Bergland, Harald; Clark, Derek J.; Pedersen, Pål Andreas

Working Paper

Rent-seeking and quota regulation of a renewable resource

Department of Economics Discussion Paper, University of Kent, No. 01,06

Provided in Cooperation with:
University of Kent, School of Economics

ISSN: 1466-0814

RENT-SEEKING AND QUOTA REGULATION OF A RENEWABLE RESOURCE

Harald Bergland*, Derek J. Clark# and Pål Andreas Pedersen$

March 2001

Abstract

The paper deals with rent-seeking behaviour among agents competing for future shares of a common renewable natural resource. Rent-seeking might become profitable when the agents expect that the distribution of the natural resource in future periods will be dependent on the agents' extraction of the resource in the past, even though high exploitation might reduce the stock that future individual quotas will be based upon. Whether aggressive rent-seeking behaviour by one agent will encourage other agents to rent-seek more, however, is generally found to be ambiguous.

JEL Classification: Q2, D7, C7.

Keywords: Rent-seeking, quota regulation, renewable resources.

Address for Correspondence: Pål Andreas Pedersen, Department of Economics, Keynes College, University of Kent at Canterbury, Canterbury, Kent, CT2 7NP, UK. Tel: (+44) 1227 827639; Fax: (+44) 1227 827850; Email: P.A.Pedersen@ukc.ac.uk.

* Harstad College, Norway

\# Department of Economics and Management, University of Tromsø, Norway and Norwegian School of Management, Tromsø, Norway.

$ Bodø Graduate School of Business, Bodø, Norway and Department of Economics, University of Kent at Canterbury, UK

RENT-SEEKING AND QUOTA REGULATION OF A RENEWABLE RESOURCE

1. Introduction

It is well known that agents who share a common-pool resource will not take account of the full social cost of their actions. This means that the non-cooperative solution leads to a sub-optimal management of the resource (Gordon, 1954). A usual response to this problem is to attempt to regulate extraction of the resource in some way in order to enforce optimal management. Indirect regulation can be implemented through a system of taxes, whilst direct regulation involves a quantity constraint on production (see for instance the overviews written by Bohm and Russell, 1985 and Munro and Scott, 1985). In this paper we examine how rational actors' expectations of a direct regulatory regime can influence its efficiency. This type of regulation implies a reduction in the exploitation of the resource for some or all of the actors, according to some pre-specified criterion. Equal rate of reduction is an often-used principle; for instance, a fishery may be regulated by the use of quotas which specify a total allowable catch for each nation. The sizes of the nations' quotas are very often based upon observable and verifiable variables such as historic catch or the number of vessels participating in the different fisheries. These magnitudes can be freely chosen by the nations in an unregulated (free) fishery. When the participants know (or suspect) that resource extraction will be directly regulated, they may have an incentive to adjust their behaviour in anticipation of this, even before regulation is implemented. Imagine that quotas will be awarded on the basis of historic catch, defined over a certain period. The nation can then attempt to secure a larger quota *ex post* by increasing the size of their catches in the periods leading up to the implementation of regulation. The incentive to over-fish is an example of rent-seeking behaviour which can counteract the efficiency of the regulatory regime. It is precisely this mechanism which is the focus of this paper. We concentrate our analysis on two aspects: first we discuss under which conditions the regulation will lead to over-fishing compared to a welfare optimal allocation and different non-cooperative solutions (situations without any explicit regulation); secondly, we examine the strategic interaction between actors which may arise within the regulatory regime. For instance, one may ask whether one nation's over-fishing may stimulate or moderate other nations' incentives to adopt such a strategy.

Rent-seeking has been discussed systematically in applied economic theory since the seminal work of Tullock (1967). The term ”rent-seeking” appears to have been coined by Krueger (1974), but the same type of activity was discussed and analysed formally as early as in 1954; see Haavelmo (1954)[1] who called the activity ”grabbing” and introduced an allotment function where the value obtained by an actor from unproductive activities is a function of his capacity for such activity relative to others. The quota allocation mechanism that we will focus on in our model is similar to the allotment function introduced by Haavelmo.

Game-theoretic resource modelling is primarily concerned with strategic aspects of externalities arising from the common exploitation of natural resources. Mesterton-Gibbons (1993) surveys resource games in fisheries and other renewable resources. Most of the literature is concerned with comparing different Nash equilibria with welfare solutions (or global optima). Many papers deal with the case of two agents (see for instance Levhari and Mirman, 1980 and Fisher and Mirman, 1996). However, the importance of the number of agents is considered by e.g. Clark (1980) and Hannesson (1997). Within the context of an infinitely repeated game, Hannesson considers how the number of agents who share a fish

---

[1] Professor Tore Thonstad, University of Oslo, made us aware of this contribution in an open lecture at University of Tromsø, 14 February 2000.

stock affects the possibility of finding a self-enforcing solution that yields the welfare-maximizing allocation. In our paper we will use game-theoretic resource modelling to focus on a rent-seeking mechanism which can result from regulation. The analysis is simplified by considering a model with only two agents and two time periods, in which there is no regulation in the first period, and where a quota regime is implemented in the second period. Two-period models have also been used to fisheries in a game-theoretic approach by e.g. Naito and Polasky (1997).

The model which we use to discuss the phenomenon of rent-seeking in anticipation of regulation may have other applications than fisheries, e.g. the extraction of other renewable natural resources or the emission of pollution. However, in order to motivate the type of regulation considered in our model, we will now present some evidence from international fisheries. For resources that are exploited by more than one nation, it is common that a total allowable catch (TAC) is negotiated by the interested parties; the size of the TAC is often determined under advisement from marine researchers. The actual allocation of this TAC between the participating nations often depends upon past harvests. An early example of such a quota allocation between nations is the whale quota agreement from 1962. According to this agreement, the five involved nations (Norway, Japan, United Kingdom, Netherlands and Soviet Union) shared the total quota according to the relative catch distribution before the agreement (Tønnesen 1970)[2]. A thorough study of quota allocation between nations is found in Underdal (1980), who examines the quota regulation of North East Atlantic fisheries within the North East Atlantic Fishery Commission. The study includes 11 different fisheries

---

[2] One exception was that the Soviet Union received a considerably higher share than their historic share of catches. This was explained by the fact that the Soviet Union, at the time it entered into this agreement, was building up its whaling industry.

involving different numbers of nations. Underdal examines to what extent the actual quota allocation deviates from the pre-regulation catch distribution. He also studies the arguments and the principles used in the negotiation process. One important conclusion is that the redistribution implied by the introduction of quota regulations is in most cases very small[3].

