Natural resources

Maryland. University. Dept of agricultural economics

1980

Resource Stocks and Supply Estimation:

An Alternative Approach

Ivar E. Strand and Robert G. Chambers

ABSTRACT

An approach to resource supply estimation is developed which circumvents the need for direct observations in the resource stock. Estimation of supply response in this framework will also permit direct estimation of several important biological parameters from economic data.

Presented at AAEA meetings, Urbana, July 27-30, 1980

Resource Stocks and Supply Estimation:
An Alternative Approach

Resource economists are frequently asked for specific policy recommendations regarding common property renewable resources. Their response usually relies on the conventional wisdom which suggests that allocation of property rights or imposition of severance taxes (or bounties) are necessary to achieve a social optimum (Mohring and Boyd). The underlying logic is that the competitive market place neglects the productive value of the resource stock; hence, the government must manage the stock to assure optimal stock size.

To determine optimal stock size, however, one must study the effect of the resource stock on the industry supply curve. One recent approach used an estimated resource growth function and a production function to derive a profit function which has resource stock as an argument (Henderson and Tugwell). The second, more common approach is to use an environmental surrogate for the resource stock and obtain a supply curve independent of resource stock (e.g., Bell; Griffin, Lacewell and Nichols). In this paper, a third approach is taken which uses fundamental production relationships to derive a supply equation which can be directly estimated.

The approach offers not only economic policy information, such as supply elasticity and marginal value of resource stock, but considerable biological information including estimates of natural mortality and average recruitment (i.e., new additions to the stock). It is therefore more generally applicable than the first approach and offers more information than the second approach. Finally it allows the researcher (under certain assumptions) to test statistically the null hypothesis of a stock independent recruitment relationship against the alternative hypothesis of stock dependent recruitment. The approach requires only industry price, output and input data. Thus, to a large extent the suggested approach circumvents the need for data on the size of the resource stock.

Background

Despite considerable attention afforded common property resources (e.g., Smith; Burt and Cummings), very little research has been undertaken to determine the optimal quantity and value of a common property resource in practical situations. Long-run, simulated steady state models have dominated most attempts at modeling optimal stock sizes (e.g., Gates and Norton). While these are useful, one must wonder why the usually more common econometric approach has not taken hold. Using this approach, one might incorporate an abundance variable as a shift factor in the industry supply function since output is usually presumed to be responsive to stock density.

The problem, of course, is that this specification requires reliable data on the stock size. However, as Plourde noted,

> "Difficult measurement problems are inevitable. One is the measurement of biomass [resource stock size]. Another is the [resource] growth function." (p. 265)

Candidates for abundance or biomass variables have included independent biological estimates of stock size (Tugwell and Henderson) and yield per effort measures (Strand and Matteucci). Biological surveys are in most instances not available, because of costs, and those available are often not reliable. The use of the yield per effort alternative is questionable because industrial changes make the effort variable subject to substantial error over time. Furthermore, including a transformation of yield as a regressor in a yield equation prevents consistent estimation by standard approaches since there is correlation between the regressor matrix and the vector of error terms.

Neoclassical theory suggests that supply is a function of factor prices, the output price and any fixed factors of production. Incorporating abundance terms in econometric supply equations implicitly assumes that abundance can be treated as a fixed factor of production. This in turn implies that abundance is freely variable over the long run and under the direct control of the economic agent. Because of the biological and social processes involved, this is usually not the case. For example, standard formulations such as a Cobb-Douglas production function with abundance entering as a fixed factor (c.f. Henderson and Tugwell) suggest that there exists some degree of substitutability, at least in the long run, between effort and stock density. While economic agents can undoubtedly substitute extra effort in response to decreasing stock density, it is not entirely clear that this relationship is symmetric since stock density is not usually under the control of the individual agent nor even necessarily under the direct control of all agents aggregated together. Thus, specifying stock density as an "input" to a production process appears questionable. This paper offers an alternative approach; namely that stock density be treated as an efficiency parameter which is capable of varying from period to period.

Once stock density is treated as a varying efficiency parameter, the way is cleared for a straightforward approach to supply estimation. A production function is specified and this along with standard assumptions about behavior in a market for a common property resource leads to a well-defined supply function that is a function of output and factor prices.[1] In fact under appropriate assumptions, consistent estimates of the production parameters can be recovered from consistent estimates of the supply parameters. The supply equation is thus a reduced-form for the production model.

