A Model of Fishing Conflicts in Foreign Fisheries

by

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Abstract

Coastal nations can impose conditions of use on foreign fishing firms that operate in their Exclusive Economic Zone. We develop a game-theoretical model in which a fishery owner maximizes the revenue that it collects from firms that operate in its EEZ by charging them a fishing fee. We find that if the number of firms is exogenous and finite the owner is likely to select a fee that is higher than socially optimal. On the other hand, if the owner can choose the number of firms it does not place any restrictions on entry to the EEZ and selects a fee that maximizes net return.

Key Words: Renewable Resources, Fisheries Management, Coastal Nations, Fishing Fee

Journal of Economic Literature Classifications Numbers: C72, Q22

1. Introduction

The Extended Fisheries Jurisdiction, adopted by the United Nations Conference on the Law of the Sea, established the formation of 200-mile Exclusive Economic Zones. It is now recognized that coastal nations have ownership rights over the 200 oceanic miles adjacent to their shores (Ishimine, 1978). These ownership rights allow coastal nations to "impose terms and conditions of access upon distant water fishing nations seeking to enter the coastal state's Exclusive Economic Zone (Clarke and Munro, 1991)."[1]

Due to the Extended Fisheries Jurisdiction many of the world's most prolific fisheries are now under the ownership of developing nations (Gopalakrishnan, 1989)**.** These developing nations often lack the necessary technology to exploit their marine resources efficiently. Consequently, many developing nations permit foreign fishing firms to harvest fish from their fisheries and then charge them a fishing fee on the harvest that they remove. For example, a group of island nations in the South West Pacific Ocean known as Parties to the Nauru Agreement collect 5% of the revenue that foreign firms earn from harvesting fish within their EEZs and contiguous areas (Campbell, 1996).[2]

This paper considers a game-theoretical model in which a coastal nation attempts to maximize the revenue that it receives from foreign fishing firms that operate in its fishery. One of our goals is to determine whether there is a fishing fee that maximizes the coastal nation's revenue when the number of firms is fixed and whether that fee is socially optimal. We also investigate how many firms the coastal nation admits into its fishery and what is the fishing fee that it selects when it can choose both the number of firms and the fishing fee that each firm must pay.

In the base model we assume that the number of firms, n, is finite and exogenous. We find that there exists a fishing fee that maximizes the coastal nation's revenue. However, the coastal nation generally selects a fee that is higher than socially optimal causing the firms to exert a level of fishing effort that is undesirably low. We later relax the assumption that n is exogenous and look at the case in which the coastal nation can choose both the number of firms and the fishing fee. We show that the best solution for the coastal nation is to not place any restrictions on entry to the fishery and to select a fishing fee that is based on the difference between the marginal benefit of effort and the marginal cost of effort. Under open access the coastal nation collects all the net return from the fishery and thus has the incentive to maximize the net return.

A few authors examine the interaction between a coastal nation and the foreign firms that operate in its EEZ. Charles (1986) develops a model in which a coastal nation divides a fixed Total Allowable Catch between a domestic fleet and a foreign fleet. He shows that a coastal nation may adopt one of four policies depending on the fishing fee, which is assumed exogenous, the domestic resource rent and the foreign resource rent. The coastal nation may allow both fleets to operate in its fishery, allow only one of the fleets to operate or cause both of the fleets to disinvest their capital. Charles does not consider the fishing fee or the number of firms that the coastal nation will choose.

Clarke and Munro (1987) examine a principal-agent model in which a coastal nation charges a single distant water fishing nation (DWFN) that has the same rate of discount as it does a fishing fee. Clarke and Munro (1991) generalize their first model by considering the possibility that the coastal nation and the DWFN discount future returns from the fishery at different rates. They find that the coastal nation can increase its discounted net return from the fishery by simultaneously using a tax on harvest and a tax or subsidy on effort instead of only one tax. However, the coastal nation is generally unable to simultaneously maximize the discounted net return from the fishery and its own discounted net return.

