IMPACT PROJECT

A Commonwealth Government inter-agency project in co-operation with the University of Melbourne, to facilitate the analysis of the impact of economic demographic and social changes on the structure of the Australian economy

THE TREATMENT OF THE FISHING INDUSTRIES IN THE LONG RUN CLOSURE OF ORANI

by

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IMPACT Project Research Centre

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The views expressed in this paper do not necessarily reflect the opinions of the participating agencies, nor of the Commonwealth government.

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ABSTRACT

ORANI 78 is a large multisectoral model of Australian industry structure. Whereas various types of arable and pastoral land distinguished in the model serve as fixed factors which set a limit to the volatility of the simulated long run behaviour of rural industries, no analogous constraints yet apply (March 1981) in the case of the fishing and mining industries. This paper explores the relevance of biological and institutional constraints for the respecification of ORANI so as to make its long run behaviour more realistic in the case of fishing. It is concluded that the latter industry needs disaggregation at least as far as two groups: predominantly exported seafood (lobsters and prawns), and the remainder. In the case of the former sector the capital stock should be treated exogenously both in long and in short run simulations. The parameter file should be revised so that the capital/labour substitution elasticity in this sector is close to zero (thus making output effectively exogenous). For the domestic market oriented sector of the industry the existing standard ORANI treatment will suffice in view of the fact that this sector's linkage to domestic consumption will effectively curb any tendency for implausibly volatile behaviour in long run simulations.

To facilitate separate treatment of the export oriented and the domestic market oriented sectors of fishing, the existing single ORANI industry will have to be disaggregated to become at least two distinct industries. This work should be given priority as a critical task for completion of the long run closure of ORANI.

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1. Introduction

ORANI 78 is a large, multisectoral model of the Australian economy which contains 113 industries producing 115 commodities.[1] The model is in an advanced stage, the remaining major issues for research centring around its closure with respect to the macroeconomy and the supply side of the labour market. One aspect of closure not yet fully resolved concerns the long run supply behaviour of the mining and fishing industries in the model. Whereas various types of arable and pastoral land are distinguished explicitly as primary factors of production which serve to limit the volatility of the long run output responses of ORANI's rural industries, no analogous constraints yet apply to the current (March 1981) treatment of the fishing and mining sectors. Consequently, in the long simulations depicting changes in their cost/price outlook, the mining and fishing industries' outputs become unrealistically volatile.[2] The aim of this paper is to explore

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1. Peter B. Dixon, B. R. Parmenter, John Sutton and D. P. Vincent, ORANI, A Multi-sectoral Model of the Australian Economy (Amsterdam : North-Holland Publishing Company, forthcoming, 1981)

2. See D. P. Vincent, "Some Implications for the Australian Economy of Trade Growth with Newly Industrializing Asia : The Use and Limitations of the ORANI Framework," IMPACT Preliminary Working Paper No. OP-26, Melbourne, July 1980. (The fixity of the capital stock in short-run simulations prevents the excessive volatility encountered in long-run simulations.)

the relevance of biological and institutional constraints for respecification of ORANI so as to make its long run behaviour more realistic in the case of fishing.

The paper is structured as follows. Section 2 contains a brief overview of the structure of the fishing industry. In Section 3 an examination is made of the relevant theoretical considerations pertaining to a reproducible resource. These theoretical results are related to the behaviour of important sub-sectors of the fishing industry in Section 4. The question of how ORANI should be respecified in the light of the insights provided by Sections 3 and 4 is taken up in Section 5, while brief concluding remarks are offered in Section 6.

In the export sector of fishing (three quarters of the total in 1978/79) the conditions pertaining either approximate those described above (lobsters and prawns with non-estuarine breeding habitats), or else involve a combination of licensed capacity and highly erratic output which is almost 100 per cent climatically determined (prawns with estuarine breeding habitats). In either case capacity and (given limited scope for capital/labour substitution) output are exogenous to ORANI, in both long and in short run modes For predominantly export commodities, prices are, to a good approximation, determined in ORANI by output and by overseas demand conditions. The endogenization of prices for lobsters and prawns in ORANI would therefore be likely to be reliable. Given the imperfect nature of the property rights bestowed by licensing, however, it follows that cost and profitability variables endogenized for these industries in ORANI should be viewed with caution.

The non-export oriented segment of fishing is a very diverse one. This heterogeneity would make it difficult to quantify the extent to which this sector's long run supply curve slopes upward as the result of bio-feedback and/or regulation. Given resources and priorities, the work involved cannot at this stage be mounted. In the meantime treatment of the non-export sector of fishing as a standard industry (with capital stock exogenous in short run simulations and with rate of return exogenous in long run simulations) will not cause the model to behave implausibly. This is because any tendency for wild variations in the simulated size of the non-export sector of fishing will be prevented by the relatively low income and price elasticities assigned to the products of this sector in the ORANI parameter file.

5.2 Mainly Import Competing Seafood

To handle this segment of the industry in other than approximate fashion would involve much more detailed information on its structure and regulation than has been possible in the context of the present exercise. A large number of species, fisheries, and regulatory authorities is involved. The aggregate picture we would expect to be one in which the biological resource constraint leads to a mild upward slope on the long run supply curve of this segment of the industry. No data are available with which to attempt to quantify this surmise. Leaving the biological resource factor out of account is not expected to lead to wild errors in ORANI simulations, however. Firstly, in short run simulations, the fixity of the capital stock rules out highly volatile behaviour. Secondly, in long run simulations the output of this sector is limited by domestic demand. With price and income elasticies for the products of this sector in the ORANI parameter file set to values well below unity, its simulation properties should remain well behaved. This is not to say, however, that accurate (as distinct from plausible) long run simulations of the import competing sector of fishing can be obtained without strengethening the data base.

6. Concluding Remarks

Many fisheries provide examples of 'self regulating resources' in which feedback from current output levels to future output levels occurs via effects on the size of the fish population. The potential for a difference to develop between social and private valuations of future output provides a rationale for regulation of the industry. Typically such regulation leads to policies which establish, to a good first approximation, regimes of stationary fish population and catch. This is achieved principally by licensing inputs. In such cases ORANI simulations should take capacity as exogenous, both in the long and the short run.

