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THE PRODUCTION OF FISHING EFFORT AND THE
ECONOMIC PERFORMANCE OF LICENCE LIMITATION
PROGRAMMES

H F CAMPBELL* and R K LINDNER**

↳ Agricultural Economics
Discussion Paper 1/89

Nedlands, Western Australia 6009

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* Department of Economics, The University of Tasmania. Hobart, Tasmania 7000, Australia.

** School of Agriculture, The University of Western Australia, Nedlands, Western Australia 6009, Australia.

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Abstract

For a variety of reasons, it is not always easy for fishery managers to control fishing catch and/or effort using first-best policy instruments. As a result, so-called buy-back programmes which effectively restrict the use of selected inputs to the production of fishing effort are a common policy instrument in many fisheries around the world. In this paper, we investigate two issues, one being the determinants of the efficiency of buy-back programmes and the other being the "optimal" (i.e. second best) level of buy-back under different circumstances.

Overall efficiency of a buy-back programme depends firstly on the efficacy of a reduction in level of use of selected fishing inputs on the level of fishing effort applied to the fish stock, and secondly on the extent to which total cost of fishing effort under a buy-back programme exceeds the minimum total cost necessary to generate the same level of effort in an unrestricted fishery. The elasticity of supply of effort given unrestricted use of selected inputs is shown to be the critical determinant of both of the above aspects. This elasticity varies directly with the elasticity of substitution between restricted and unrestricted inputs to fishing effort, and inversely with the share of total cost of fishing effort accounted for by inputs subject to the buy-back programme. For particular cases investigated in the paper, this elasticity is affected by the intensity of exploitation of the fish stock.

We conclude that a buy-back programme is likely to be close to first-best as long as non-restricted inputs cannot easily be substituted for restricted inputs and/or as long as restricted inputs account for a large proportion of total factor cost. Our results also suggest that efficiency of a buy-back programme will be higher if the economic pressure to exploit the fish stock intensively is not too great. When these conditions are not present, buy-back programmes are likely to be a relatively inefficient policy instrument for generating a net social surplus for society.

Introduction

Anderson (1985) has demonstrated that fishery regulation by means of licence limitation may generate rents in a commercial fishery. He points out that, while restricting the amount of a major input used in the production of effort may increase the unit cost of effort, the reduction in the total amount of effort devoted to the fishery will yield a benefit through a shift of resources to higher value uses elsewhere. He argues that licence limitation programmes should not be rejected out of hand because they increase the cost of fishing effort. Instead the costs and benefits should be analysed to determine whether the programme can produce a net gain and, if so, at what level of the programme the net gain is maximised. Such an optimum would of course be a second-best optimum as compared with that which could in theory be achieved by a sole owner. However, since the first-best optimum is likely to be unattainable in the practical world of fishery regulation the relevant comparison is among the

second-best optima of a variety of policies. When the problem is posed in these terms it is clear that licence limitation programmes should not be dismissed without proper analysis.

There are two levels at which research can be conducted on licence limitation programmes. One is at the level of the individual fishery involving collection of fishery-specific data and estimation of the rents which can be generated by licence limitation. Examples of this direction of research are provided by Campbell (1988) who estimates the welfare effects of a licence limitation programme for the Tasmanian rock lobster fishery, and Dupont (1988) who analyses input substitution and rent dissipation in the British Columbia salmon fishery. At a more general level it may be useful to analyse how the characteristics of the production function for fishing effort under a licence limitation programme influence the capacity to generate rents equal to a significant proportion of the theoretical maximum. Fisheries in which suitable characteristics exist could then be the subject of detailed analysis to determine the extent of the optimal programme. For fisheries which do not possess suitable characteristics an investigation of alternative methods of regulation is likely to prove more fruitful. The purpose of the present paper is to examine the influence of the parameters of the production function for effort on the likely net social benefits of licence limitation.