Raissi (2001) considers a model with a coastal nation that uses a dual tax system on two fishing firms – a foreign firm and a domestic firm with an inferior fishing technology. Raissi shows that without regulations the foreign firm will eliminate domestic competition by exerting the maximum fishing effort. However, it may be optimal for the coastal nation to induce the two firms to converge to an equilibrium where they are both exploiting the fishery by using taxes. Neither Raissi (2001) or Clarke and Munro (1987, 1991) allow the coastal nation to choose the number of firms that operate in its fishery.

Our paper makes several contributions to the existing literature on foreign fisheries, i.e. fisheries that are controlled by a coastal nation but are exploited by DWFNs. This is the first paper on foreign fisheries that examines a model with n firms instead of one or two. Most of the world foreign fisheries are exploited by many firms from different DWFNs.[3] Generalizing the model to n firms is important because it allows us to investigate how changes in n affect the behavior of the fishing firms and the coastal nation. Moreover, this is the first paper to model the number of firms as a choice variable in the coastal nation's objective function. Finally, we discuss under what circumstances allowing foreign exploitation is optimal for society. Other authors only focus on the welfare of the coastal nation.

This paper models the strategic interaction amongst the firms and between the firms and the coastal nation using non-cooperative game theory. Several other authors use non-cooperative game theory to model the strategic interaction between firms in an unregulated, international fishery. Levhari and Mirman (1980) and Fischer and Mirman (1996) examine the strategic interactions between fishing firms using a utility maximization model. Dockner et al (1989) and Ruseski (1998) examine the strategic interaction between fishing firms using a profit maximization model. All of these authors conclude that the firms will over-fish the stock. Fischer and Mirman (1996) demonstrate that firms over-fish even when there is a negative biological externality between their target species.[4] Ruseski shows that the national government of each firm that competes over the fishery has the incentive to license more vessels than is socially optimal and to subsidize its firm's effort, which exacerbates over-fishing.

We use a static framework similar to the one used by Ruseski (1998). We assume, as Ruseski does, that firms maximize their profits in steady state, which occurs when the size of the stock reaches a biologically stable equilibrium. Ruseski's framework requires assuming that agents do not discount future returns, as we shall assume in this paper. This assumption greatly simplifies the analysis and allows us to focus on the strategic interaction of the agents. A dynamic model may be too complex to analyze the two-stage, multi-variable, n + 1 agents game proposed here.[5] We also feel justified using a static model rather than a dynamic model, in which the coastal nation can choose a different fishing fee in each period, because "long-term cooperative agreements between coastal and distant water nations are more likely to involve simple fixed-rate royalty schemes, in order to provide stability to the arrangement (Charles, 1986)."

The paper is organized as follows. In section 2 we model the strategic interaction between n, exogenously determined fishing firms and a coastal nation. In section 3 we allow the coastal nation to choose both the number of firms and the fishing fee that each firm must pay. In section 4 we discuss why coastal nations may choose not allow open access to their fisheries even though doing so will increase their revenue.

2. A Model with an Exogenous Number of Firms

Consider a fishery that is exploited by n identical foreign fishing firms. For tractability, we assume that n is continuous. The firms may belong to a single or to several distant water fishing nations (DWFNs). We shall assume that the firms' governments do not regulate their behavior and that no collaboration exists amongst the firms. The fishery is assumed to be under the control of a single coastal nation that we shall refer to as the fishery owner. We shall assume that neither the firms nor the owner discount future returns from the fishery. In this section we shall assume that the number of firms is finite and exogenous. In the following section we will relax this assumption and allow the fishery owner to determine the number of firms that operate in the fishery.

The strategic interaction amongst the firms and between the firms and the owner is modeled using non-cooperative game theory as a two-stage game. In the first stage of the game the owner selects a fishing fee. The fishing fee, r, denotes the percent of the revenue from the harvest that is caught in the fishery which the owner retains from itself. In the second stage of the game the firms, having observed the fishing fee, simultaneously choose their levels of effort in order to maximize their profit.