2. The Australian Fishing Industry : Brief Overview

The Australian Fishing Industry essentially consists of two sectors. First, there is the import competing sector which, relative to the second - - the exporting sector - - is small in size. The exporting sector consists primarily of the prawning industry (which is based in Queensland, Western Australia and the Northern Territory) and the rock lobster industry (based both in Western and South Australia), with abalone, oyster, shark and tuna forming the major part of the remainder. As an indication of their relative sizes, consider Table 1, which details the values of their respective catches for the 1978-79 year.

Table 1 : Major Components of Australian Fishing, 1978-79

Species	Value of Catch (Principal States) ($'000)	Total Australia ($'000)	Per Cent
Prawns	Qld.: 47,656; W.A.: 16,000 N.T.: 17,100	100,648	38
Rock Lobsters	W.A.: 56,820	73,624	28
Total Molluscs (Abalone, Oyster, Scallop, etc.)	N.S.W.: 15,095; Tas.: 6,250	32,348	12
Total Scale Fish (Shark, Tuna, etc.)	N.S.W.: 17,526; Vic.: 13,125; S.A.: 8,714	56,617	22
Grand Total		263,237	100

Source : A.B.S., Australian Fisheries, 1978-79 (Canberra).

The Table shows that the prawn industry contributed about 40 per cent of total output, whilst the rock lobster industry contributed approximately 30 per cent. The importance of these two sectors is further demonstrated in Table 2 which shows the values of exports of each of three principal fishing sectors in 1978-79 and the composition of fishing exports by value for 1974-75 to 1978-79.

Table 2 : Composition of Australian Fishing Exports, 1974-75 to 1978-79

Species	Percentage Composition of Value of Fishing Exports					Value of Exports 1978-79 ($'000)
	1974-75	1975-76	1976-77	1977-78	1978-79	
Prawn	36	37	39	41	49	93,367
Rock Lobster	48	46	43	44	36	70,428
Other	16	17	18	15	15	30,334
Total	100	100	100	100	100	194,129

Source : A.B.S., Australian Fisheries, 1978-79 (Canberra).

In 1978-79 prawns and rock lobsters contributed more than 80 per cent of total fishing exports. Given their importance, these two sectors will be considered in some detail. It is these two sectors especially that contribute to the problems faced in a long run ORANI simulation, for they are subject to a highly elastic overseas demand and hence their output is not constrained effectively by the demand side of the market; that is, for a given export price, they could, in the absence of supply considerations, expand virtually indefinitely.

While (24) would give the appropriate price determination mechanism, care would be needed in interpreting some other variables. Consider, for example, the consequences of a windfall gain consisting of an exogenous 4 per cent increase in world demand ($f^e_{(i1)}$ = 4 per cent). At the initial level of exports (viz., $x^{(4)}_{(i1)} = 0$) this translates into a four per cent increase in the f.o.b. price ($p^e_{(i1)} = 4$). According to the ORANI specification, such a price increase, if unmatched by corresponding cost increases, leads to a short run increase in the rentals on capital equipment, i.e. in profitability. In the standard way of computing longer run ORANI simulations it would lead to increased investment and a higher capital stock; in the case of fishing this would mean more or larger boats, etc. But as we have seen above in Section 4, neither of these conclusions is warranted in the case of a regulated natural resource industry like lobsters and/or prawns.

In the short run the windfall price rise does not necessarily translate fully into higher short run profitability as the intensity of fishing effort may rise competitively within the fishery to eliminate part or all of the windfall gain. Such activity is not modelled in ORANI. To put it slightly differently, ORANI would get the price right but the changes in costs and rentals wrong.

In standard long run ORANI simulations the rates of return on assets are set exogenously by the going international supply prices of capital of various sorts; capital stocks then adjust to yield Australian industries whose sizes are consistent with these externally set rates of return at the future date to which the model solution applies. Under the proposals made above, however, the rates of return on prawning and lobster catching would remain endogenous in both long and short run simulations.

1. See Vincent, op. cit.

for ORANI computations. There is little scope for capital/labour substitution in prawn and lobster fishing and such scope as exists is attenuated by the regulation of these industries. The capital/labour substitution elasticity σ_{KLj} for these industries should therefore be set close to zero (for both long and short run simulations).[1]
With $\sigma_{KLj} = 0$, the percentage change in output $x_{j1}^{(0)}$ of commodity j is equal to the percentage change in capital capacity $k_j(0)$. Exogenizing the latter, therefore, effectively exogenizes the former.

Since domestic consumption of prawns and lobsters is small in relation to total output, the major influences on price formation are the export demand schedule and the quantity produced locally. This is reflected in the ORANI structural form equation.

$$(24) \qquad p_{(i1)}^{e} = f_{(i1)}^{e} - \gamma_i x_{(i1)}^{(4)}$$

which states that the percentage change $p_{(i1)}^{e}$ in the foreign-currency export price (f.o.b.) is equal to the percentage shift upward $f_{(i1)}^{e}$ in the export demand schedule for good i (lobsters or prawns) minus an allowance $\left(\gamma_i \, x_{(i1)}^{(4)}\right)$ for the depressing effect on world price occasioned by the percentage increase $x_{(i1)}^{(4)}$ in Australian exports. The coefficient γ_i is the flexibility of export demand, so that $(1/\gamma_i)$ is the export demand elasticity.

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1. In ORANI 78 (Dixon, Parmenter, Sutton and Vincent, op. cit.) the substitution among factors follows the CRESH specification. There is, however, a unique substitution elasticity associated with any given setting of the CRESH parameters. Working in the other direction, it is not difficult to find values of the CRESH parameters which imply $\sigma_{KLj} = 0$.

Whilst these two industries are similar in their importance in relation to export earnings, they are quite different in terms of the forces underlying the biological behaviour of their populations over time, and in the reaction of those populations to the activities of the fishermen in the respective industries. The rock lobster is a slowly growing, long lived species (whose life span exceeds 5 years),[1] in which, therefore, the population level at any one period is closely related to the levels in the years preceding it, with the consequence that the current level of fishing activity has an immediate adverse impact upon population levels over the next several years. Prawns and shrimps provide a complete contrast. According to Anderson,

> "... the population of this species in any one year depends chiefly upon certain ecological conditions during critical phases of its life cycle and bears little relation to population size in the previous year."[2]

In the Australian context, the banana prawn of the Gulf of Carpentaria fishery is very fast growing and short lived (with a life span of about a year). The critical ecological conditions in this case are those in the estuaries and creeks in which the prawns breed.[3] These in turn depend largely on rainfall.

