118	1.366	1.573	0.915	1.394
1960	1.000	1.000	2.471	4.445	1.971	2.985	1.423	2.171	1.165	2.020
1961	1.001	1.101	2.729	4.718	2.133	3.270	1.278	2.043	1.102	1.891
1962	0.984	1.001	2.785	4.943	2.487	3.962	1.604	2.555	1.153	1.970
1963	0.994	1.177	2.870	5.269	2.527	4.063	1.623	2.567	1.327	2.089
1964	0.959	1.139	2.755	5.042	2.571	4.217	1.594	2.773	1.585	2.606
1965	0.909	1.075	2.970	5.636	3.057	5.609	1.461	2.609	1.553	2.554
1966	0.937	1.089	3.251	6.293	3.148	6.112	1.554	2.970	1.836	3.063
1967	0.930	1.090	3.119	6.035	3.529	7.409	1.073	2.082	1.657	2.817
1968	0.911	1.080	2.973	5.786	3.328	6.916	1.098	2.189	1.538	2.758
1969	0.960	1.188	2.973	5.786	3.325	6.957	1.098	2.189	1.491	2.671
1970	0.875	1.088	2.404	4.725	3.268	6.915	1.268	2.406	1.377	2.446
1971	0.893	1.114	2.407	4.738	3.299	7.082	1.172	2.090	1.723	3.141
1972	0.783	0.919	2.458	4.935	3.295	7.111	0.963	1.648	1.648	2.860
1973	0.774	0.902	2.447	4.979	3.322	7.226	1.153	2.086	1.547	2.561
1974	0.860	1.110	2.612	5.505	3.309	7.260	1.250	2.365	1.504	2.474
1975	0.766	0.909	2.612	5.505	3.313	7.268	1.229	2.315	1.592	2.636

[a] Index I utilizes the estimated fishing power function given in equation (13).

[b] Index II is estimated under the assumption of unitary output elasticities.

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FOOTNOTES

[1] The product function as used here implies that $h(X_1, \ldots, X_n) = X_1X_2, \ldots, X_n$. Given an index such as that given in equation (6), it can be seen that each factor is implicitly assumed to have the same effect on fishing power and hence standardized fishing effort.

[2] This point will be discussed further in the ensuing discussion.

[3] The constant term usually found in equations similar in form to equation (10) is set at one. Scaling this parameter in such manner involves no loss of generality.

[4] The derived equilibrium form of equation (12) approximates only half the traditional sustainable yield function. From a management standpoint this does not limit the usefulness of the notion in that the region of approximation corresponds to the economic region of production.

[5] The Gulf of Mexico coastal states include Florida, Alabama, Mississippi, Louisiana and Texas.

[6] The fishing power index is given by $I_{it} = \left(\frac{CS_{it}}{CS_b}\right)^{.9635} \left(\frac{VS_{it}}{VS_b}\right)^{.4601}$,

where I_{it} is the effort index. The index base values correspond to average vessel size and crew size of Florida vessels in 1960.