We begin by solving for the equilibrium efforts, the levels of effort that the firms will select in subgame perfect Nash equilibrium. Subgame perfection in the second stage of the game occurs when every firm chooses the profit-maximizing level of effort given the fishing fee and the levels of effort chosen by the other firms. Subgame perfection in the first stage of the game occurs when the owner selects the fee that will maximize its revenue after computing the equilibrium efforts as a function of r.

Since Schafer's (1957) seminal work on the exploitation of fish it is common to assume that the size of a fish stock, x, grows according to a stock dependent growth function. The change in the size of the stock at a given point in time, dx/dt, equals the stock's natural growth rate, G(x), minus the sum of the harvests collected by the firms that utilize the fishery. Let h_i represent the harvest of firm i.

(1) $$\frac{dx}{dt} = G(x) - \sum_{i=1}^{n} h_i$$

We shall assume, as other authors have (e.g. Clarke and Munro, 1991; Ruseski, 1998; Raissi, 2001), that the stock grows according to a linear logistic function.

$$(2) \qquad G(x) = \gamma x\left(1 - \frac{x}{K}\right)$$

γ is the stock's intrinsic rate of growth, which equals the birth rate of the stock minus its mortality rate, and K is the carrying capacity of the fishery. The carrying capacity is the largest stock size that the fishery can sustain. If the stock is smaller than K then the size of the stock will increase over time and if the stock is larger than K then the size will decrease over time. Thus, if the fishery is not commercially exploited the size of the stock will eventually converge to the carrying capacity of the fishery, $\lim_{t\to\infty} x(t) = K$.

Each firm harvests fish from the fishery according to a catch per unit of effort (CPUE) production function. A CPUE production function implies that the portion of the stock that each firm harvests per unit of effort is constant. Let e_i represent the effort exerted by firm i and e be a vector of efforts, e = [e_1, …, e_i,…, e_n].

$$(3) \qquad h_i(e) = \begin{cases} qxe & \text{if } e_i < \dfrac{1}{nq} \\ \dfrac{x}{n} & \text{otherwise} \end{cases}$$

q is the catchability coefficient, $0 < q < 1$. For simplicity, we assume that q does not depend on the size of the stock and that it is identical for all the firms, which suggests that the firms are using an identical fishing technology. The total harvest, H, can never exceed the size of the stock, H ≤ x. Since the firms are identical then the total harvest equals $n \times h_i(e)$, which implies that $n \times qxe_i \le x$. Rearranging, if $e_i \ge 1/nq$ then the entire stock will be evenly split amongst the firms and the species will be driven to extinction. Since firms do not discount future returns by assumption they would never want to drive the species to extinction. If they drove the stock to extinction they would be given up an infinite streams of returns from the fishery. Substituting (2) and (3) into (1):

(4) $$\frac{dx}{dt} = \gamma x\left(1 - \frac{x}{K}\right) - qx\sum_{i=1}^{n} e_i$$

The size of the stock will reach a steady state when dx/dt = 0. We determine the steady-state stock, $\dot{x}(e)$, by setting (4) equal to zero and solving for x.

(5) $$\dot{x}(e) = K\left(1 - \frac{q}{\gamma}\sum_{i=1}^{n} e_i\right)$$

We assumed that neither the firms nor the owner discount future returns from the fishery. Therefore, each firm will attempt to maximize the profit that it earns when the size of the stock reaches a steady state. Firms take the effort levels of other firms and the fishing fee as given when deciding on their effort. Each firm knows what the fishing fee is before making its decision, but can not observe the levels of effort that are chosen by other firms. For simplicity we assume that the total harvest extracted from the fishery is too small to influence the price of the species, p. We also assume that firms face a constant and identical marginal cost of effort, c.[6] Firm i will attempt to:

(6) $$\underset{e_i}{Max}\,\Pi_i = (1 - r)p \times q\dot{x}(e)e_i - ce_i$$

The first term on the right-hand side of (6) is the firm's revenue, which equals the firm's harvest in steady state, $q\dot{x}(e)e_i$, times the price of the species multiplied by the portion of the revenue that the firm retains after paying the fishing fee, (1– r). The second term is the cost of effort. Since all the firms are identical by assumption, the owner has no reason to charge each firm a different fishing fee. Each firm takes into account the effect of its own effort on the steady-state stock but must take the effects of the other firms' efforts as given. Rewriting the objective function of firm i by substituting (5) for $\dot{x}(e)$:

(7) $$\underset{e_i}{Max}\,\Pi_i = (1 - r)b\left(1 - \frac{q}{\gamma}e_i - \frac{q}{\gamma}\sum_{j \neq i}^{n} e_j\right)e_i - ce_i \quad \text{where b = pqK}$$

b is the marginal revenue of effort. It represents the increase in revenue that occurs when effort increases by one unit but the steady-state stock does not change. Since the firms are identical they must select the same effort levels in subgame perfect Nash equilibrium. Let $\hat{e}_j$ represent the effort that any other firm j, j = 1, …,n, j ≠ i, selects in equilibrium. We derive the best response of firm i to the effort levels chosen by all other firms, $e_i(\hat{e}_j)$, by rearranging the first order conditions of firm i's objective function.

$$(8) \qquad e_i(\hat{e}_j) = \frac{1}{2}\left[\frac{[(1-r)b-c]\gamma}{(1-r)bq} - (n-1)\hat{e}_j\right]$$

Observe that when other fishing firms increase their effort firm i's best response is to reduce its effort. By symmetry, in equilibrium the effort level that firm i selects must be the same as the effort levels selected by all other firms. We obtain the effort level that any of the n firms will select in subgame perfect Nash equilibrium by substituting e_i for $\hat{e}_j$ in (8) and solving for e_i.

$$(9) \qquad e_i(r) = \begin{cases} \dfrac{\gamma}{(n+1)q}\left(1-\dfrac{c}{(1-r)b}\right) & \text{if } (1-r)b > c \\ 0, & \text{otherwise} \end{cases}$$

$e_i(r)$ is the equilibrium effort of firm i, the effort that firm i selects in subgame perfect Nash equilibrium given r. We write the equilibrium efforts as a function of r because the fishing fee is a policy variable that is determined by the owner. An increase in the intrinsic rate of growth, the carrying capacity of the fishery, or the price of the species will increase the equilibrium efforts of all the firms. An increase in the marginal cost of effort, the number of firms that operate in the fishery or the fishing fee will reduce the equilibrium efforts of all the firms. The effect of the catchability coefficient on the equilibrium efforts depends on the values of the parameters.

An increase in the fishing fee will cause an inwards shift in the firms' reaction functions. To illustrate, suppose that there are only two firms operating in the fishery, firm 1 and firm 2. Figure 1 shows the firms' reaction functions, from (8), in (e_1, e_2) Euclidean space.