The Basic Model

The basic model for the analysis is illustrated by the model of fishery equilibrium described in Anderson's Figure 3 and we reproduce that model with minor amendments in Figure 1 of the present paper. At the outset we note that this model is a static model and that conclusions drawn from it about the optimal level of effort are valid only if the rate of interest is zero. Nevertheless, we believe that the model is useful for analysing practical fishery management problems and for this reason we confine ourselves to its framework. Figure 1 shows a linear value of the average product of effort schedule, AR_E , such as that which can be derived from the Schaefer model (Schaefer, 1967), and a perfectly elastic long-run supply curve of effort, S_E , indicating that effort is produced under constant returns to scale with constant factor prices. It should be noted that the Schaefer model is based on a logistic growth function for biomass, and on the assumption that catch per unit of effort is always a constant proportion of stock. The Schaefer model is the only one, as far as we are aware, that yields a linear average product of effort schedule. In the absence of regulation, long-run steady-state equilibrium is at the effort level E_0 at which the value of average product of effort equals the long-run average cost of effort, C_0 .

The curves MC_E^0 and MC_E^1 are long-run supply curves of effort when one or a range of inputs is restricted in supply to the fishery because of licence limitation. If we start off at the open access equilibrium E_0 and

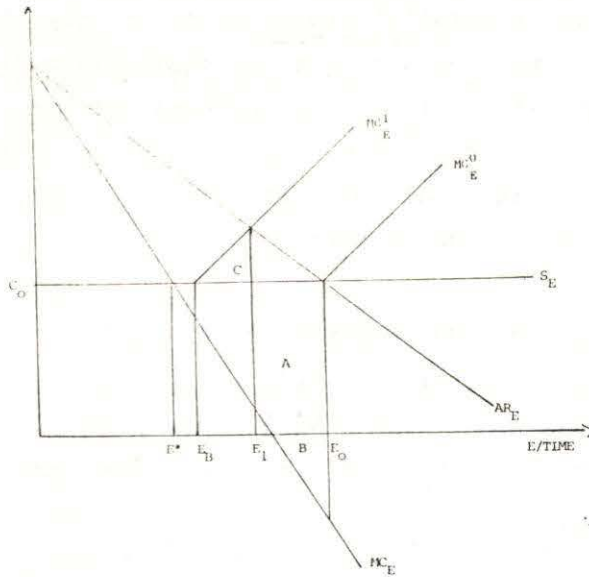


Figure 1

Equilibrium in a Regulated Fishery

restrict the supply of a particular input to its current level then any increase in the level of effort beyond E_0 will involve increases in the marginal cost of effort as indicated by the supply curve, MC_E^0 , which is analogous to the short-run supply curve of a firm employing a fixed factor. If at the open access equilibrium level of effort we decide to reduce the supply of the restricted input, the supply curve of effort would shift to the left as illustrated by MC_E^1 and a new equilibrium level of effort, E_1 , would be reached. At E_1 the value of fishery rent has risen by the sum of areas A and B in the diagram. This increase in fishery rent is at the expense of a loss of efficiency in the production of effort caused by the input restriction. This efficiency loss is measured by area C. A second-best optimum is given by a level of licence limitation which maximises the area $(A+B-C)$. Since fishery rent starts to decline once the equilibrium effort declines below E^* it is clear that the optimal limitation programme will produce an equilibrium level of effort in the range $E^* \leq E < E_0$.

It can be seen from Figure 1 that the effect of the limitation programme is to reduce the level of effort at which the input restriction ceases to be binding from E_0 to E_B . Since our assumption of constant returns to scale implies that the production function for effort is homothetic, we can assert that $E_B = (1-B)E_0$ where B is the proportion of the restricted input which is removed from the fishery. Nothing can be

said about the form of the supply curves MC_E^0 and MC_E^1 without making more detailed assumptions about the production function for effort. For the moment we assume these functions are linear and we also assume that a limitation scheme involves a parallel inward shift of the supply curve. With these assumptions we now work out the equilibrium level of effort under a limitation scheme which gives a second-best optimum.

We need to specify functional forms for the average product of effort schedule and the supply or marginal cost of effort schedule consistent with the assumptions we have made so far:

$$AR_E = a - bE \quad \text{subject to } a, b > 0; \quad [1]$$

$$MC_E = C_0 + C_1 (E - E_B) \\ \text{subject to } C_0, C_1 > 0, E \geq E_B; \quad [2]$$