A final example of an international quota allocation is the agreement between the members of the European Union established in 1983. According to this agreement, the TAC - mainly based on biological criteria - is shared by the members according to a rule which is fixed from one year to the next. One of the determinants of the shares is the historic catch distribution between the EU nations, especially for the period 1973-1978 (Holm 1990).

Our examples suggest that, in the regulation of international fisheries, the distribution of historic catches play an important role in the division of the TAC among the involved nations. This leads us to the following conjecture: given that past catch performance will play a prominent role in the allocation from any future regulatory regime, there is an incentive to increase current catches in order to secure a large share of the TAC in the future, i.e. there is an incentive to rent-seek. Possible rent-seeking mechanisms in natural resource quota allocation have earlier been mentioned by Hannesson (1991) and formally studied by Boyce (1998). When searching for optimal allocation principles and evaluating different possible allocation rules which might be used to distribute the common resource to several participants in a competition, Boyce finds that the allocation where the winner takes all, combined with full compensation from the winner to the losers, gives a first-best solution. Unlike Boyce, we

---

[3] When comparing the last year with free fishing and the first year of quota regulation, he finds that in 3/5 of the cases the changes are less than +/-2% of the total. In only approximately 15% of the cases are the changes +/-5% or more - see table 4.3 in Underdal (1980).

do not go through any normative analysis searching for optimal allocation mechanisms. As commented on above we restrict ourselves to discussing allocations where all participants obtain a level of the resource after regulation has been implemented which is a function of the actors' historical exploitation of the resource.

The model on which the analysis is based is introduced in Section 2. There we present widely known solutions to the resource allocation problem, which we compare with our rent-seeking solution in Section 3. Conclusions are offered in Section 4.

2. The Model

We consider a model with two periods and two actors (countries). In order to simplify our analysis, the actors exploit a common renewable natural resource. At the beginning of period 1 we have a given historic stock volume. The natural growth of the stock in each period is depending on the stock volume at the beginning of the period. Furthermore, because we consider only two periods, it is reasonable to introduce a restriction on the stock volume at the end of period 2. This means that the stock cannot be lower than a certain level at the end of period 2. In this section we will consider the resource constraint and establish the welfare optimum solution and two non-cooperative solutions.

Let S_t be the stock volume at the end of period *t* and h_t be the total harvest in period *t*. Then we can define the resource dynamics in the model by:

$$S_1 = S_0 + G(S_0) - h_1, \quad S_2 = S_1 + G(S_1) - h_2, \quad S_2 = \overline{S}, \tag{1}$$

where S_0 is a given stock size at the start of period 1, and $\bar{S}$ is a given stock volume which is required at the end of period 2.[4] Furthermore, $G(S_t)$ is the natural growth of the stock in period *t*; the function has first derivative denoted by $G'(S_t)$. Normalizing the product price in both periods to unity, we can write actor *i*'s rent in period *t* as:

$$r_t^i = h_t^i - C^i(S_{t-1}, h_t^i),\ \ i = 1,2,\ \ t = 1,2 \qquad (2)$$

$$\frac{\partial C^i}{\partial h_t^i} > 0,\ \ \frac{\partial^2 C^i}{\partial h_t^{i2}} > 0,\ \ \frac{\partial C^i}{\partial S_{t-1}} < 0,\ \ \frac{\partial^2 C^i}{\partial S_{t-1}^{\ 2}} \geq 0,\ \ \frac{\partial^2 C^i}{\partial h_t^i \partial S_{t-1}} \leq 0\,,$$

where h_t^i is actor *i*'s harvest in period *t* and C^i is the cost function for actor *i*, assumed to be identical for both periods. The cost is supposed to be strictly increasing and convex in the harvest volume and decreasing in the stock volume. Furthermore, we assume that the cost is convex in stock volume and that the marginal cost in harvest is non-increasing in the stock volume.

We can now define the present value of actor *i*'s two-period profit as:

$$V^i = h_1^i - C^i(S_0, h_1^i) + \delta\left[h_2^i - C^i(S_1, h_2^i)\right],\ \ i = 1,2\,, \qquad (3)$$

where $1 \geq \delta \geq 0$ is a common discount factor. Using the three equations in (1), we may write the resource dynamic constraint as:

$$\bar{S} = S_0 + G(S_0) - h_1 + G(S_0 + G(S_0) - h_1) - h_2 \qquad (4)$$

where $h_t = h_t^1 + h_t^2,\ \ t = 1,2\,.$

---

[4] We may think of two types of history for the resource stock we consider:

(a) High historic exploitation and therefore a requirement of building up the stock, i.e. $S_0 < \bar{S}$.

(b) A resource which is "discovered" in period 1 and therefore high historic stock volume compared to the required future stock size, i.e. $S_0 > \bar{S}$.

2.1 Three Allocations

In the following we will define three standard solution concepts for the allocation problem. As they are standard, we give a brief definition of each and then collect the first-order conditions which govern their solutions in a table to facilitate comparison with the rent-seeking approach adopted in Section 3.

Welfare Solution (WS)

We define the welfare solution (WS) as the catch allocation which maximises the sum of the actors' present value $W = V^1 + V^2$ subject to the resource constraint in (4). The solution to this problem is given by equations (5) and (6) in Table 1, where λ is the increase in the welfare (total present value) from a small reduction in the required stock volume at the end of period 2 ($\overline{S}$).

Non-cooperative Solutions

Within the standard neo-classical framework, each actor will exploit the resource in order to maximize his own resource rent. The solution concept is of the Nash-Cournot type meaning that each actor takes into account the effect that his own actions have on the common resource stock but disregards the effects emanating from others. We will consider two cases of this non-cooperative solution depending upon the actors' attitude towards the resource constraint.

NS(I) The non-cooperative solution with a binding common resource constraint

The non-cooperative solution with a common resource constraint, denoted by NS(I), is the catch allocation which maximises V^i subject to the resource constraint in (4). In this case it is assumed that the actors are individually rational, and that they consider the common future stock requirement given by (4) to be a real constraint on their behaviour. The solution in this regime is given by equations (7) and (8), where μ^i is the increase in agent *i*'s present value from a small reduction in the required stock volume at the end of period 2 ($\bar{S}$).