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1. A useful reference for the biodynamics of the rock lobster population is : P. W. George, G. R. Morgan, B. F. Phillips, "The Western Rock Lobster, *Panulirus Cygnus*," Journal of the Royal Society of Western Australia, Vol. 62, Parts 1-4, 1979, pp. 45-51.
2. Lee G. Anderson, The Economics of Fisheries Management (Baltimore & London : Johns Hopkins, 1977), p.103.
3. CSIRO, private communication, February 1981.

Within each fishery, the level of fishing activity is controlled to a greater or lesser extent by the relevant statutory authorities. Such control usually originates from the past, when periods of severe overfishing caused the authorities to intervene in order to protect the long term interests of the industry. Such control usually consists of a licensing system to limit entry into the fishery - - this being the case for the Western Australian rock lobster and the North Queensland prawn fisheries - - and/or of a set of regulations controlling one or more of the following : the amount and type of fishing equipment that is permissible, the size of fish that may be caught and the times when fishing may be undertaken. All of these are designed to limit the level of fishing activity and the size of the fish catch.

demand for their output is primarily domestically based. Scale fish are almost entirely domestically consumed and are thus subject to domestic demand constraints. Abalone however, is primarily exported - - although the size of the exports is relatively insignificant.[1]

5. Specification of ORANI Simulations

The foregoing description of Australian fishing has been partial, particular emphasis being given to the northern prawn fishery and the Western Australian rock lobster fishery. With respect to lobsters, it is believed that broadly similar considerations would apply to the fisheries in other states.

Given sufficient data on cost structures and sales patterns, the optimal procedure from the viewpoint of ORANI would involve a three way split along the following lines:

(a) Mainly Exported Seafood

(a.i) Prawns

(a.ii) Lobsters

(b) Mainly Import Competing Seafood.

5.1 Mainly Exported Seafood

Under such a classification output of prawns and lobsters would be set effectively exogenously in ORANI simulations (both long and short run). The direct instrument controlling output is capital capacity, and it is this variable which would be declared as exogenous

1. Australian Bureau of Statistics, Australian Fisheries 1978/1979, Canberra.

where it appears that breeding patterns are highly dependent upon climatic conditions (that is, the population dynamics of all species with estuarine breeding grounds exhibit a climatically induced volatility reminiscent of the North Queensland Banana Prawn).[1]

The mollusc sector comprises mainly oysters and abalone, of which N.S.W. and Tasmania respectively are the major producers. Whilst oyster farming is entirely different in concept to any other fishery in that property rights to the oysters apply through the incorporation of private oyster farm leases, abalone, it appears, is subject to a population dynamics that enables the application of the Schaefer model. In particular, the principal aim in the Victorian fishery is to regulate the level of effort (through non-transferable licences) between the levels associated with the M.E.Y. and M.S.Y.[2] Tasmania also has a limited entry abalone fishery, but in this case the licences are fully transferable, the value of a licence being over $45,000 in late 1977.[3]

The remaining crustacean sector consists only of crab - - primarily fished in Queensland, where entry into the fishery is open (but subject to closure from time to time).[4] Its level of output is, however, very insignificant.

It must be noted that these fisheries are not particularly relevant for the problem faced in a long run ORANI closure since the

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1. From personal communications with the Victorian Division of Fisheries and Wildlife, February 1981.
2. Ibid.
3. Background paper for Seminar Feb, 1980, op. cit.
4. Ibid.

3. Theory of Reproducible Resources and Optimal Fishery Management : the Shaefer Model

The stock of fish in the sea may be classified as a reproducible resource, for although depletion of the stock may occur as a result of activity carried out by the fishing industry, the stock is self generating due to the process of natural reproduction. In fact, the processes of fishing activity, natural breeding, and changes in the size of the fish stock are mutually dependent. The purpose of this section is to examine these interdependencies and their implications for optimal fishery management - - management that aims to yield the optimum (in some sense) benefit to members of the fishing industry and/or to society as a whole. The bulk of the material contained in this Section may be collectively referred to as 'the Shaefer model', after the marine bioeconomist who developed the stationary state analysis of population stock and fishing effort based on the logistic growth law which we now describe.[1]

3.1 The Logistic Growth Law[2]

The relationship between the reproductive process, the stock of fish and the activity of the fishing industry is essentially biological in nature. Previous research has indicated the suitability of the logistic function as a vehicle for capturing the pattern of biological population growth over time.[3] In a population subject only to natural competition and the constraints of the available habitat, the logistic growth law states that the time rate of increase of the population (number of fish per year, say) at instant t is directly proportional to the existing population $N(t)$ and inversely proportional to the proportional

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1. M.B. Schaefer, "Some Considerations of Population Dynamics and Economics in Relation to the Management of Marine Fisheries," Journal of the Fisheries Research Board of Canada, Vol. 14 (1957), pp. 669-681.
2. This section and the next draw heavily on Colin W. Clark, Mathematical Bioeconomics : The Optimal Management of Renewable Resources (New York : Wiley, 1976), and on Lee G. Andersen, op. cit.
3. More sophisticated less symmetrical sigmoidal curves are of course available. The extra complications involved in their use in the present exercise did not seem to be justified by the very limited pay-off in terms of general insights.

gap $(1 - \frac{N(t)}{N_S})$ between that existing population and the limiting population N_S which the given species would achieve in the given habitat in the absence of artificial competition (viz., fishing). Thus the logistic growth law may be written as

$$\dot{N}(t) = rN(t)(1 - \frac{N(t)}{N_S}) , \quad (1)$$

where the constant of proportionality r may also be interpreted as the growth rate of the population in its earliest stages (viz., when totally unfettered by competition, even from itself). That is,

$$\dot{N}(t) / N(t) \doteq r , \quad (2.1)$$

when $N(t)$ is small relative to its ceiling value N_S ; viz., when

$$\frac{N(t)}{N_S} << 1 . \quad (2.2)$$

In the levels the logistic law (1) takes the form

$$N(t) / [N_S - N(t)] = e^{a+rt} , \quad (3)$$

which demonstrates that the sigmoidal curve (3) has three parameters : N_S , r , and a . The last mentioned may, for a given value of N_S , be found from an initial condition ,

$$N(0) = \bar{N} \quad (\bar{N} \text{ being given}) , \quad (4)$$

or, given known values of N_S and r , from knowledge of the value of N at some other t .