The equilibrium condition for the fishery is $AR_E = MC_E$, and so it follows that:

$$E_B = [(C_1 + b)E - (a - C_0)]C_1^{-1} \quad [3]$$

The fishery rent can be defined as:

$$\Pi_F = (a - C_0 - bE)E \quad [4]$$

and the level of effort which gives a first-best optimum can be calculated as:

$$E^* = 0.5(a - C_0)b^{-1} \quad [5]$$

In open-access equilibrium $\Pi_F = 0$ so that $E_0 = (a - C_0)b^{-1}$. The efficiency loss resulting from the input restriction can be expressed as:

$$L = 0.5(MC_E - C_0)(E - E_B), \quad [6]$$

which, on substituting for MC_E and E_B , simplifies to:

$$L = 0.5[(a - C_0) - bE]^2 C_1^{-1} \quad [7]$$

The second-best optimum level of effort, \hat{E} , is obtained by choosing E to maximise: $W = \Pi_F - L$. The solution value is:

$$\hat{E} = 0.5(a - C_0)b^{-1} [(C_1 + b)/C_1 + b/2] \\ = E^* [(C_1 + b)/(C_1 + b/2)] \quad [8]$$

Given our assumptions about the production of effort, the proportion of the restricted input excluded from the fishery by the limitation programme is defined as: $\hat{B} = 1 - (E_B/E_0)$. Substituting for E_B and E_0 and setting $E = \hat{E}$ gives the level of the second-best optimum licence limitation programme:

$$\hat{B} = 0.5[(C_1 + b)/(C_1 + b/2)] \quad [9]$$

The policy implications of the solution values of \hat{E} and \hat{B} can be analysed by considering polar forms of the marginal cost of effort schedule. At one extreme if the restricted input is used in fixed proportions with the unrestricted inputs the marginal cost of effort schedule, MC_E , will be totally inelastic. The implications of a zero elasticity of substitution of the unrestricted inputs for the restricted inputs for the values of \hat{E} and \hat{B} can be obtained by taking limiting values

as $C_1 \rightarrow \infty$. The values are: $\hat{E}_\infty = E^*$, and $\hat{B}_\infty = 0.5$. In this case the second-best optimum coincides with the first-best optimum, the efficiency loss is zero, and the whole value of the fishery rent is generated. At the other extreme, if the unrestricted inputs are perfect substitutes for the restricted input, MC_E is perfectly elastic. When C_1 is set equal to zero the solution values for \hat{E} and \hat{B} become: $\hat{E}_0 = 2E^* = E_0$, and $\hat{B}_0 = 1$. In this case all the units of the restricted input can be excluded from the fishery without disturbing the open-access equilibrium. There is no efficiency loss and fishery rent remains at zero.

The conclusion which is derived from the basic model is that the second-best optimum licence limitation programme yields the first-best level of rent when the elasticity of substitution between the restricted and unrestricted inputs is zero, and no rent when the elasticity of substitution is infinitely high. When the elasticity of substitution assumes an intermediate value the parameter c_1 is in the range $0 < c_1 < \infty$ and the basic model tells us little about the optimal limitation programme beyond the fact that \hat{E} lies in the range $E^* < \hat{E} < E_0$ and $\hat{B} > 0.5$.

At this point we make a simple modification to the basic model to ascertain whether our results depend upon the assumption that a limitation programme causes a parallel inward shift of the MC_E function, which consequently becomes less elastic the greater the extent of the limitation. An alternative assumption is that reducing the supply of the restricted input does not affect the elasticity of the MC_E function. This assumption can be incorporated into the basic model by assuming that the MC_E function is described by the appropriate segment of a ray through the origin. This means the slope of the marginal cost function is set at: $b = C_0/E_B$, and the elasticity equals unity. The optimal value for equilibrium effort then becomes: $\hat{E} = E^*[1 + b^2/C_0(a - C_0)]$, and the optimal limitation proportion becomes: $\hat{B} = 0.5[1 + b^2/C_0(a - C_0)]$. As in the basic model with c_1 in the range $0 < C_1 < \infty$, for this constant elasticity case the optimal effort level $\hat{E} > E^*$, and the optimal limitation proportion $\hat{B} > 0.5$.

The Importance of the Effort Production Function Parameters

It is clear from the above analysis that the level and performance of an optimal licence limitation programme depend upon the nature of the marginal cost function for effort. The MC_E function is derived from the production function for fishing effort and it is the form and parameters of this function which will determine whether a limitation programme is a relatively efficient way of regulating a fishery. Our approach in this section is to simulate a fishery which is initially in open access equilibrium and generating no economic rent. We then introduce restrictions on the total quantity of one of the inputs used in the

fishery. The restrictions are established at various levels and the net amount of rent generated by the fishery under each of these levels after deducting efficiency losses from gross rent generated is computed in the manner described in Section 2, and expressed as a percentage of the theoretical maximum flow of rent which could be earned by a sole owner. This percentage is used as a measure of the efficiency of the limitation programme.