NS(II) The non-cooperative solution without a binding resource constraint

Here the actors are assumed to disregard the resource constraint ($\bar{S}$), so that (4) does not constrain their behaviour (i.e. $\mu^i = 0,\ i = 1,2$). This is equivalent to free maximization of V^i; equations (9) and (10) dictate the solution to this problem.

In Table 1 below we have collected the first order conditions for these three standard regimes.[5] One of our main concerns will be how regulation affects the allocation of the harvest between time periods.[6] Table 2 presents the conditions which govern this allocation in the three regimes presented so far.

[5] We have dropped the presentation of the second order conditions which here, and for all other regimes analysed throughout the paper, are supposed to be satisfied.

[6] It should be noticed that in the NS(I) regime the actual catch distribution between the actors in period 2 is not determined in the model. One could possibly think that the catch volumes in period 2 are decided upon in a negotiation between the agents, or by public authorities. For our purpose here, the main thing is that the agents under this regime want to meet the resource constraint in (4) and that the decisions taken in period 1 do not influence the actual catch distribution in period 2.

Table 1

First-Order Conditions for the Standard Solutions

Allocation	First-order conditions
WS	$1-\frac{\partial C^i}{\partial h_1^i}+\delta\left[\frac{\partial C^i}{\partial S_1}+\frac{\partial C^j}{\partial S_1}\right]-\lambda(1+G'(S_1))=0,\ i=1,2,\ \ j=1,2,\ i\neq j$ (5) $\delta\left(1-\frac{\partial C^i}{\partial h_2^i}\right)-\lambda=0,\ i=1,2$ (6)
NS(I)	$1-\frac{\partial C^i}{\partial h_1^i}+\delta\frac{\partial C^i}{\partial S_1}-\mu^i(1+G'(S_1))=0,\ i=1,2$ (7) $\delta\left(1-\frac{\partial C^i}{\partial h_2^i}\right)-\mu^i=0,\ i=1,2$ (8)
NS(II)	$1-\frac{\partial C^i}{\partial h_1^i}+\delta\frac{\partial C^i}{\partial S_1}=0,\ i=1,2$ (9) $\delta\left(1-\frac{\partial C^i}{\partial h_2^i}\right)=0,\ i=1,2$ (10)

Table 2

Allocation of Harvest between Periods[7]

Allocation	First-order conditions
WS	$1-\frac{\partial C^i}{\partial h_1^i}+\delta\left[\frac{\partial C^i}{\partial S_1}+\frac{\partial C^j}{\partial S_1}\right]=\delta\left(1-\frac{\partial C^i}{\partial h_2^i}\right)(1+G'(S_1)),\ i,j=1,2,\ i\neq j$ (11)
NS(I)	$1-\frac{\partial C^i}{\partial h_1^i}+\delta\frac{\partial C^i}{\partial S_1}=\delta\left(1-\frac{\partial C^i}{\partial h_2^i}\right)(1+G'(S_1)),\ i=1,2$ (12)
NS(II)	$0=1-\frac{\partial C^i}{\partial h_1^i}+\delta\frac{\partial C^i}{\partial S_1}=\delta\left(1-\frac{\partial C^i}{\partial h_2^i}\right),\ i=1,2$ (13)

[7] Equation (11) is derived from (5) and (6); (12) comes from (7) and (8), whilst (13) follows from (9) and (10).

2.2 Comments on the Allocations

Welfare Solution (WS)

From (5) and (6) it follows that:

$$\frac{\partial C^1}{\partial h_t^1} = \frac{\partial C^2}{\partial h_t^2}, \ t = 1,2,$$

so that the marginal costs for each of the periods should be the same for both actors.

Equation (11) corresponds to the standard "golden rule equation" for the optimal equilibrium biomass.[8] However, this condition for optimality in the harvest allocation between the periods can also be directly interpreted from (11). The two first terms of the left hand side express the marginal rent in period 1. The third term is the discounted marginal cost effect following from reduced stock volume in period 2. This marginal increase in the present value for an extra unit catch in period 1, measured by the left hand side of (11), should be equal to the right hand side. We see that the right hand side is a product of three factors. The two first factors are the discounted marginal rent for period 2, while the third factor is the harvest volume effect in period 2 caused by one unit harvest in period 1, where the resource constraint is taken into account[9].

---

[8] In order to deduce the standard golden rule equation (see Clark and Munro, 1975) from equation (11), one has to formulate biological equilibrium harvest, introduce the connection between the discount factor and the rate of interest and specify the cost function as $C^i = c^i(S)h^i$.

[9] It is reasonable to assume that $1 + G'(S_1) > 0$ for an exploited resource (i.e. in the case where S is not too high), and this condition is assumed to hold in the rest of this paper.

Non-cooperative Solution NS(I)

In this case, μ^i is the increase in agent *i*'s present value from a small reduction in the required stock volume at the end of period 2 ($\bar{S}$). If the two agents have different costs, these resource shadow prices will also be different. If the stock requirement represents a true constraint on actor *i*, it follows that $\mu^i > 0$. Furthermore, by comparing the NS(I) and WS solutions in Table 1, it is seen that in the second period, the NS(I) solution gives a sub-optimal allocation of harvest between the agents when their resource shadow prices differ. It also follows that the allocation between actors in the first period is not optimal, both because of possible difference in resource shadow prices and because the cost effects of the stock volume might be different for the two actors, i.e. $\partial C^1 / \partial S_1 \neq \partial C^2 / \partial S_1$.

Equation (12) shows that the NS(I) solution will not give an optimal harvest allocation between periods. The right hand side of (12) is the same qualitative expression as the right hand side of (11). However, by comparing the left hand side of these two equations, we see that the non-cooperative actors, although being aware of the stock requirement in the future, will not take account of the full social cost of their actions. Each actor takes account of the cost increase only for himself in period 2 caused by lower resource stock in period 2, but disregards the same effect for the other actor. Because of the assumption that the cost is strictly increasing and convex in the harvest volume, we find that the harvest volume in period 1 is too high in the NS(I) case compared to the welfare solution (WS).