4.3 Other Species

The remainder of the Australian fishing industry accounts for 34 per cent of the value of output, but only 16 per cent of total exports.[1] It consists of a wide variety of species which are fished under varying levels of regulation. There are essentially three groups of species: scale fish, molluscs and crustaceans.

The scale fish sector comprises mainly shark, tuna and whiting, all of which are found in "deep sea" areas. It appears to be the conventional wisdom that deep sea fish are not particularly susceptible to climatic conditions in their reproductive capacity and that their population dynamics follow the theory expounded in Section 3 - - but there has been little work done in this area.[2]

The level of regulation depends not only upon the species but also upon the statutory authority controlling the fishery. In the case of Southern Blue Fin Tuna, entry into the New South Wales and South Australian fisheries is licensed (and restrictions in equipment also apply), whereas entry into the Western Australian fishery is unrestricted. Shark fishing takes place under open access conditions in all three of the important shark fishing states (Victoria, South Australia and Tasmania), although minor restrictions on equipment are in force. For the minor scale fish fisheries, regulations vary from open access in Western Australia to tightly controlled non-tradeable licences in Victoria's beach, estuarine and inlet fisheries,[3]

1. Refer to Section 2, Tables 1 and 2.
2. Derived from personal communications with the Victorian Division of Fisheries and Wildlife, February 1981.
3. Anon., "Background Paper on Major Commercial Fisheries in Australia", op. cit.

ORANI? The most important conclusions seem to be:

(i) Long run output is exogenous, being determined by the interaction of the natural capacity of the fishery and the regulations which result in a sustainable yield being achieved at a level which is fixed, or at most, increasing slowly over time.

(ii) Long run price and cost conditions in the industry change the value of the social resource rental embedded in the present values of licences. Capital gains and losses generated in this way may be dampened by changes in real private input costs due to the less than perfect definition of property rights obtainable by licensing.

Suppose we now introduce into the ecosystem a new predator (man) who at instant t removes individuals from the population at the rate $[f(t)N(t)]$ per unit of time. We then must modify (1) to read :

(5) $$\dot{N}(t) = r\,N(t)(1 - \frac{N(t)}{N_S}) - f(t)N(t) \quad .$$

Given some known time dependency law relating f to t, it is possible to solve (2) explicitly for $N(t)$.[1] In the case where $f(t)$ is a stationary function, so that $f(t) = f$ (a constant) for all relevant t, then (5) remains logistic. Its solution in the levels[2] is

(6) $$N(t) \,/\, [K - N(t)] = e^{b+(r+f)t} \quad ,$$

where the new parameters are

(7) $K = (1 - \frac{f}{r})N_S$, and (7.2) $b = -\ell n\left\{\frac{(r - f)N_S}{r\,N(0)} - 1\right\}$.

Before interpreting (6) and (7), it is useful first to identify f. From our discussion above, the size of the catch (numbers of individuals per unit time) is just the product of f and the population size. Thus f may be thought of as the intensity of fishing activity, or more simply as "effort."

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1. The general form of the solution is

$$N(t)/N_S = \{N(0)\exp[r\int_0^t g(\tau)\,d\tau]\} \div \{N_S + r\,N(0)\int_0^t \exp[r\int_0^\tau g(s)ds]\,d\tau\} \ ,$$

where $g(t) \equiv 1 - [f(t)\,/\,r]$ - - see Dennis Sams, "The Effect of Consumption on a Renewable Resource," IMPACT Research Memorandum No. OA-53, May 1979. Numerical, as opposed to analytical, integration may be necessary, depending on the functional form of f.

2. Sams, op. cit.. The result may be checked by differentiating (6) to obtain (5).

Equation (7) tells how sustained fishing effort affects the long run population. At any given sustained effort level f there is a unique asymptote K to which the fish population tends over time. The elasticity of this long run population level with respect to sustained effort is

$$\frac{\partial \ell n K}{\partial \ell n f} = \frac{-f}{r - f} \quad (8)$$

Let

$$X(t) = N(t)f(t) \quad (9)$$

be the time rate of catch (numbers of individual fish caught per week, say). Equation (9) is a production function in which f (after multiplication by a unit, but dimensioned, constant) must have dimensions "proportion of the fish stock caught per unit time." This is not entirely inconsistent with measuring effort (as an input) in trawler hours per week. In the case of the trawling activity, for example, we would choose the number of trawler hours which, with the population at some base period reference level $N(t)$, results in one fish being caught. Note that the conversion factor from trawler-hours to units of effort is thus time dependent to the extent of variations in N . Let $g(t)$ trawler hours per week in the period t be sufficient to catch one fish; let $G(t)$ be the total number of trawler hours per week expended at t . Then, from (9) ,

$$X(t) = [G(t)/g(t)]$$

$$= [G(t)/g(t^o)]\left[\frac{g(t^o)}{g(t)}\right] \quad (10)$$

at least in part, the increase in resource rental generated by the price rise. In any event, these increases in inputs are unlikely (in the light of Table 5) to lead to any significant response in total yield. An initial autonomous drop in fishing costs at a fixed product price level (due, say, to a major improvement in fishing technology) would similarly lead to increased effort but not to significant increases in catch.

We turn now to (iv), the question of the responsiveness of controls imposed by the regulatory authority to changes in prices and costs in the industry. If the authority followed the MSY criterion, these would be irrelevant - - neither prices (P) nor costs (Q) appear in (18). This, however, may be too extreme a view of the relative stationarity of the W.A. system of controls. In 1978, for instance

> "the length of the season was reduced by six weeks to assist fishermen to maintain a viable economic return."[1]

This response seems to have been in an attempt to reduce the private impact of the socially unnecessary costs of competition referred to above, rather than a response to a movement in P or Q which, if MEY were being strictly followed, would lead to adjustments along the lines of the formulae given in Table 3. On the other hand, the decision to attempt to reduce costs of competition may have been triggered by the cost price situation faced by the industry at that time.