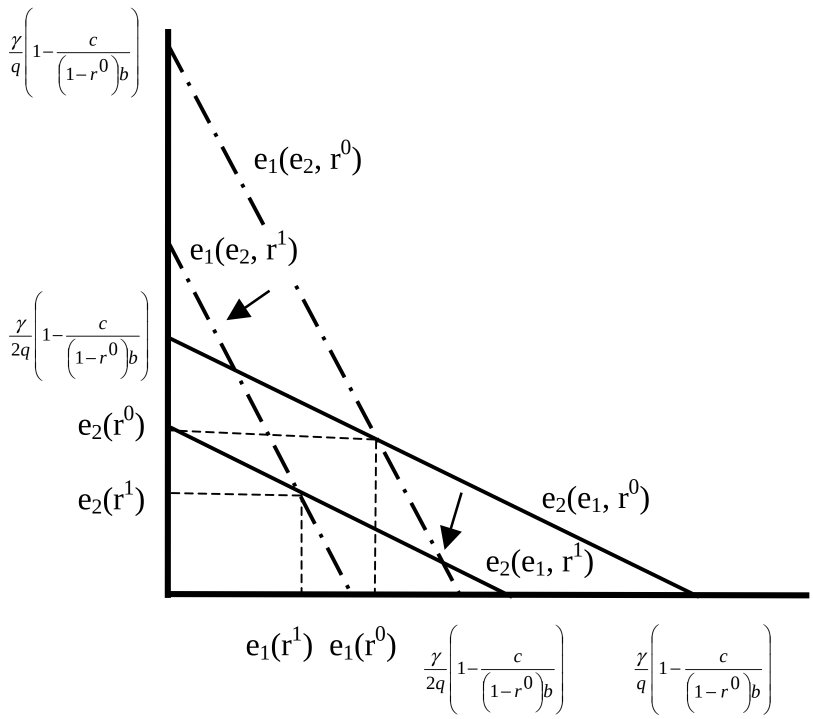

Figure 1 – The Effects of an increase in the Fishing Fee

Figure 1 shows how an increase in the fishing fee from r^0 to r^1 will shift the reaction functions of both firms inwards. The equilibrium effort of firm 1 decreases from $e_1(r^0)$ to $e_1(r^1)$ and the equilibrium effort of firm 2 decreases from $e_2(r^0)$ to $e_2(r^1)$.

None of the firms will exert any effort and the fishery will not be commercially exploited if $(1 - r)b \leq c$. We shall assume that if the owner does not charge a fishing fee then the fishery is exploitable, which means that b, the marginal revenue of effort, is larger than c, the marginal cost of effort. If the owner charges a fee that is too high it will make it unprofitable for firms to operate in its fishery. Let r_{MAX} represent the highest fee that the fishery owner can charge without making the fishery unprofitable for commercial exploitation. From (9) we know that the firms will choose a positive level of effort as long as $(1 - r)b > c$.

$$(10) \qquad r_{MAX} = 1 - \frac{c}{b}$$

If r is equal or larger than r_{MAX} then the profit maximizing effort for each firm is zero. Note from (9) that as long as the fishing fee is below r_{MAX} then any firm that can potentially exploit the fishery will do so regardless of the number of firms that already operate in the fishery. The owner will select a fee that will maximize its revenue. It makes no sense for the owner to choose a fee that is equal to or is higher than r_{MAX} since the fishery will not be exploited and it would not earn any revenue if it did so. Therefore, we can suppose that $(1 - r)b > c$, which implies that the firms will exert a positive effort. Since the firms' equilibrium efforts are identical by symmetry the total equilibrium effort, E(r), must equal $n \times e_i(r)$.

$$(11) \qquad E(r) = \frac{n\gamma}{(n+1)q}\left(1 - \frac{c}{(1-r)b}\right)$$

Next, we solve for the steady-state stock that the fishery converges to in subgame perfect Nash equilibrium. This stock size is often referred to in the literature as the bionomic equilibrium stock since it is the biologically stable size that the stock reaches when the firms that utilize the fishery achieve an economic equilibrium. Substituting (11) into (5):

$$(12) \qquad \dot{x}(r) = K\left[1 - \frac{n}{n+1}\left(1 - \frac{c}{(1-r)b}\right)\right]$$

The harvest that each firm removes from the fishery when the fishery reaches a bionomic equilibrium, $h_i(r)$, is found by substituting (12) and (9) into the CPUE production function, equation (3). Define the bionomic equilibrium harvest, H(r), as the total harvest that will be removed from the fishery when the fishery reaches a bionomic equilibrium. By symmetry all the firms are going to harvest the same quantity of fish. Therefore, H(r) equals $n \times h_i(r)$.