Non-cooperative Solution NS(II)

Here it follows directly from (10) that the marginal rents for both actors in the second period will be identical, meaning an optimal allocation of the total harvest in period 2. However, the total harvest in period 2 will be higher than for NS(I) and WS. Furthermore, it follows from (9) that each agent only takes account of the private cost effect on reducing stock in period 2, meaning that the harvest volume for both actors also will be too high in period 1. From equation (13), it is seen that the relative catch distribution between the periods will be different in this case compared to both NS(I) and WS. Ignoring the resource constraint means a relatively more intensive fishery in period 1 compared to the harvest volume in period 2 than in NS(I) or WS.

3. Quota Regulation and Rent-seeking

So far our model findings correspond to the standard results. Agents who share a common-pool resource will not take account of the full social cost of their actions, which means that the non-cooperative solutions lead to a sub-optimal management of the resource. This is well known in the literature back to Warming (1911) and Gordon (1954). A natural response to this problem is to attempt to regulate extraction of the resource in some way in order to enforce optimal management. For fishery resources where more than one nation are involved in the exploitation, it is common that a total allowable catch (TAC) are determined and distributed among the involved nations. Past harvest is often one important criterion when it comes to the allocation between nations as mentioned in Section 1. When participants know (or suspect) that the resource extraction will be directly regulated in this way, they may have an incentive to adjust their behaviour in anticipation of this. Imagine that quotas will be awarded on the basis of historic catch, defined over a certain period. The country can then attempt to secure a larger quota ex post by increasing the size of their catch in the periods leading up to the implementation of regulation. In this section we will focus on this possible rent-seeking mechanism and compare this to the allocations in Section 2.

In our analysis of a quota regulation regime based on historic catch, we will consider two different situations: in the first case, both actors choose their harvest in period 1 simultaneously, denoted by RS(A); the second solution is characterised by sequential choices where one of the nations observe the other nations harvest in period 1 before it chooses its own harvest in period 1. This solution is denoted by RS(B). In both cases, the actors are supposed to be unregulated in period 1, whilst direct regulation is introduced in the second period. This means that the countries are free to choose the level of economic activity (harvest) in the first period, but face a quantity constraint in the second via the introduction of a quota scheme which limits the total amount of resource extraction. Countries' individual shares of the total quota in period 2 are decided by the size of their harvest in period one. The introduction of this quota regime is known to both actors in the first period. In order to simplify the analysis, we assume that these allocations in period 2 are non-tradeable.

We begin our analysis of this regulated case by noting that the resource constraint in (4) defines the total quota for period 2, i.e.

$$\overline{h}_2 = S_0 + G(S_0) - h_1 + G(S_0 + G(S_0) - h_1) - \overline{S} = \overline{h}_2(h_1)\,, \tag{14}$$

where $\overline{h}_2 = \overline{h}_2^1 + \overline{h}_2^2$ and $\overline{h}_2^i$ is the individual quota for actor *i* in period 2. Furthermore, we assume that the actors' catch volumes in period 1 determine the distribution of the total quota in period 2. This can be written as:

$$\overline{h}_2^i = g^i(h_1^1, h_1^2)\overline{h}_2(h_1),\ \ i = 1,2\,, \tag{15}$$

where the individual share functions sum up to one, $g^1(h_1^1, h_1^2) + g^2(h_1^1, h_1^2) = 1$. Furthermore, it is supposed that actor *i*'s share is increasing and strictly concave in own harvest in period 1 and decreasing in the other actor's harvest in period 1, i.e.

$$\frac{\partial g^i(h_1^1,h_1^2)}{\partial h_1^i} > 0,\ \ i = 1,2 \quad \text{and} \quad \frac{\partial g^i(h_1^1,h_1^2)}{\partial h_1^j} < 0,\ \ i, j = 1,2,\ \ i \neq j\ .$$

As mentioned above, a special case of this allocation rule will be that the relative amounts of the total harvest in period 2 in the regulation case are the same as the catch distribution before regulation is implemented, i.e.[10]

$$g^i(h_1^i,h_1^j) = \frac{h_1^i}{h_1^1 + h_1^2},\ \ i = 1,2,\ \ j = 1,2,\ \ i \neq j. \tag{16}$$

The problem facing actor *i* in period 2 is to maximise its profit in period 2, subject to the given quota. This means that actor *i* maximises (2), interpreted for period 2, subject to:

$$h_2^i \leq \overline{h}_2^i,\ \ i = 1,2. \tag{17}$$

The first-order condition for maximum is then given by:

$$1 - \frac{\partial C^i}{\partial h_2^i} = \beta^i,\ \ i = 1,2\ , \tag{18}$$

where β^i is the increase in actor *i*'s rent from a small increase in its individual quota. We will assume that the direct regulation represents a true constraint on actor *i*, which means that $\beta^i > 0$ and (17) holds as an equality. When the quota allocation in period 2 is non-tradeable, as we have assumed, these quota shadow prices might be different because the actors may have different costs and because the quota obtained by the actors in period 2 may vary.[11]

---

[10] According to Underdal (1980) this has been a common principle in the quota allocation between nations in the North East Atlantic Fishery Commission (NEAFC).

[11] In this case we have that the welfare optimum condition from (6) is not fulfilled. However, if the individual quotas in period 2 are tradeable in an atomistic quota market, the marginal rent in period 2 would be equal for all actors (identical β's), and the condition in (6) is fulfilled. However, the model and its results concerning the allocation between actors in period 1 and the allocation between period 1 and period 2 would not be affected if the quotas were supposed to be tradeable.