What is the relevance of the above to the closure of

1. George Morgan and Phillips, op. cit., p.45.

The rise in effective effort shown in Table 5 has occurred in spite of stationary controls. This reflects the attempts by fishermen to increase their yields at given nominal levels of controlled inputs by increasing the number of pot lifts per pot and/or per boat per year.[1] As noted earlier, such increases involve real increases in marginal costs. Note, however, that these increased costs may have been socially wasteful in view of the lack of response in total yield. The increased costs will have been privately necessary in order to preserve shares of the fishery, but socially wasteful.

Turning now to the second question (that of the incidence of social opportunity costs), the non-zero price paid for licences indicates that at least some portion of these are borne by fishermen. The average price at which licences which changed hands in 1980 was approximately $200,000.[2] This may represent less than the full present value of the social resource rental for two reasons. First, the number of licences may exceed the social optimum and/or the method of licensing may be inefficient. Second, the socially unnecessary costs of competition within the fishery are real private costs which will tend to lower the market valuation of the licences.

As far as the elasticity of effort with respect to price and cost changes goes (question (iii)), the foregoing suggests that increased product prices may lead to increased competition and input costs within the framework of the existing, static, nominal controls. Costs may thus increase within the industry to offset,

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1. George, Morgan and Phillips, op. cit., p.45.
2. Private communication, Department of Primary Industry, Canberra, February 1981.

The first term in square parentheses on the right of (10) is an orthodox production-function type measure of input. This is because at a given level of technology and with a given population size in the fishery, there is (stochastic influences aside) a one to one relationship between the number of trawler hours and the number of fish caught. We might therefore also reasonably assume

$$\frac{g(t^o)}{g(t)} = \frac{N(t)}{N(t^o)} \; ; \qquad (11)$$

that is, the number of trawler hours necessary to catch one fish is inversely proportional to the size of the fish population. Substituting (11) into (10) we see that

$$X(t) = f(t)\,N(t) \quad , \qquad (12)$$

where

$$f(t) = G(t)\,/[g(t^o)\,N(t^o)] \; . \qquad (13)$$

Returning now to (7) we see that the interpretable domain of this equation is the region in which f does not exceed r ; i.e., the extraction rate may not exceed the biological reproduction rate.[1]

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1. As elsewhere, this treatment assumes the habitat is closed (by distance, or otherwise) to outside migrants of the same species (or that no such potential immigrant stock exists).

3.2 Fishery Management

(a) Maximum Sustainable Yield

In the theory of optimal fishery management the basic question often is formulated along the following lines :

> What sustained level of fishing effort, F_{MSY} , is consistent with achieving the maximum sustainable catch X_{MSY} ?

In other words, what is the maximum sustainable yield (MSY) of the fishery, and what limitations should be placed on fishing effort to achieve it? An associated problem is the computation of the stationary population level N_{MSY} uniquely consistent with F_{MSY} . Before proceeding to the standard solution of this problem we note that the MSY policy is not necessarily socially optimal : first, it fails to take explicit account of demand-side factors such as pure time preference discounting and possibly non-stationary expectations about the future value of the resource; secondly, cost considerations are completely left out of the MSY criterion. Thus there is no reason to suppose that the exploitation rate equating marginal social cost with marginal social benefit will correspond to MSY. Finally, the licensing arrangements used to implement the MSY policy may result in given levels of output being produced at more than minimum feasible cost. Our interest in this paper is not in the normative significance of MSY , however, but derives solely from its apparent use as a reference point by licensing authorities.

Table 5 : Effort and Yield for the Western Rock Lobster Industry

Year	Effort[a] ($f \times 10^6$)	Catch ($kg \times 10^6$)
1960/61	3.777	7.790
1961/62	5.700	8.744
1962/63	7.500	9.324
1963/64	4.648	8.119
1964/65	4.798	7.486
1965/66	5.036	8.120
1966/67	5.147	8.635
1967/68	5.173	9.953
1968/69	4.292	8.078
1969/70	5.771	8.918
1970/71	7.888	8.013
1971/72	7.536	8.171
1972/73	7.253	6.809
1973/74	7.127	6.780
1974/75	8.035	8.877
1975/76	8.100	8.873
Average change per year	+3.48 (b)	-0.016 (c)

Source : Morgan 1979 (op. cit.)

(a) f is measured as effective effort, where not only pot lifts but also the spatial and temporal distributions of pot lifts are considered.

(b) Differs significantly from zero at 0.1 per cent level.

(c) Fails to differ significantly from zero at 5 per cent level.

(ii) Do fishermen incur the social opportunity cost (viz., pay the social resource rent) associated with the catch?

(iii) Are the levels of effort and output elastic with respect to price/cost changes?

(iv) Are the licensing arrangements responsive to the economic fortunes of the industry?

Morgan has observed that relatively large variations in effort levels have resulted only in a small variation in the size of the fish catch, as can be seen in Table 5. Since these data are not stationary, one cannot necessarily infer that the sustainable catch versus sustained effort curve is very flat, but a parabolic form for this curve with a relatively flat top would be consistent with the observations.[1] On the basis of Table 5 we might speculate that the level of application of effort is in the neighbourhood of maximum sustainable yield (MSY). If this is the case, then, relative to the maximum economic yield (MEY) criterion, overfishing is taking place. It should be noted, though, that MEY (as formulated in Section 3) is a conservative criterion, and not necessarily socially optimal, being based on a zero pure time preference discount rate. Given that policy actions rarely (if ever) conform exactly to optima as indicated by policy models, this lack of a sharp identification of current practice with either MSY or MEY will occasion no surprise.

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1. Substitution of the parameter estimates given above ($r = 1.647$, $N_s = 21 \times 10^6$) into equation (15) yields a very flat inverted parabola.

Setting the left of equation (5) to zero (and using the definition (9)) we see that the population would be instantaneously stationary at t ($\dot{N}(t) = 0$) provided that

(14) $$X(t) = r\,N(t)\left(1 - \frac{N(t)}{N_S}\right) .$$

If we now keep the catch $X(t)$ fixed at this value ($\bar{X}$, say) for all subsequent t, there can be no further change in $N(t)$, which will have achieved a long run stationary value ($\bar{N}$, say) in equilibrium with $\bar{X}$. In practice particular stationary equilibria $\{X, N\}$ are more likely to arise as limiting states $\{fK, K\}$ of growth paths like (6).