(13) $$H(r) = K\gamma\left(\frac{n}{(n+1)}\right)\left(1-\frac{c}{(1-r)b}\right)\left[1-\left(\frac{n}{(n+1)}\right)\left(1-\frac{c}{(1-r)b}\right)\right]$$

An increase in the intrinsic rate of growth or the carrying capacity of the fishery will increase the bionomic equilibrium harvest. An increase in either γ or K will increase the amount stock that can be removed from the fishery on a sustainable basis. From (11) an increase in the price of the species or a decrease in the marginal cost of effort will increase total equilibrium effort. But since the increase in effort will reduce the bionomic equilibrium stock the net effect on the bionomic equilibrium harvest is unclear. The owner will attempt to maximize the revenue that it collects from the firms when the fishery reaches a bionomic equilibrium. The owner's revenue equals the revenue from the bionomic equilibrium harvest times the fishing fee. The owner's objective is to:

(14) $$\underset{r}{Max}\, R = rpH(r)$$

Substituting (13) for the bionomic equilibrium harvest in (14):

(15) $$R(r) = rp \times K\gamma\left(\frac{n}{(n+1)}\right)\left(1-\frac{c}{(1-r)b}\right)\left[1-\left(\frac{n}{(n+1)}\right)\left(1-\frac{c}{(1-r)b}\right)\right]$$

Note from (15) that the owner's revenue is continuous in r. Taking the derivative of the owner's objective function with respect to r yields a polynomial of the third degree.

(16) $$R_r(r) = \frac{\left[b^2(r-1)^3 + c^2 n(1+r) - bc(n-1)(1-r)\right]ny}{qb(n+1)^2(r-1)^3}$$

There is no closed solution for the revenue-maximizing fishing fee, r^*. Setting (16) equal to zero and solving for r yields a system of complex roots.[7] Even though there is no closed solution for r^* it is nonetheless straightforward to prove that r^* exists.

Proposition 1: There exist at least one fishing fee, r^*, that will maximize the owner's revenue from the fishery. r^* must be smaller than r_{MAX} and strictly positive. $0 < r^* < r_{MAX}$.

Proof: If the fishery owner does not charge a fishing fee, r = 0, it will not collect any revenue. Similarly, if the owner sets r equal to or higher than r_{MAX} no firm will harvest from the fishery and the owner will not collect any revenue. If the owner sets r anywhere between 0 and r_{MAX} it will earn a positive amount of revenue since the total harvest is positive between these values and the owner retains a positive share of the revenue from the harvest that is sold. Since R(r) is continuous in r, there must exist at least one fishing fee between 0 and r_{MAX} that will maximize the owner's revenue.

Proposition 1 guarantees the existence of a revenue-maximizing fishing fee; however, it does not guarantee its uniqueness. The revenue-maximizing fee must be unique if the revenue function is globally concave with respect to r. The revenue function is globally concave with respect to r if and only if its second order derivative with respect to r is negative. Taking the second-order derivative of (15):

$$(17) \qquad R_{rr}(r) = -\frac{3cn[3cn-(1-r)(n-1)b]K\gamma}{b^2(1+n)^2(r-1)^4}$$

The condition that n > b/(b – 3c), hereinafter the concavity condition, is necessary and sufficient to assure that the owner's revenue function is globally concave with respect to r. If the concavity condition holds then r^* must be unique. If the concavity condition does not hold then r^* may or may not be unique, depending on the shape of the owner's revenue function. Note from the concavity condition that the revenue function must be globally concave if b/c < 3 or if the number of firms becomes infinitely large, n = ∞.

Proposition 1 establishes that there is a revenue-maximizing fishing fee r^*. The next natural question is whether the fishing fee that the owner chooses is socially optimal. A socially optimal set of strategies is a set of strategies that maximizes the net return from the fishery. Therefore, the socially optimal fee is the fishing fee that maximizes the net return from the fishery. In order to determine whether the fishing fee that the owner selects is socially optimal we solve for the socially optimal fee and compare it to the revenue-maximizing fee.