Let us now consider the actors' choices of harvest in the first period. The present value of the actors' rents can now be written as:

$$V^i = h_1^i - C^i(S_0, h_1^i) + \delta\left[\overline{h}_2^i - C^i(S_1, \overline{h}_2^i)\right],\ \ i = 1,2. \tag{19}$$

(a) Simultaneous Moves

The actors who are unregulated in the first period can freely choose the harvests which maximise (19). This means that the first-order conditions in the case of simultaneous moves, are given by:

$$1 - \frac{\partial C^i}{\partial h_1^i} + \delta \frac{\partial C^i}{\partial S_1} = -\delta\left(1 - \frac{\partial C^i}{\partial h_2^i}\right)\frac{\partial \overline{h}_2^i}{\partial h_1^i},\ \ i = 1,2. \tag{20}$$

Furthermore, it follows from (14) and (15) that:

$$\frac{\partial \overline{h}_2^i}{\partial h_1^i} = \frac{\partial g^i}{\partial h_1^i}\overline{h}_2 + g^i \frac{\partial \overline{h}_2}{\partial h_1^i},\ \ i = 1,2, \tag{21}$$

where $$\frac{\partial \overline{h}_2}{\partial h_1^i} = \frac{\partial \overline{h}_2}{\partial h_1^j} = -(1 + G'(S_1)) < 0,\ \ i, j = 1,2.$$

Let us take a closer look at the expressions in (21). In general, when an actor increases his harvest in period 1, he may experience higher or lower individual quota in period 2. The first term on the right hand side is clearly positive because the actor *i*'s share of the total quota is increasing in his harvest volume in period 1, see (15). However, the second term measures the decrease in the total quota in period as a consequence of increasing harvest in period 1. Rearranging (21) gives us that:

$$\frac{\partial \overline{h}_2^i}{\partial h_1^i} > 0 \quad \text{if} \quad \frac{\partial g^i}{\partial h_1^i}\frac{h_1^i}{g^i} = El_{h_1^i} g^i > -El_{h_1^i}\overline{h}_2 = -\frac{\partial \overline{h}_2}{\partial h_1^i}\frac{h_1^i}{\overline{h}_2},\ \ i = 1,2\,. \tag{22}$$

Equation (22) tells us that actor *i*'s quota in period 2 will be increasing in his harvest volume in period 1 if the relative increase in actor *i*'s share of the quota in period 2, caused by a marginal increase in harvest in period 1, is higher than the relative decrease in the total quota in period 2, caused by the same marginal increase harvest in period 1. Using the allocation rule in (16), the condition in (22) becomes $g^j \bar{h}_2 > h_1^i (1 + G'(S_1)),\ i, j = 1,2,\ i \neq j,$ where the left hand side is the quota for actor *j* in period 2, and the right hand side is the reduction in total quota in period 2 caused by a marginal increase in the catch of actor *i* in period 1. In the case of the allocation rule in (16), this means that (22) holds for both actors when the individual catch quotas for period 2 are higher than the reduction on the stock in period 2 which one unit catch in period 1 causes.

By inserting (20) in (21), we obtain the first order conditions in this RS(A) case:

$$1 - \frac{\partial C^i}{\partial h_1^i} + \delta \frac{\partial C^i}{\partial S_1} = \delta \left(1 - \frac{\partial C^i}{\partial h_2^i} \right) \left[g^i (1 + G'(S_1)) - \frac{\partial g^i}{\partial h_1^i} \bar{h}_2 \right],\ i = 1,2. \tag{23}$$

Let us now compare the condition in (23) with the condition in (12). Generally, we know that $g^i (1 + G'(S_1)) - \frac{\partial g^i}{\partial h_1^i} \bar{h}_2 < 1 + G'(S_1)$ because $g^i < 1$ and $\frac{\partial g^i}{\partial h_1^i} > 0$. This means that the right hand side of (23) is always less than the right hand side of (12). Because the cost function is strictly increasing and convex in the harvest volume, we find that the harvest volume in period 1 will always be higher for both actors in this regulated solution, (RS(A)), than in the non-cooperative solution with a binding resource constraint (NS(I)). However, if we compare this regulated solution to the case where the actors do not feel any responsibility to meet the common future stock constraint (NS(II)) it follows that harvest for the two actors in period 1 under RS(A) will be higher only if (22) holds. This means that more intensive harvesting is seen in the RS(A) case than in the NS(II) case if the individual quotas in period 2 are increasing in the actors' harvest volume in period 1. The conclusions are summed up in result 1 below.

Result 1:

(I) *The individual harvests in period 1 under the regulated solution with simultaneous moves, RS(A), are always higher than the harvests in period 1 under the non-cooperative solution when actors feel responsible for meeting the common future stock requirements, NS(I).*

(II) *Moreover, the actors' harvests in period 1 under the quota regime with simultaneous moves, RS(A), will also be higher than the actors' harvests in period 1 under the non-cooperative solution without a binding resource constraint, NS(II), if the individual quotas are increasing in the harvest volume in period 1, i.e.* $\frac{\partial \overline{h}_2^i}{\partial h_1^i} > 0$, *implying that condition (22) holds.*

To give a better understanding of Result 1, we may think of what is going on in our model both as a game against the other actor, and a stock game from the resource constraint. To see this, we divide the total game into a pure "strategic game" and a pure "stock game". Isolating the strategic game by excluding the stock game means that we ignore the common future stock constraint in the non-cooperative solution, i.e. we have the NS(II) case where $\mu^i = 0,\ i = 1,2.$ The analogous solution in the RS(A), where the stock game is excluded, will be found by disregarding that the individual harvest volume in period 1 has any quota effect in period 2, i.e. assuming $\frac{\partial \overline{h}_2}{\partial h_1^i} = 0,\ i = 1,2.$ In this pure strategic game we have that the left hand side of (12) is equal to zero, while the right hand side of (23) is negative. This means that in the pure strategic game caused by the quota allocation mechanism in (15) leads to over-fishing compared to the non-cooperative solution, i.e. the allocation rule results in a race for quotas between the two actors.

The pure stock game is found by excluding the strategic game. The relevant non-cooperative solution is now NS(I). In order to obtain the isolated effects caused by the stock game in RS(A), we look on the case where the quota shares are given in advance, i.e. $\frac{\partial g^i}{\partial h_1^i} = 0$. The right hand side of (23) now becomes $\delta\left(1 - \frac{\partial C^i}{\partial h_2^i}\right)\left[g^i(1 + G'(S_1))\right]$, which is less than the right hand side of (12) because $g^i < 1$. Hence, the regulation quota regime leads to over-fishing in period 1 compared to the relevant non-cooperative solution. The reason is quite simple: the introduction of an individual quota means that the actors will feel less responsible for the future of the resource stock in the regulation case than in the non-cooperative case with a binding common resource constraint. This is because in the regulation case, the quota effect in period 2 of increased harvest in period 1 is only multiplied by the private share which the actor obtains (equal to $g^i < 1$), while it is multiplied with the whole effect on the future stock in the NS(I) case (equal to1).