Keeping $\dot{N}(t)$ equal to zero, (14) shows that the size of sustainable catches X_{SY} is quadratic in corresponding stationary population levels; viz.,

(15) $$X_{SY} = r\,N_{SY} - \frac{r}{N_S} N_{SY}^2 .$$

Maximizing (15) with respect to N_{SY}, we find the population consistent with maximum sustainable yield to be

(16) $$N_{MSY} = N_S / 2$$

(the stationary population consistent with the maximum sustainable yield is one half the saturation level); the corresponding value of catch is

(17) $$X_{MSY} = (r\,N_S) / 4 .$$

The maximizing effort

(18) $$f_{MSY} = X_{MSY} / N_{MSY} = r / 2 ;$$

the optimum application of effort is one half of the inherent biological growth rate. To translate effective effort (f) into physical input units (G) we use (13) and (18):

(19.1) $$G_{MSY} = (r/2)\ g(t^{o})\ N(t^{o}) \quad .$$

If the base year t^{o} is one in which the MSY regime applies, then we may identify $N(t^{o})$ with N_{MSY} in (16), and so obtain

(19.2) $$G_{MSY} = (r/4)\ g(t^{o})\ N_{S} \quad .$$

(b) Maximum Economic Yield

The neglect of the cost side in the formulation of the MSY criterion has been recognized (at least in the literature) and has led to the concept of a maximum economic yield (MEY).

The analysis is simplified by (i) assuming a zero social pure time preference discount rate, and (ii) a flat (infinitely

Morgan has estimated the values of N_s (the natural upper limit on the biomass) to be (approx) 21 million kilogrammes, whilst r the inherent biological growth rate is estimated to be 1.6. From the latter value it can be deduced that the rate of mass growth in the early stages of the logistic process will be 520 per cent per annum (although as the mass rises, this rate of increase of course will fall).[1] Comparison of equation (13) in Section 3 with Morgan's formulation identifies the term

$$\{1/[g\ (t^{o})\ N\ (t^{o})]\}$$

as the 'catchability coefficient', which represents the proportion of the base period biomass caught by expanding one real unit of fishing effort. In the rock lobster industry, the latter concept is measured by 'number of pot lifts'. This coefficient was estimated by Morgan to be of the order of 1.4×10^{-7} (or 1.4×10^{-5} per cent of the base period biomass per pot lift). The reciprocal of the catchability coefficient, 7×10^{6}, is the number of pot lifts required to annihilate the base period population. The actual number of pot lifts in that period was 1.4×10^{5}, or 2 per cent of the theoretical fishing intensity which would have destroyed the fishery.

The remaining issues are institutional and economic. In particular,

(i) Is the level of effort currently being applied consistent with the maximum sustainable yield, the maximum economic yield, on some other criterion?

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1. In the exponential growth phase, $N(t) = N(0)e^{rt}$. Putting $t = 1$ and $r = 1.647$ gives $N(1) = 5.19N(0)$.

less plausible in the case of biomass. This and other aspects of the simple aggregation of weight lead, as noted by Morgan, to the potential for oversimplification in the application of Shaefer's model.[1] Nevertheless, the plot of catch against effort in the W.A. rock lobster fishery produces the parabola required by the theory.[2]

The relevance of the Shaefer model to the W.A. industry is not confined to its biological dimension, however. The Western Australian Department of Fisheries and Wildlife uses the model as a basis for management of the fishery.[3] Morgan, in a study of the W.A. Fishery,[4] has estimated the values of the parameters in the Schaefer model. These values have been used by the authorities in that state as an aid to regulation of the industry.[5] It must be noted, however, that N has been interpreted by Morgan to be the level of the population biomass, rather than the size of the population itself. The difference is an important one, for a constant population size may have an increasing biomass - - although it would not change the overall analysis to any great extent if Section 3 were now considered in terms of mass and not numbers. The procedure does, nevertheless, lead to the charge of oversimplification mentioned above.

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1. Morgan, op. cit.
2. Strictly, the theory only requires this plot to follow a single parabola provided all the data points are stationary equilibria. Of necessity at least some of the data points must represent transient states.
3. Private communication, February 1981.
4. Morgan (1979), op. cit.
5. Derived from personal communication with the W.A. Department of Fisheries and Wildlife, February 1981.

elastic), stationary demand curve.[1] From (15) we know how sustainable catch relates to the stationary population level under a stationary effort (f) regime. From (6) we can express the stationary population N_{SY} in terms of the stationary effort level, f_{SY}, by identifying N_{SY} with K. Thus

$$N_{SY} = \left(1 - \frac{f_{SY}}{r}\right) N_S \quad . \tag{20}$$

Substituting (20) into (15), we obtain

$$X_{SY} = N_S f_{SY}\left(1 - \frac{f_{SY}}{r}\right) \quad . \tag{21}$$

The time rate of gross revenue generation is obtained (under these stationary conditions) as the product of the price of fish and (21).[2] From (13), the stationary cost function (real terms) is

$$G_{SY} = f_{SY}\, g(t^o)\; N(t^o) \quad . \tag{22}$$

If p is real price of fish (viz., nominal price after deflation by a price index for inputs) the real net revenue function associated

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1. In the ORANI applications of concern to this paper, the export demand elasticity is typically assumed to be of the order of -10.
2. Implicit in this treatment is the assumption that the average weight of individual fish caught is invariant to the particular stationary regime $\{f_{SY}, N_{SY}\}$ adopted. In principle, the variations in the stationary age compositions of the different stationary populations could invalidate this assumption. In the current context the corrections involved, however, are expected to be second order. Alternatively, the difficulty can be side-stepped (as in Shaeffer, op.cit.) by specifying X in terms of weight, rather than as number of individual fish.

with different stationary regimes is

$$(23) \qquad R = p N_S f_{SY}(1 - \frac{f_{SY}}{r}) - Q f_{SY} g(t^o) N(t^o) \quad ,$$

where Q is a constant which translates physical inputs into the same constant dollar units as the sales revenue obtained from the catch.[1] Maximization of (23) with respect to f_{SY} leads to the maximum economic yield (MEY). The solution values R_{MEY}, N_{MEY}, f_{MEY} and G_{MEY} respectively for the net revenue, population, effort and real cost, are given in Table 3. The gross revenue curve (quadratic in f_{SY}) and the cost of effort curve (linear in f_{SY}) are depicted in Figure 1.

1. If the nominal price of fish is deflated by the cost, in base year t^o, of purchasing $g(t^o)$ units of real fishing effort, then $Q \equiv 1$.