The following analysis applies to fisheries whose production function for effort exhibits homotheticity and constant returns to scale. The simplest production function which has these properties and which allows a range of elasticities of substitution is the CES:

$$E = \gamma \left[\delta R^{-\rho} + (1 - \delta)L^{-\rho} \right]^{-1/\rho} \quad [10]$$

where R represents the restricted input, L represents the unrestricted input, γ is a scale parameter, δ is a parameter which reflects the productivity of the restricted input, and ρ is a parameter which determines the elasticity of substitution between the restricted and unrestricted inputs, $\sigma = (1+\rho)^{-1}$. As a limiting case as $\rho \rightarrow 0$, the CES reduces to the Cobb-Douglas production function with $\sigma = 1$:

$$E = \gamma R^{\delta} L^{(1-\delta)}, \quad [11]$$

where, in this special case, δ is the share of the restricted input in total cost. In the CES and other more general cases the cost share of the restricted input depends on the capital/labour ratio and the substitution parameter, ρ , as well as on the productivity parameter, δ .

As described in Section 2 the equilibrium level of effort, E_0 , in an open-access fishery is determined by the intersection of the AR_E with the long-run cost of effort, C_0 . In this section, we base the AR_E schedule on the Schaefer model (Schaefer, 1967):

$$AR_E = p[AK - (A^2K/r)E] \quad [12]$$

where p is the price of fish (assumed to be determined exogenously), K and r are parameters of the logistic growth equation, and AK is catch per unit effort at the unexploited biomass level, K. The unit cost of effort, C_0 , in open-access equilibrium is assumed to be minimum long-run average cost which in the CES case can be expressed as:

$$C_0 = (1/\gamma) \cdot \left[\delta^{1/(1+\rho)} v^{\rho/(1+\rho)} + (1-\delta)^{1/(1+\rho)} w^{\rho/(1+\rho)} \right]^{(1+\rho)/\rho} \quad [13]$$

where v and w are the rental prices of the restricted and unrestricted inputs respectively. When unit costs are minimised the industry is on its long-run expansion path and the amount of effort produced per unit of input R employed is given by:

$$(E_0/R_0) = \gamma \left[\delta + (1-\delta)[w\delta/v(1-\delta)]^{\rho/(1+\rho)} \right]^{-1/\rho} \quad [14]$$

The effect of a limitation programme is to reduce the availability of the restricted input from R_0 to $R_B = R_0(1-B)$ where B is the proportion of the restricted input which is retired from the fishery. The equilibrium level of effort is then determined by the intersection of AR_E and MC_E where, in the CES case:

$$MC_E = w(1-\delta)^{1/\rho} \left[1 - \delta(E/R_B)^\rho \gamma^{-\rho} \right]^{-(1+\rho)/\rho} \cdot (1/\gamma) \quad [15]$$

At the equilibrium level of effort under the limitation scheme the average cost of effort, AC_E , now exceeds C_0 because the effect of the input restriction is to force the industry off its expansion path. From equation [14] we can define a level of effort, E_B , below which the input restriction is not binding. For $E < E_B$, $AC_E = C_0$. As the equilibrium level of effort rises in the range $E > E_B$ the marginal cost of effort rises

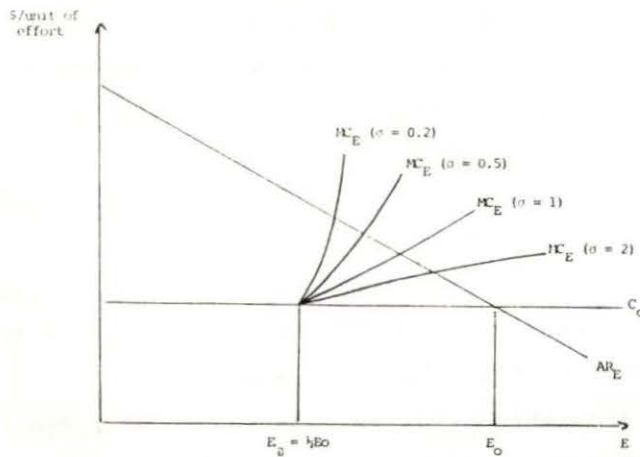


Figure 2

Effect of a 50% limitation Under Different Assumptions
About Elasticity of Substitution

above C_0 as indicated by equation [15]. Figure 2 shows the effect of a 50% limitation programme on the equilibrium level of effort under various assumptions about the substitution elasticity.