(b) Non-simultaneous Moves

The following regulation solution is symbolised by RS(B). We now assume that actor *i* is taking his action after actor *j*'s harvest volume in period 1 is known, i.e. that actor *j* is a leader and actor *i* is a follower in a non-simultaneous game going on in period 1. This means that the optimal behaviour of actor *i* is still defined by equation (23). However, when actor *j* chooses his catch volume in period 1, he will take into account the reaction which he causes on actor *i*'s behaviour in the same period. Generally, this reaction will be implicitly defined by (23) and might be written as:

$$h_1^i = h_1^{iR}(h_1^j) \tag{24}$$

where differentiation of (23) with regard to the leader's harvest in period 1, in general terms, gives:

$$\frac{dh_1^{iR}}{dh_1^j} = -\frac{\dfrac{\partial^2 V^i}{\partial h_1^i \partial h_1^j}}{\dfrac{\partial^2 V^i}{\partial (h_1^i)^2}}$$

The denominator is negative when the second order conditions are fulfilled, so the sign of the reaction is determined by the sign of the numerator. By using the specifications in our model, the numerator can be written as:

$$\frac{\partial^2 V^i}{\partial h_1^i \partial h_1^j} = \delta \left\{ \begin{array}{l} \underbrace{\dfrac{\partial^2 C^i}{\partial S_1 \partial h_2^i}\left[\left(\dfrac{\partial g^i}{\partial h_1^i}+\dfrac{\partial g^i}{\partial h_1^j}\right)\bar{h}_2 - 2g^i(1+G'(S_1))\right]}_{I} - \underbrace{\dfrac{\partial^2 C^i}{(\partial S_1)^2}}_{II} - \\ \underbrace{\dfrac{\partial^2 C^i}{\partial (h_2^i)^2}\left[\dfrac{\partial g^i}{\partial h_1^i}\dfrac{\partial g^i}{\partial h_1^j}(\bar{h}_2)^2 - \bar{h}_2 g^i(1+G'(S_1))\left(\dfrac{\partial g^i}{\partial h_1^i}+\dfrac{\partial g^i}{\partial h_1^j}\right) + (g^i)^2(1+G'(S_1))^2\right]}_{III} + \\ \underbrace{\left(1-\dfrac{\partial C^i}{\partial h_2^i}\right)\left[\dfrac{\partial^2 g^i}{\partial h_1^i \partial h_1^j}\bar{h}_2 - (1+G'(S_1))\left(\dfrac{\partial g^i}{\partial h_1^i}+\dfrac{\partial g^i}{\partial h_1^j}\right) + g^i G''(S_1)\right]}_{IV} \end{array} \right\} \quad (25)$$

When taking a closer look at (25), it is seen that our general assumptions regarding the cost function and the distribution function give ambiguity regarding the sign of the sum of the four terms of the right hand side. Only the sign of the second term *II* is clearly non-positive. Furthermore, it is seen that the first, the third and the fourth term consist of combinations of what we above have called strategic effects, where the actor *i*'s share changes, and stock effects which influence on actor *i*'s marginal present value. One way to examine the sign of the expression in (25) further, will be to separate the total effect into a pure "stock game" (where $\frac{\partial g^i}{\partial h_1^i} = \frac{\partial g^i}{\partial h_1^j} = 0$) and a pure "strategic game" (where $\frac{\partial \bar{h}_2}{\partial h_1^i} = 0$), see the Appendix. However, as seen in the appendix, the sign of (25), and thereby the sign of the slope of the reaction function in (24), is generally ambiguous in both the pure strategic and pure stock game. This is a consequence of many different kinds of mechanisms working simultaneously in our model. As an illustration let us consider two effects which work in opposite directions. For instance, a positive effect follows from term *I* as a consequence of the stock game. The marginal cost for actor *i* in period 2 is lowered because actor *i*'s quota is reduced as a consequence of reduced stock when the leader increases his harvest in period 1. An example of a negative effect that reduces the marginal present value for actor *i* is seen in term *II*. This effect measures the increase in marginal cost when the stock level is reduced as a consequence of more intensive harvesting in period 1.

Let us now turn to the leader's optimal choice of harvest in period 1. Given the reaction function in (24), actor *j*, as the first mover, maximises the present value $V^j(h_1^j, h_1^{i^R}(h_1^j))$ with regard to his harvest volume in period 1. The first order condition for maximum is then given by:

$$\frac{\partial V^j}{\partial h_1^j} + \frac{\partial V^j}{\partial h_1^i}\frac{dh_1^{i^R}}{dh_1^j} = 0 \qquad (26)$$

where

$$\frac{\partial V^j}{\partial h_1^i} = \delta\left[\frac{\partial \bar{h}_2^j}{\partial h_1^i}\left(1 - \frac{\partial C^i}{\partial h_2^j}\right) + \frac{\partial C^i}{\partial S_1}(1 + G'(S_1))\right] < 0 \qquad (27)$$

In (27) it is seen that the present value for actor *j* is a decreasing function of the harvest volume for actor *i* in period 1. Increased harvest in period 1 from actor *i* causes reduced present value for actor *j* in two different ways: The first term in (27) is the effect of reduced quota for actor *j*, both as a consequence of a lower share of the total quota and lower total quota in period 2. The second term measures the increased costs because of reduced stock in the regulated period.

When we now use (27) in (26), it is seen that the sign of the second term on the left hand side will be conditional on the sign of the slope of the reaction function. If the harvest volumes in period 1 are strategic substitutes (complements), i.e. that the slope is negative (positive), the sign of this second term in (26) will be positive (negative); see Bulow *et al* (1985). Remembering that the present value for actor *j* is assumed to be concave in actor *j*'s harvest volume in period 1, this leads to a higher (lower) catch volume for first mover actor *j* in period 1 in this non-simultaneous case compared to the situation where the actors move simultaneously if the harvests are strategic substitutes (complements). Furthermore, it follows that second mover actor *i* chooses lower harvest in case RS(B) than in RS(A), no matter what the slope of the reaction function. This means than in the case where the harvest volumes in period 1 are strategic complements, we know for sure that the total harvest in period 1 in the situation of non-simultaneous moves is less than the total harvest in the situation of simultaneous moves. However, when the fish levels in period 1 are strategic substitutes, the total harvest in period 1 in the RS(B) case can be both higher, the same and lower than in the RS(A) case, conditional on the sizes of increase and decrease in actor *j*'s and *i*'s harvest respectively, when going from the simultaneous to the non-simultaneous case. These findings are summed up in Result 2 below.