4.2 The Rock Lobster Industry

The Shaefer model, described above in Section 3, is far more appropriate to the rock lobster industry than to prawning. The relatively slow growth rate of the lobster and the dependence of its current population size upon previous levels place it clearly within Shaefer's 'self-regulating resource category' (i.e., the one for which his model was developed). The suitability of the Shaefer framework for the analysis of the Western Australian rock lobster fishery has been examined by Morgan who concluded that Shaefer's model provided '... a surprisingly good fit to the observed catch versus effort data',[1] a degree of fit that was at least as good as that of alternative models used in a further study of the fishery.[2]

In Shaefer's 1957 formulation the variable whose growth was assumed to follow the logistic growth law was population stock (i.e., number of individuals).[3] Catch, however, was specified as mass of fish.[4] Later uses of the Shaefer model work entirely in terms of biomass, i.e., the combined weight of all individuals in the population replaces nominal population size, while catch continues to be measured in tons or kilogrammes. Whereas the logistic story might be expected on a priori grounds to work well with population measured by count, its symmetry is

1. G.R. Morgan, "Aspects of the Population Dynamics of the Western Rock Lobster and their Role in Management," Ph.D thesis, University of Western Australia, Nedlands 1977, p.305.
2. G.R. Morgan, "Assessment of the Stocks of the Western Rock Lobster *Panulirus Cygnus* Using Surplus Yield Models", Aust. J. Mar. Freshwater Res., 1979, Vol.30, pp.355-363.
3. Shaefer, op. cit.
4. In Section 3 we have developed the model with both variables measured as numbers of individuals. Only slight (and obvious) changes in assumptions are required to cast the story in terms of biomass.

present value has nothing to do with social resource rents. On such a reading of the evidence the value of licences represents monopoly rents collected either by the state (as in the sale of licences by auction) or by those lucky enough to receive an initial allocation (as in the administrative bestowal of licences or in a lottery system).

From the viewpoint of the closure of ORANI the relevant factors are:

(i) Potential output is stochastically determined by exogenous variables outside of policy control.

(ii) At any given level of the stochastic variable (climate) conditioning potential output, the actual output will be virtually exogenous to ORANI, being determined by licensed capacity.

In (ii) the qualification 'virtually' is needed since it is at least theoretically possible to construct scenarios in which the output price falls so low that it does not even cover short run harvesting costs. We neglect this possibility. Also, we assume that licensed capacity is totally inelastic, even in the long run, to product prices and fishing costs.

Table 3 : Values of Resource Rental, Population Size, Effective Effort and Real Cost associated with Maximum Economic Yield (MEY)

Variable	Notation for MEY Solution Value	Solution in terms of Biological and Economic Parameters[(a)]
Resource Rental	R_{MEY}	$\frac{r}{4}\, p\, N_S\, [1 - g(t^o)\, \frac{Q}{p}\, \frac{N(t^o)}{N_S}]^2$
Fish Population	N_{MEY}	$\frac{N_S}{2}\, [1 + g(t^o)\, \frac{Q}{p}\, \frac{N(t^o)}{N_S}]$
Effective Effort	f_{MEY}	$\frac{r}{2}\, [1 - g(t^o)\, \frac{Q}{p}\, \frac{N(t^o)}{N_S}]$
Real Cost of Effort	G_{MEY}	$\frac{r}{2}\, N(t^o)\, g(t^o)\, [1 - g(t^o)\, \frac{Q}{p}\, \frac{N(t^o)}{N_S}]$

(a) Notation is as follows: r = inherent biological growth rate (proportional increase per unit time);
p = real price of fish (real $ per fish), assumed stationary;
N_S = maximum carrying capacity of fishery (number of fish);
$g(t^o)$ = real fishing resource input per fish caught in the base period t^o;
Q = cost in constant dollars of one unit of real fishing resource input;
$N(t^o)$ = fish population in base period t^o.

An example of the units of g would be 'number of standard trawler hours per fish caught'. In that case the units of Q would be 'real dollars per standard trawler hour'.

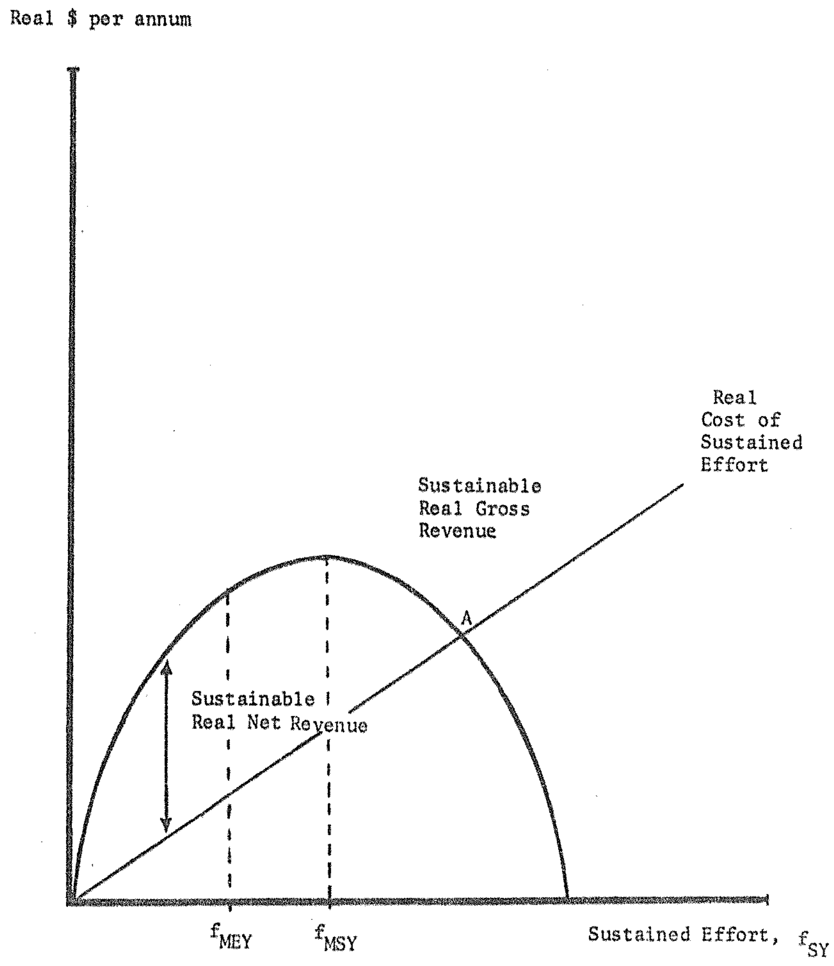

Figure 1 : Sustainable Real Gross Revenue and Real Cost of Sustained Effort under Perfectly Elastic Product Demand