We can think of the excess of MC_E over C_0 at any given level of E as a marginal efficiency loss resulting from the limitation programme. The total efficiency loss can be expressed as the excess of cost of producing a given level of effort in a restricted fishery over the cost of producing the same effort in an unrestricted fishery, and is given by:

$$L = \int_{E_B}^E MC_E dE - C_0 (E - E_B) \quad [16]$$

In the simulations, the equilibrium level of effort, E_B , was determined using the precise non-linear form of the marginal cost function but we used a linear approximation to MC_E to evaluate the integral so that our estimate of L_B at E_B was calculated from:

$$\hat{L}_B = 0.5(MC_E - C_0)(E - E_B) - C_0(E - E_B) \quad [17]$$

In Appendix A, we discuss possible biases arising from the use of this approximation.

Because analytical solutions are not available for the cases we wish to consider, we use simulations to analyse the impact of various values of the production function parameters. In our simulations we want to compare the effects of various limitation programmes applied to a hitherto open-access fishery. To make the comparisons meaningful we need to use a given open-access equilibrium as the base case. At the same time we want to be able to vary the values of the parameters ρ and δ to see how they affect the efficiency of limitation programmes. An obvious difficulty is that varying ρ and δ will affect the value of C_0 and this will in turn affect the open-access equilibrium level of effort, E_0 . In summary we are interested in (ρ, δ) pairs consistent with a specific value of E_0 . Since equations [12], [13] and [14] also contain the parameters A, K, r and γ , the exogenously determined variables p, v , and w , and the endogenously determined variable R_0 , it is clear that there is a very large number of combinations of values of these variables which will make a given (ρ, δ) pair consistent with the chosen initial equilibrium, E_0 . We have run the simulations for a range of these combinations and have found that our results, expressed in percentage terms, are invariant to the chosen values of parameters and variables other than ρ, δ and E_0 .

When we run our simulations for various values of ρ and δ we express the percentage efficiency of the limitation programme as: $(\Pi_B/\Pi_F) \times 100$ where Π_B is the flow of rent under the limitation programme and Π_F is the theoretical maximum flow of rent under sole ownership. The flow of rent under the limitation scheme can be calculated as:

$$\Pi_B = [AR_E - C_0] E - \hat{L}_B, \quad [18]$$

which can be computed using equations [12], [13], [15] and [17] together with the equilibrium condition, $AR_E = MC_E$. The theoretical maximum flow of rent is defined as:

$$\Pi_F = [AR_E - C_0] E^*, \quad [19]$$

where E^* is the first-best optimum level of effort. The value of E^* is obtained by solving $\partial[(AR_E - C_0)E]/\partial E = 0$ for E^* and it remains constant in our initial set of simulations. Since the Schaefer model is used to derive the AR_E schedule, the AR_E schedule is linear and, in consequence, $E^* = 0.5E_0$.

Results

Our first set of results is for a 50% limitation programme applied to a fishery with an initial open-access equilibrium level of effort of $E_0 = 666.7$. Although a particular sample set of parameter values reported in Table 1 was used in the simulations, as was explained earlier, the results of the model are invariant to changes in these values which preserve the

initial open access level of effort. Table 2 reports the effects of a 50% limitation programme under alternative values of the restricted input productivity coefficient, δ , and of the elasticity of substitution, σ . In each case we show the percentage reduction in the equilibrium level of effort ($E_0 = 666.7$) actually achieved under the limitation scheme, and the actual gross rent, $(AR_E - C_0)E$, and the net rent, Π_B , achieved under the 50%

Table 1

A Sample Set of Starting Values

Catchability Coefficient A	Environmental Carrying Capacity K	<u>Parameters</u>		Production of Effort Scale Coefficient γ
		Intrinsic Growth Rate r		
.000355	12,550	0.597		0.667
<u>Exogenous Variables (\$)</u>				
Price of Restricted Input v		Price of Other Inputs w		Product Price p
5		5		5.58
<u>Endogenous Variables</u>				
Open Access Level of Restricted Input R_0		Open Access Level of Other Input L_0		Open Access Level of Effort E_0
1000		1000		666.67

limitation programme, each expressed as a percentage of the potential rent, $\Pi_F = \$1,642$. Note that the closer the reduction in effort is to 50%, the more effective the limitation scheme has been in reducing effort and in generating rent.