---

1 Because of the varying parameter forms of the efficiency term, it will also be necessary to include an effort term in the constant.

The analysis begins with a theoretical development of population dynamics in a renewable resource industry. The current population or resource size is presented as a solvable difference equation. The solution is then incorporated in production and supply relationships. As it turns out, the resulting supply equation is autoregressive but can be estimated using maximum likelihood methods.

THEORETICAL FOUNDATION

Resource Stock Considerations

Renewable resource stocks (numbers or biomass) at a point in time (t+1) are dependent on a variety of factors that are best categorized as previous stock size (X_t), effort (E_t) or other measures of variable input to the production process and environmental factors (Z_t):

$$X_{t+1} = g(X_t, E_t, Z_t) \qquad (1)$$

The form of g(...) and the components of Z_t will vary according to the resource under consideration. For example, if the resource was an estuarine finfish (e.g., striped bass), next year's stock of the resource would depend on the current stock level, the current effort expended to harvest current stocks, and the salinity or temperature changes during the critical embryonic stage of development. In the case of insect populations, the environmental factors might include spring rainfall or mean winter temperature.

A plausible approach[2] to specifying equation (1) is to assume that the function g(...) is separable to a degree that permits quasi-independent investigation of the effect of previous stock level and environmental factors. For a wide variety of resource stock problems, the effect of environmental

[2] For purposes of exposition, stock size is defined as numbers of the resource. This is a useful approximation for resources that do not grow in size during exploitation or for pests where the total biomass is not relevant. For many resources, however, more development (and mathematical clutter) is required.

factors can be confined to the level of recruitment (new specimens entering the stock). It will be assumed in the succeeding analysis that g(...) is in fact additive and further that recruitment (R_t) can be decomposed into a stock dependent and stock independent effect, i.e.,

$$R_t = A_t + r(X_t) \tag{2}$$

where A_t is stock independent recruitment which is taken to be a random variable with mean A_o and additive stochastic component ε_t; $r(X_t)$ is the stock dependent recruitment function. To simplify, it is assumed that the stock dependent recruitment function is proportional to stocks (i.e., $r(X_t) = r \cdot X_t$). This will be a reasonable approximation in instances where stocks do not vary greatly. Finally, the non-environmental portion of g(...) will be specified as $\gamma_t(E_t)X_t$ which is the amount of current population transmitted to the next period. Equation (1) can therefore be rewritten as the following difference equation:

$$\begin{aligned} X_{t+1} &= \gamma_t(E_t)X_t + rX_t + A_t \\ &= (\gamma_t + r)X_t + A_t \end{aligned} \tag{2'}$$

Equation (1') has the general solution

$$X_{t+1} = X_{t-m} \prod_{i=0}^{m} (\gamma_{t-i} + r) + \sum_{i=0}^{m} A_{t-i} \prod_{j=0}^{i-1} (\gamma_{t-j} + r) \tag{3}$$

where for notational convenience $\prod_{i=t}^{t-1} (\ldots) = 1$. Letting m tend to infinity and recognizing that both γ_t and r are less than one, reduce (3) to:

$$X_{t+1} = \sum_{i=0}^{m} A_{t-i} \prod_{j=0}^{i-1} (\gamma_{t-j} + r). \tag{4}$$

Current stocks can be expressed solely as an infinite order distributed lag function of past recruitment and effort. Therefore for practical econometric purposes, the current level of stocks can be viewed as independent of previous stock levels. The actual form of γ_{t-j} further limits the effect effort in period k has on current stock since γ_{t-k} will identically equal zero for large enough k. Therefore, effort only enters the distributed lag with a finite order.