The number of prawning licences is strictly controlled in each state. In some states there are additional regulations limiting the type of fishing gear and the season within which prawning is allowed.[1] Licences are fully transferable and the prices at which they are traded currently range between $100,000 and $500,000 (see Table 4). These prices clearly represent the present valuation placed by the market

Table 4 : Estimated Average Market Values of Prawning Licences, Major Prawn Producing States, 1980

Fishery	Average Market Value of a Prawning Licence[a] ($)
Shark Bay, W.A.	500,000
Exmouth Gulf, W.A.	375,000
Spencer & St. Vincent Gulfs, S.A.	350,000
Northern Prawn Fishery, N.T. and Queensland	100,000

a Excludes value of boat.

Source : Department of Primary Industry, Canberra.[2]

on the access rights to the fishery. If one believes that fishing has no feedback on yields, then, since additional current harvesting has no opportunity cost in terms of future production foregone, this

1. See anon., "Background Paper on Major Commercial Fisheries of Australia". Paper prepared for the Seminar on "Economic Aspects of Limited Entry and Associated Fisheries Management Measures", 6-8 February 1980, Melbourne, pp.30 (mimeo).

2. The Department gives as its source T.G.Kailis, "Limited Entry, Not a Miracle Measure, An Industry View," paper prepared for the seminar cited in footnote 1.

4. Relevance of the Theory for the Australian Fishing Industry

We now consider major components of the Australian fishing industry in the light of the preceding theoretical analysis in order to determine which factors exert a constraining influence upon the output of that industry.

4.1 The Prawning Industry

As we have seen above (Section 2) there seems to be very little feedback from one year's catch into the succeeding year's population level. Such feedback (if it operates) is in any event heavily masked by the climatically induced fluctuations in population and harvests.[1] These fluctuations are particularly violent for the fisheries in which the prawns breed in estuarine regions - - the North Queensland banana prawn being the key example. For species which breed outside of creeks and estuaries, the fluctuations are less severe, due to the fact that breeding grounds in deeper waters are much less affected by rainfall (which appears to be the major form of climatic influence).[2] Examples include the Western Australian king and tiger prawns which breed mainly in the outer waters of Exmouth Gulf and Shark Bay respectively.[3] Using Shaefer's terminology[4] we would, to a good first approximation, regard prawning as a 'non-self-regulating resource'. This being the case, the focus of research in prawning has tended to concentrate on the significance of various environmental factors in the growth and survival of the prawn rather than on population dynamics. The material in Section 3 is therefore of limited relevance to prawning.

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1. W. D. MacLeod, "Limited Entry Management for the Northern Prawn Fishery: A Review Essay on its Development". Paper prepared for the seminar on "Economic Aspects of Limited Entry and Associated Fisheries Management Measures", 6-8 February 1980, Melbourne, pp.51 & 58 (mimeo).
2. CSIRO, private communication, February 1981.
3. D. A. Hancock, private communication, March 1981.
4. Op. cit.

In Figure 1 net revenue may be interpreted as the resource rent accruing to the fishery. If this rent were charged as a cost to those carrying out the fishing activity, then no pure profits would be earned by them. In a social context a positive rent should pertain and be charged to the fishing activity in order to ensure that the positive social valuation placed on future consumption is reflected in current production decisions. If zero rent is charged to the fishing activity (as in an open access fishery), net revenue will be seen as a pure profit by potential fishermen who will enter the industry and expand fishing effort until this rent is eliminated : that is, effort will expand to the point A in figure 1.[1] This divergence between private behaviour and what is socially optimal comes about because the social opportunity cost (in terms of future consumption foregone) of current fishing activity appears, under open access, as an externality to the industry. Clearly open access (point A in Figure 1) is socially inefficient - - there is a higher level of effort but a lower catch than at a wide range of points to the left of A (including MSY). Intervention by a licensing authority is justified by the need to internalize the externality and so to re-establish equality between social and private costs.

The above considerations imply that it is optimal from society's point of view to constrain the level of effort to f_{MEY}. This conclusion may to some extent be modified by relaxation of the assumption that the pure time preference social discount rate is zero ;

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1. This assumes that entrepreneurs take the long view, and base decisions upon sustainable quantities. In practice an expansion beyond A is likely as fishermen compete for high short run profits.

qualitatively similar results could be expected to continue to apply. Under positive social discounting open access will still lead to overfishing at the point A in Figure 1 : prospective pure profits are driven to zero in all periods regardless of the discount rate. The MEY will, however, alter. The reason is that a higher level of effort in the short term will yield a higher short term catch and hence revenue, but at the expense of smaller future yields. Given discounting, this smaller future catch is acceptable in view of the higher immediately obtainable yield. This current increase in output is unsustainable, being made possible by a decline in the size of the fish population. Analysis of stationary states as in Figure 1 becomes inadequate for the truly intertemporal social utility maximization problem now involved - - Euler-Lagrange variational methods, and/or control theory become the relevant tools.[1]

Various methods are used by statutory authorities in their attempts to internalize the resource rental cost of the fishery. These include effort control (control of inputs), licence limitations (eliminating open access) and catch control. Effort controls include limitations on the times and places at which fishing may be undertaken, and limitations on the amount and type of equipment that may be used. Such controls usually result in cost increases because they encourage input substitutions that are uneconomic at the socially relevant supply prices of the resources. Thus more intensive fishing methods will be used to compensate for an arbitrary shortening of the times at which fishing may be legally carried out, etc..

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1. Clark, op. cit., pp. 38 et seq.

The issuance of a limited number of licences establishes a system of shared property rights to the fishery which will allow, at least to some extent, internalization of its resources rent cost. The present value of the rents may initially be given to the licensee, or accrue to the government (as in sale of licences by auction). In either case transferability of the licences ensures that the resources rent (to the extent that it is successfully imbedded in the licences in the first place) continues to act as a real private production cost.