It can be seen from Table 2 that the limitation programme is more effective at reducing fishing effort and more efficient in generating rent, the higher is δ , the share coefficient of the restricted input, and the lower is σ , the elasticity of substitution between the restricted and unrestricted input.

The reason why efficiency of a limitation programme is so sensitive to elasticity of substitution can be appreciated by referring to Figure 2. This diagram illustrates a hypothetical case involving excluding 50% of an input which enters the CES function with a productivity coefficient of $\delta = 0.5$, and demonstrates how the MC_E schedule depends on the elasticity of

Table 2

Effects on Effort Reduction and Rent Generation of a 50% limitation Scheme for Various Values of δ and σ

δ	σ	% Reduction in Effort Achieved by 50% limitation, $100 \times (1 - E/E_0)$	% of Potential Rent Generated by Effort Reduction, $100 \times (AR_E - C_0)E/\Pi_F$	Net Efficiency = % of Potential Rent Realised by 50% limitation, $100 \times \Pi_B/\Pi_F$
0.1	0.2	37	94	84
	0.5	21	67	55
	1.0	10	37	28
	2.0	5	18	13
0.5	0.2	48	100	98
	0.5	44	99	94
	1.0	38	94	84
	2.0	27	78	66
0.9	0.2	50	100	100
	0.5	49	100	99
	1.0	48	100	98
	2.0	46	99	96

Note: δ = Productivity coefficient for restricted input(s)
= Factor cost share for Cobb-Douglas case ($\sigma=1$).

σ = elasticity of substitution
= $1/(1 + \rho)$.

substitution. If inputs cannot be substituted easily (e.g. $\sigma = 0.2$), the MC_E schedule is highly inelastic, so a 50% limitation results in an almost equivalent reduction in effort and the generation of almost all of the rent potentially available from the fishery. Furthermore the deadweight costs of fishing effort required to generate these rents are quite small as long as the MC_E function is highly inelastic. When the MC_E function is more elastic, the rent generated is smaller because effective effort is reduced by a smaller proportion, and efficiency is further reduced by the larger offsetting deadweight costs of fishing effort. The value of the productivity coefficient of the restricted input, δ , has an equivalent effect on the MC_E schedule, with higher values making the schedule less elastic, *ceteris paribus*.

From the point of view of fishery management, these results suggest that administrators of any limitation scheme should seek to include as many inputs to fishing effort as possible within the scope of the scheme. In practice, however, the combined productivity coefficient of the inputs subject to limitation may rarely, if ever, exceed 0.5. Where it is less than 0.5 it is clear from Table 2 that the success or otherwise of a limitation scheme depends critically on the elasticity of substitution between the two classes of inputs. For instance, if it is possible to exclude inputs which have a very low elasticity of substitution with other inputs (e.g. $\sigma = 0.2$), then overall efficiency can be high (e.g. 84%) even if the productivity coefficient of the excluded input is very low (e.g. $\delta = 0.1$). On the other hand, where δ is as low as 0.1, efficiency falls off dramatically as it becomes technically easier to substitute other inputs for those subject to limitation.

The analysis above treats the level of limitation as predetermined by administrative or other considerations. We know from Section 2 that the second-best optimum limitation programme involves in excess of 50% limitation, and that the optimal level of limitation will depend, *inter alia*, on the key variables discussed above. We now turn our attention to higher levels of the limitation programme.

For most combinations of higher values of σ and/or lower values of δ , it is still possible to generate most or all of the potential rent by reducing effort to somewhere near the first best level, but only by excluding substantially more than 50 per cent of the restricted input. In extreme cases where the productivity coefficient of the restricted input is low and its elasticity of substitution high, even excluding 99 per cent of the restricted input might not reduce effort sufficiently to generate a high level of rent. Furthermore, levels of exclusion greater than 50 per cent incur increasingly large deadweight losses which partly offset the rents generated, thus reducing overall efficiency of even second best levels of limitation. For instance, where $\delta = 0.1$ and $\sigma = 1.0$, the second best optimum involves excluding about 90 per cent of the restricted input and even then only achieves a net efficiency level of just over 50 per cent.