Result 2:

> *In a non-simultaneous game (denoted RS(B)), the first mover's harvest in period 1 will be higher (lower) and the second mover's harvest in period 1 will be lower than in a simultaneous game (RS(A)) when the these harvests are strategic substitutes (complements). The total harvest in period 1 will be lower in case RS(B) than in RS(A) when the harvest volumes in the unregulated period are strategic complements, while it*

is not clear whether RS(B) gives lower or higher total harvest in period 1 than RS(A) when the harvest levels in period 1 are strategic substitutes.

Hence, whether the non-simultaneous game gives less or more rent-seeking than the simultaneous game is an open question. Based on our analyses above, it is seen that in situations where the harvest levels in period 1 are strategic complements, and in situations where the harvests are strategic substitutes, but the increase in actor *j*'s harvest is less than the reduction of actor *i*'s harvest when moving from the simultaneous to the non-simultaneous case, we would see a less intensive rent-seeking behaviour in the RS(B) compared to the RS(A) case.

4. Conclusions

Fisheries have often been regulated by agreements which determine total allowable catches for different fish stocks. Furthermore, the total quota is often distributed to agents based on actual choices of individual catches in the past. Based on a simple model in which the agents know this allocation mechanism and the dynamic growth in the renewable resource, we have seen that it might be individually advantageous for agents to attempt to influence the allocation through rent-seeking behaviour. This individual quota regime might be worse than a situation without any regulation for two reasons: firstly, if the actors feel responsible for meeting a future resource constraint in a non-regulated situation, the first period harvests will be lower than when the fishery is regulated by giving individual quotas in period 2 if the actors move simultaneously. This is because the individual quota regulation weakens the actor's individual responsibility for meeting the future constraint on the level of the resource. Secondly, individual quota regulation where the actors' shares are based on historical catches, unlike the non-regulated situation, opens the possibility for the actors to influence the level of the individual shares of the total quota which induces a race for quotas (Result 1).

Furthermore, we have focused on whether the order of moves taken by the actors influences the rent-seeking activity within a quota regulation without finding unambiguous conclusions. Among other things, the results are conditional on whether the first mover, by choosing an aggressive strategy induces the second mover to choose an aggressive reply, i.e. whether the harvests in period 1 are strategic complements or substitutes (Result 2).

Our conclusions are based on a model where we have made several simplifying assumptions. Finally, let us comment on some of the most critical assumptions. Firstly, in practical policy the total quota may be distributed to agents based on actual choices of other individual variables than only catch volume in the past (e.g. inputs). This aspect, together with the case of an endogenous number of agents, is discussed in Bergland *et al* (2000). Furthermore, we have assumed that the agents have perfect information about the future total quota (i.e. the resource constraint), the actual quota allocation rule chosen by the regulation authority, and the exact point of time when regulation is implemented. However, in practice agents will often have only imperfect information concerning possible future regulation, which means that there will be uncertainty as to the possible future gains from rent-seeking. This would very possibly lead to less rent-seeking compared to a situation where the relevant information concerning the future public regulation was known for sure. For instance, we could think of a situation where the authorities shared the total allowable quota in the future on individual average production and individual average levels of inputs, estimated on the basis of statistics for some unknown years in the past. Then the agent's current ability to influence future individual quotas is weakened, and the possible advantage of adopting rent-seeking behaviour for a single year is reduced.

Even though our analysis is based on several simplifying assumptions, also others than those explicitly commented on here, we believe that this paper points to an important issue which occurs in the practical regulation of common natural resources. However, further theoretical research concerning the type and size of possible rent-seeking mechanisms is necessary, as are empirical studies from different common natural resources. For instance, it is still an open question whether the over-fishing seen in many international fisheries today can be attributed, at least in part, to the type of rent-seeking mechanism that we have examined. As we have demonstrated, the regulation of a renewable resource is considerably complicated by the existence of rent-seeking behaviour. Furthermore, there are many relationships that need to be determined and quantified in order before one can be sure that quota regulation will have the desired effect.

APPENDIX

Here we analyse the sign of the components of (25) by looking at a stock game and a pure strategic game (as defined in the text). Firstly, by ignoring the strategic game in order to isolate the influence from the stock game, (25) becomes:

$$\frac{\partial^2 V^i}{\partial h_1^i \partial h_1^j} = \delta \left\{ \underbrace{\frac{\partial^2 C^i}{\partial S_1 \partial h_2^i}\left[-2g^i(1+G'(S_1))\right]}_{I} - \underbrace{\frac{\partial^2 C^i}{(\partial S_1)^2}}_{II} - \underbrace{\frac{\partial^2 C^i}{\partial (h_2^i)^2}\left[(g^i)^2(1+G'(S_1))^2\right]}_{III} + \underbrace{\left(1-\frac{\partial C^i}{\partial h_2^i}\right)\left[g^i G''(S_1)\right]}_{IV} \right\} \tag{A1}$$

On the right hand side of (A1), *I* is supposed to be non-negative, while the other terms (*II*, *III* and *IV*) are supposed to be either negative or non-positive when $G''(S_1) \leq 0$ [12]. This means in the pure stock game, we know that (A1) is negative if the marginal cost is independent of the stock volume, $\frac{\partial^2 C^i}{\partial S_1 \partial h_2^i} = 0$. This means that in this case the marginal present value for actor *i* w.r.t. actor *i*'s harvest in period 1 will be decreasing in actor *j*'s harvest in period 1. Hence, it follows from (24) that in this special case actor *i* would choose to reduce his harvest volume as the harvest volume of actor *j* increases, implying a negatively sloped reaction function so that the individual harvest levels are strategic substitutes in the model. Moreover, when $\frac{\partial^2 C^i}{\partial S_1 \partial h_2^i} < 0$, we cannot exclude the possibility that the reaction function is positively sloped in this pure stock game, i.e. that the individual harvest levels in period 2 are strategic complements. This case might occur if the absolute value of $\frac{\partial^2 C^i}{\partial S_1 \partial h_2^i}$ is sufficiently high such that the first term dominates the three following terms in (A1).