Modeling Supply

In this section, a general supply equation is developed. The assumed industry production relation is

$$Y_t = \exp(\beta X_t)E_t^{\alpha} \quad (5)$$

where β is normalization factor, and Y_t is output at time t and X_t is defined above. Free entry into the market and the common property nature of the resource can force the industry to a zero profit situation.[3] Hence,

$$P_tY_t = W_tE_t \quad (6)$$

where P_t is output price and W_t is the price of effort. Taking logarithms and solving (5) and (6) obtains

$$\ln E_t = [\ln P_t + \beta X_t - \ln W_t]/(1-\alpha). \quad (7)$$

Substitution of this expression into (6) yields the industry supply function (in logarithmic form)

$$\ln Y_t = [\beta X_t + \alpha \ln (P_t/W_t)]/(1-\alpha). \quad (8)$$

Expression (8) is the industry supply function and contains the stock level as a shifter. As is clear from previous specifications, the X_t term consists of a parametric component (albeit varying) and a stochastic component. Subsequent development will make use of this fact. Finally, substitution of (4) into (8) yields

---

[3] In many instances, one might choose other alternative equilibrium conditions.

$$\ln Y_t = [\beta \sum_{i=1}^{\infty} A_{t-i} \prod_{j=1}^{i-1} (\gamma_{t-j} + r) + \alpha(\ln P - \ln W)]/(1-\alpha) \tag{9}$$

which, upon noting that $A_t = A_o + \varepsilon_t$, can be rewritten as

$$\ln Y_t = [\beta \sum_{i=1}^{\infty} A_o \prod_{j=1}^{i-1} (\gamma_{t-j} + r) + \alpha \ln(P_t/W_t)]/(1-\alpha) +$$

$$\beta[\sum_{i=1}^{\infty} \varepsilon_{t-i} \prod_{j=1}^{i-1} (\gamma_{t-i} + r)]/(1-\alpha). \tag{10}$$

Hence, the optimal supply for the industry under question can be represented as possessing an infinite order, moving average error process.

Econometric Considerations

Expression (10) suggests that there are some serious econometric problems that must be faced in estimating any such supply equation. Both the constant term and the error structure contain the parametric expression, γ_t, which is capable of varying from one time period to the next. Secondly, the error structure is both heteroscedastic and autocorrelated. Put another way, the covariance matrix for the error terms (assuming ε_t is i.i.d with mean zero and variance σ^2) can be written as $\Omega(\sigma\beta/1-\alpha)^2$ where Ω is the matrix with typical diagonal element $\omega_{tt} = [1 + \sum_{j=1}^{\infty} \prod_{k=1}^{j} (\gamma_{t-k} + r)^2]$

and off-diagonal element $\omega_{t,t-s} = \prod_{j=1}^{s} (\gamma_{t-j} + r)[1 + \sum_{i=s+1}^{\infty} \prod_{k=s+1}^{i} (\gamma_{t-k} + r)^2]$.

Therefore, each element of the covariance matrix is itself of infinite order so that in the most general case estimation will be impossible because of a lack of degrees of freedom. Fortunately, the very nature of γ_t obviates this problem. First of all, there will be some finite k (say d) such that

$\gamma_{t-k}=0$ for all $k>d$. Hence, the expression for ω_{ii} will simplify in that after d is reached, the expression for ω_{tt} can be decomposed into a finite order term and an infinite series in r, i.e.,

$$\prod_{j=1}^{d-1} (\gamma_{t-j}+r)^2 + \prod_{i=d}^{\infty} (r^2)^i.$$

Of course, a similar decomposition will apply for each of the off diagonal elements.

Biological studies will often leave the researcher with an excellent idea of exactly how to specify $\gamma_t(E_t)$. Suppose, following Beverton and Holt, that $\gamma_t(E_t) = \exp(-M-cE_t)$ where M and c are defined as instantaneous natural mortality rate and a parameter that relates effort to instantaneous fishing mortality, respectively. Both are assumed constant but unknown. This assumption reduces the problem associated with the covariance matrix to that of estimating these parameters. Of course, there is still somewhat of a degrees of freedom problem but this can be compensated for by performing the statistical estimation starting with the $d+1^{th}$ observation.