The discussion so far has taken as a reference point an open access fishery in long-run equilibrium (i.e. total rent dissipation). Over time the open-access level of effort might change due to changes in product price, technology, and prices of inputs to fishing effort. Assuming given values for the biological parameters of the fishery, we can create an index of the relative intensity of the economic pressure to exploit the fishery by dividing E_0 , the equilibrium open access level of effort, by E_{\max} , defined as the sustainable level of effort just sufficient to totally deplete the fish stock. This intensity of stock exploitation index

Table 3

Efficiency of Various Levels of limitation
Under Various Values of σ and δ

		$\delta = 0.1$				$\delta = 0.5$	
σ	% Buy-Back	% Reduction in Effort	% of Potential Rent Generated	Net Efficiency (% of Potential Rent)	% Reduction in Effort	% of Potential Rent Generated	Net Efficiency (% of Potential Rent)
0.2	50	37	94	84	48	100	98
	60	48	100	89	58	98	95
	70	60	96	84	68	87	84
	80	73	79	69	79	67	65
	90	86	48	41	89	38	37
	99	99	5	5			
0.5	50	21	67	55	44	99	93
	60	30	83	65	54	99	93
	70	40	96	72	65	91	84
	80	54	99	71	76	72	67
	90	74	77	53	88	42	39
	99	97	12	8			
1.0	50	10	37	29	38	94	85
	60	14	47	34	48	100	88
	70	18	59	40	58	97	84
	80	24	73	46	71	83	70
	90	35	91	53	84	53	43
	99	70	84	43			
2.0	50	5	18	13	27	78	66
	60	6	22	16	34	90	72
	70	7	27	18	42	98	74
	80	9	33	20	53	100	71
	90	11	40	22	68	88	57
	99	15	51	26			

Table 4
 Efficiency of Various Levels of limitation
 Under Various Values of σ and δ
 When $E_0 = 333.3$

		$\delta = 0.1$				$\delta = 0.5$		
σ	% Buy-Back	% Reduction in Effort	% of Potential Rent Generated	Net Efficiency (% of Potential rent)	% Reduction in Effort	% of Potential Rent Generated	Net Efficiency (% of Potential rent)	
0.2	50	43	98	92	49	100	99	
	60	54	100	93	59	95	95	
	70	64	92	85	69	85	84	
	80	76	74	67	79	66	65	
	90	88	43	39	90	37	36	
	99	99	5	4				
0.5	50	33	88	77	47	100	97	
	60	42	98	83	57	98	95	
	70	54	99	82	68	87	84	
	80	67	89	71	78	68	65	
	90	82	59	46	89	39	37	
	99	98	7	6				
1.0	50	21	67	54	45	99	94	
	60	28	80	62	55	99	93	
	70	36	92	67	65	91	85	
	80	47	100	68	76	72	67	
	90	63	93	59	88	43	39	
	99	93	25	14				
2.0	50	11	40	31	39	95	86	
	60	14	49	36	48	100	89	
	70	18	59	40	59	97	84	
	80	22	69	44	71	83	70	
	90	28	81	46	84	53	44	
	99	39	95	48				

can affect the efficiency of a limitation programme under certain circumstances outlined below.

For the case of parallel shifts of linear marginal cost of effort schedules considered in Section 2 and illustrated by Figure 1, the ratio of the equilibrium level of effort under a limitation scheme, E_1 , to the initial open-access level of effort, E_0 , can be shown from equations [1] and [2] to be $(E_1/E_0) = 1 - [C_1B/(C_1+b)]$, where B is the proportion of the restricted input retired from the fishery. Since in this case (E_1/E_0) is independent of the level of E_0 , a given limitation scheme will have the same level of effectiveness, expressed as the percentage reduction of the level of effort devoted to the fishery, irrespective of the level of the index of resource stock exploitation, E_0/E_{\max} .

When we consider the more general case in which the marginal cost of effort schedule is nonlinear and/or exclusion induces non-parallel shifts, the effectiveness of the limitation programme becomes sensitive to the level of effort in the initial open access equilibrium. This can be seen from Table 4 which reports results for a fishery with the same cost structure as for the case depicted in Table 3, but with a lower output price such that the initial open-access level of effort, E_0 , for the case presented in Table 4 is half that used to generate the results reported in Table 3. Since $E_{\max} = r/A$ for the Schaefer model, the exploitation intensity index equals 39 and 19.5 per cent in Tables 3 and 4 respectively.