---

[12] This means that the growth in the stock increases less the higher the stock becomes, which is a usual assumption in bio-economic models describing the dynamics of a fish stock.

When we isolate the effects following from a pure strategic game, i.e. when ignoring the stock game, (25) becomes:

$$\frac{\partial^2 V^i}{\partial h_1^i \partial h_1^j} = \delta \left\{ \begin{array}{l} \underbrace{\frac{\partial^2 C^i}{\partial S_1 \partial h_2^i}\left(\frac{\partial g^i}{\partial h_1^i}+\frac{\partial g^i}{\partial h_1^j}\right)\overline{h}_2}_{I} - \underbrace{\frac{\partial^2 C^i}{(\partial S_1)^2}}_{II} - \\ \underbrace{\frac{\partial^2 C^i}{\partial (h_2^i)^2}\left[\frac{\partial g^i}{\partial h_1^i}\frac{\partial g^i}{\partial h_1^j}\left(\overline{h_2}\right)^2 - \overline{h}g^i\left(1+G'(S_1)\right)\left(\frac{\partial g^i}{\partial h_1^i}+\frac{\partial g^i}{\partial h_1^j}\right)\right]}_{III} + \\ \underbrace{\left(1-\frac{\partial C^i}{\partial h_2^i}\right)\left[\frac{\partial^2 g^i}{\partial h_1^i \partial h_1^j}\overline{h} - \left(1+G'(S_1)\right)\left(\frac{\partial g^i}{\partial h_1^i}+\frac{\partial g^i}{\partial h_1^j}\right)\right]}_{IV} \end{array} \right\} \quad \text{(A2)}$$

As in the case of the pure stock game, the slope of the response curve is generally ambiguous in this pure strategic game because the sign of (A2) can be both positive, zero and negative. In order to obtain some more information about the sign of the right hand side of (A2), we may take a closer look at the case where the distribution function is given by (16).[13] As in the general case, where both the stock and the strategic game are going on, we have that the second term in (A2) is non-positive. Furthermore, the first and the fourth term are non-positive (negative) when $h_1^j \geq (<) h_1^i$, while the third term is clearly positive when $h_1^j \geq h_1^i$. This means that we are unable to draw any unambiguous conclusions regarding the slope of the reaction function in (24), both in the pure stock and pure strategic game, and of course in the case where both games are working simultaneously.

---

[13] In this case we have $\frac{\partial g^i}{\partial h_1^i} = \frac{h_1^j}{(h_1^i + h_1^j)^2}$, $\frac{\partial g^i}{\partial h_1^j} = -\frac{h_1^i}{(h_1^i + h_1^j)^2}$, $\frac{\partial^2 g^i}{\partial h_1^j h_1^i} = \frac{h_1^i - h_1^j}{(h_1^i + h_1^j)^3}$.

REFERENCES

Bergland, H., Clark, D.J. and Pedersen, P.A. (2000), Rent-seeking and the regulation of a natural resource, mimeo.

Bohm,P. and Russell C.S. (1985), Comparative Analysis of Alternative Policy Instruments, in Knees, A.V. and Sweeney J.L. (Eds.), Handbook of Natural Resource and Energy Economics Vol I, North Holland, Amsterdam.

Boyce, J.R. (1998), Rent-seeking in natural resource quota allocations. *Public Choice*, 96, 271-294.

Bulow, J., Geanakoplos, J. and Klemperer, P. (1985), Multimarket oligopoly: Strategic substitutes and complements. *Journal of Political Economy*, 93, 488-511.

Clark, C.W. (1980), Restricted access to common-property fishery resources: A game-theoretic analysis, in Liu P.T. (Ed.) Dynamic Optimization and Mathematical Economics, 117-132, Plenum, New York.

Clark, C.W. and Munro, G.R. (1975), The economics of fishing and modern capital theory: a simplified approach. *Journal of Environmental Economics and Management*, 2, 92-106.

Fisher, R.D. and Mirman, L.J. (1996), The complete fish wars: Biological and dynamic interactions. *Journal of Environmental Economics and Management*, 30, 34-42.

Gordon, H.S. (1954), The Economic Theory of a Common Property Resource: The Fishery. *Journal of Political Economy*, 62, 124-142.

Hannesson, R. (1991), From common fish to rights-based fishing. Fisheries management and the evolution of exclusive rights to fish. *European Economic Review, Papers and Proceedings of the Fifth Annual Congress of the European Economic Association*, 35, 397-407.

Hannesson, R. (1997), Fishing as a Supergame. *Journal of Environmental Economics and Management*, 32, 309-322.

Holm, P. (1990), EU's fisheries policy and the Norwegian fishing industry. (in Norwegian: EF's fiskeripolitikk og norsk fiskerinæring.) *Internasjonal Politikk*, 48, 239-251.

Haavelmo, T. (1954), A study in the theory of economic evolution. North Holland, Amsterdam.

Krueger, A.O. (1974), The Political Economy of the Rent-Seeking Society. *American Economic Review*, 64, 291-303.

Levhari, D. and Mirman, L.J. (1980), The great fish war: An example using a dynamic Cournot-Nash solution, *Bell Journal of Economics*, 11, 322-334.

Mesterton-Gibbons, M. (1993), Game-Theoretic Resource Modelling. *Natural Resource Modelling*, 7, 93-147.

Munro, G.R. and Scott A.D. (1985), The Economics of Fisheries Management, in Kneese, A.V. and Sweeney J.L. (Eds.), Handbook of Natural Resource and Energy Economics Vol II, North Holland, Amsterdam.

Naito, T. and Polasky, S. (1997), Analysis of a Highly Migratory Fish Stocks Fishery: A Game Theoretic Approach. *Marine Resource Economics*, 12, 179-201.

Tullock, G. (1967), The Welfare Costs of Tariffs, Monopolies, and Theft. *Western Economic Journal*, 5, 224-232.

Tønnesen, J.N. (1970), The history of the modern whaling industry. Origin and development. (in Norwegian: Den moderne hvalfangsts historie. Opprinnelse og utvikling.) Vol.4, Sandefjord.

Underdal, A. (1980), The politics of international fisheries management. Universitetsforlaget, Oslo.

Warming, J. (1911), Rent from fishing grounds. (in Danish: Om grundrente av fiskegrunde.) *Nationaløkonomisk Tidsskrift*, 11, 499-505.