From the preceeding arguments, it is apparent that estimation (if possible) of the supply function in the form of (10) will provide the researcher with some valuable biological and economic information. This follows from the fact that this supply model is a reduced form for the production model. Direct estimation, say by maximum likelihood methods, will provide estimates of the output elasticity with respect to effort (α) the mean recruitment level (A_o), the rate of instantaneous mortality (M), the density dependent recruitment rate (r) and the catch coefficient (c). Additionally, transformation of these estimates will provide maximum likelihood estimates of $\alpha/1-\alpha$, the elasticity of supply with respect to output price. The estimation of the biological parameters r and M is particularly relevant as it suggests that much of the biological information that is currently gathered by survey techniques could be estimated consistently from observable market data. Furthermore, some important biological hypotheses are easily tested within this framework. For example, there is a widespread belief that for certain resources the level of recruitment is really stock independent and the result of random environmental factors. In the framework of the above model the hypothesis of stock independent recruitment is equivalent to the supposition that $r=0$. Therefore, it is possible to test directly the null hypothesis of stock independent recruitment via classical techniques.

Policy Considerations

Because many of the resources to which this model applies are common property resources, it is interesting to examine the possible policy content of the proposed methodology. Fisheries resources, wildlife resources and pests are among classes of resources that have required government intervention to preclude over or under-utilization. The nature of most externalities associated with common property resources are supply associated and therefore should be contained in equation 10.

Considering the production processes (equation (1') and (5) and a fixed output price (P_t)), a single owner of the resource would solve the following:

$$\max_{E_t} \quad L = \sum_{t=0}^{T} [(P_t \exp(\beta X_t) E_t^{\alpha} - W_t E_t)(1+i)^{-t} - \lambda_{t+1}(X_{t+1} - X_t \exp(-M-cE_t) - A_c)]$$

where λ_{t+1} is the discounted marginal value of the resource in t+1 and i is the discount rate.

Solving the first order conditions yields

$$P_t Y_t - W_t E_t = E_t (1+i)^t [\lambda_{t+1} c X_t \exp(-M-cE_t)] \tag{11}$$

Comparing this result with the equilibrium represented in (6) leads one to the typical conclusion that competitive exploitation over-exploits for beneficial resources ($\lambda_{t+1}>0$) and under exploits for harmful resources ($\lambda_{t+1}<0$). One could also use the information gained from estimation of equation (10) to solve the sole owner problem and determine optimal levels of effort.

CONCLUSION

The purpose of this paper was to propose an alternative method of estimating supply for natural resource industries. The method does not require information on the stock of resources but rather relies on appropriate specification and randomness of resource growth to obtain consistent estimates of production, market and bioligical relationships. Application of the method is currently underway and should offer guidance as to its general usefulness.

Literature Cited

Ball, Frederick W., "Technological Externalities and Common Property Resources: An Empirical Study of the U.S. Lobster Industry", J. of Pol. Econ., Vol. 80 (1972): 148-158.

Beverton, R.J.H., and S.V. Holt, 1957. On the Dynamics of Exploited Fish Populations, Fishery Investigations, II, Vol. 19, London: HMSO.

Burt, O.R. and R.G. Cummings, "Production and Investment in Natural Resource Industries", Amer. Econ. Rev. 110 (1970): 576-590.

Gates, John M. and Virgil J. Norton, "The Benefits of Fisheries Regulation: A Case Study of the New England Yellowtail Flounder Fishery", Marine Tech. Report, No. 21, U. of Rhode Island, Kingston, Rhode Island, 1974.

Griffen, W. L., R.D. Lacewell, and J.P. Nicholls, "Optimum Effort and Rent Distribution in the Gulf of Mexico Shrimp Fishery". Am. J. Agr. Econ., 58 (1976): 644-652.

Henderson, J.V. and M. Tugwell, "Exploitation of the Lobster Fishery: Some Empirical Results", J. of Env. Econ. and Man., Vol. 6 (1979): 287-296.

Mohring, H. and J.H. Boyd, "Analyzing 'Externalities:' 'Direct Interaction' vs 'Asset Utilization' Frameworks," Economica, August, 1971: 347-361.

Plourde, C.G., "Exploitation of Common-Property Replenishable Natural Resources," West. Econ. J., 28 (1973): 256-267.

Smith, Vernon L., "On Models of Commercial Fishing". Journal of Political Economy, 77 (1969): 181-198.

Strand, I.E. and A. Matteucci, "Economic Interdependencies in Fisheries: Empirical Evidence and Management Implications", Paper presented at the American Agricultural Economics Assoc. Meeting, San Diego, CA, 1977.