Hence, a comparison of the results in Tables 3 and 4 can be used to derive propositions about the efficiency of a limitation programme in a lightly exploited fishery (Table 4) with that in a more heavily exploited fishery (Table 3), given the assumptions made about the production of effort. First note that exclusion of a given proportion of inputs achieves a greater proportionate reduction in ultimate effort level in the lightly exploited fishery. Consequently, the optimal level of limitation can be seen to be directly related to the intensity of exploitation of the fish stock, while net efficiency of the optimal level of limitation varies inversely with exploitation intensity.

Conclusion

For a variety of reasons, it is not always easy for fishery managers to control fishing catch and/or effort using first-best policy instruments. As a result, so-called licence limitation programmes which effectively restrict the use of selected inputs to the production of fishing effort are a common policy instrument in many fisheries around the world. In this paper, we have investigated two issues, one being the determinants of the efficiency of limitation programmes and the other

being the "optimal" (i.e. second best) level of exclusion of inputs under different circumstances.

Overall efficiency of a limitation programme depends firstly on the effect of a reduction in level of use of selected fishing inputs on the level of fishing effort applied to the fish stock, and secondly on the extent to which total cost of fishing effort under a licence limitation programme exceeds the minimum total cost necessary to generate the same level of effort in an unrestricted fishery. The elasticity of supply of effort given restricted use of selected inputs was shown to be the critical determinant of both of the above aspects. This elasticity varies directly with the elasticity of substitution between restricted and unrestricted inputs to fishing effort, and inversely with the share of total cost of fishing effort accounted for by inputs subject to limitation. For particular cases investigated in this paper, this elasticity was found to also be affected by the intensity of exploitation of the fish stock.

We conclude that a limitation programme is likely to be close to first-best as long as non-restricted inputs cannot easily be substituted for restricted inputs and/or as long as restricted inputs enter the production function for effort with a reasonably high productivity coefficient which implies that they are a significant proportion of total factor cost. Our results also suggest that efficiency of a limitation programme will be higher if the economic pressure to exploit the fish stock intensively is not too great. When these conditions are not present, limitation programmes are likely to be a relatively inefficient policy instrument for generating a net social surplus for society.

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Appendix A

The approximate estimate of efficiency loss obtained from equation 16 may over- or underestimate the true efficiency loss. The extent to which it does so will depend on the degree of curvature of the MC_E function. For the special case of a Cobb Douglas production function,

$$MC_E = w(1 - \delta)^{-1} (\gamma)^{-1/(1-\delta)} (E/R)^{\delta/(1-\delta)} \quad [A.1]$$

Note that if $\delta = 0.5$, then marginal cost is linear in E, in which case equation 16 above measures the efficiency loss exactly. More generally, it can be shown that as long as $\delta = 0.5$, the slope of the MC_E function will be increasing in E if the elasticity of substitution, $\sigma < 1.0$, and vice versa if $\sigma > 1.0$. In other words, our approximate measure of efficiency loss overestimates the true value when $\sigma < 1.0$, and involves underestimation when $\sigma > 1.0$. If δ is less than 0.5, then it can be seen from equation A.1 above that the slope of MC_E decreases with increasing E even when $\sigma = 1$ (i.e. the Cobb Douglas case). Thus where δ is low our measure of efficiency loss most likely underestimates the true value, although there is still some possibility of overestimation if the elasticity of substitution is close enough to zero.

Using the selected parameter values reported in Table 1, we were able to calculate the true efficiency loss for the special cases where $\sigma = 1.0$ and where $\sigma = 0.5$. For the Cobb Douglas case, we found the degree of underestimation to be less than 10 per cent when factor cost share, and $\delta = 0.1$, and the extent of overestimation to be only 4 per cent when $\delta = 0.9$. For the other special case, $\sigma = 0.5$, we found that our approximate measure overestimated the true efficiency loss by less than 10 per cent for all factor cost shares between 10 and 90 per cent.

Finally, note that, because the efficiency loss typically is a minor component of net social surplus generated by a limitation programme, our procedure is much more accurate than the above figures might suggest in terms of assessing overall economic efficiency of limitation programmes.