The net return from the fishery, Π, equals the total revenue from the harvest minus the cost of effort of all the firms. Summing (7) across the n firms, the total profit earned by the firms is $(1 - r)\times b(1 - qE/\gamma)E - cE$, where E is the total effort exerted by the firms. The owner's revenue equals $r\times b(1 - qE/\gamma)E$. The net return from the fishery equals the total profit of the firms plus the owner's revenue.

$$(18) \qquad \Pi = b\left(1 - \frac{q}{\gamma}E\right)E - cE$$

Setting the derivative of Π with respect to E equal to zero, we find the total effort that will maximize the return from the fishery, $\hat{E}$.

$$(19) \qquad \hat{E} = \frac{\gamma(b-c)}{2qb}$$

Let E(0) denote the total equilibrium effort that the firms exert in an unregulated fishery, that is a fishery where r = 0 and there are no other restrictions on the firms' behavior. By substituting 0 for r in (11), we find that if n ≥ 1 then $E(0) \geq \hat{E}$. Specifically, when n =1 then $E(0) = \hat{E}$ and when n > 1 then $E(0) > \hat{E}$. These findings are consistent with other game-theoretical models of fishing conflicts (e.g. Levhari and Mirman, 1980; Dockner et al 1989), which conclude that when two or more firms compete over the same stock of fish they will exert more effort than is socially optimal.

Since total equilibrium effort is decreasing in r, there must exist a socially optimal fee, $\hat{r}$, such that $\hat{r}$ induces the firms to select $\hat{E}$. The fishing fee that the owner charges essentially acts as a tax by reducing the marginal benefit from effort for each firm.[8] To find the socially optimal fee set (11) equal to (19) and solve for r.

(20) $\hat{r} = \frac{(b-c)(n-1)}{b(n-1)+c(n+1)}$

From (20) one can show that when more than one firm operate in the fishery, n > 1, then $0 < \hat{r} < r_{MAX}$. When only one firm operates in the fishery, n = 1, then the socially optimal fee is zero. An increase in the number of firms will increase the socially optimal fee. Essentially, the more intense the competition between firms the more strictly they need to be regulated through the imposition of a higher fishing fee.

The goal of the owner, however, is to maximize its revenue not to maximize the net return from the fishery. Since both the total equilibrium effort and the bionomic equilibrium harvest are functions of r, the net return from a fishery can be written as a function of r. By imposing a fee the owner determines both its revenue and the net return from the fishery in bionomic equilibrium.

(21) $\Pi(r) = pH(r) - cE(r)$

Proposition 2: *If the concavity condition holds then the revenue maximizing fishing fee must be higher than the socially optimal fishing fee,* $r^* > \hat{r}$. *Therefore, the total equilibrium effort exerted by the fishing firms is lower than is socially optimal.*

Proof: We find the slope of the owner's revenue function at the socially optimal fee by substituting (20) for r into the first order derivative of the owner's revenue function, equation (16).

(22) $R_r(\hat{r}) = \frac{(b-c)[b(3n-1)+c(n+1)]}{4b^2 n(n+1)}$

From (22) the owner's revenue function is increasing at the socially optimal fee. Therefore, there must exist some fishing fee that yields a higher revenue for the owner than the socially optimal fee. If the revenue function is globally concave with respect to r then the revenue-maximizing fee must be higher than the socially optimal fee.[9] Since the total equilibrium effort is decreasing in r, from (11), the total equilibrium effort exerted by the firms must be lower than socially optimal if $r^* > \hat{r}$.

Global concavity guarantees the uniqueness of the revenue-maximizing fee and, therefore, implies that the revenue-maximizing fee must be higher than the socially optimal fee. If the concavity condition does not hold the relationship between the revenue-maximizing fee and the socially optimal fee may depend on the values of the exogenous parameters. Nonetheless, the revenue-maximizing fee turned out to be higher than the socially optimal fee under all the sets of values that we examined, even when the revenue function was not globally concave.

Regardless of whether the concavity condition holds or not the revenue-maximizing fishing fee will always be larger than the maximum sustainable yield fee, r_{MSY}, defined as the fishing fee that maximizes the bionomic equilibrium harvest. From (14) taking the derivative of the revenue function with respect to r, R'(r) = pH(r) + prH'(r). Since r_{MSY} maximizes H(r) it must be the case that $H'(r_{MSY}) = 0$. Thus, $R'(r_{MSY}) = pH(r_{MSY}) > 0$, which implies that the owner can increase its revenue by selecting a fishing fee that is larger than r_{MSY}. r^* can never be smaller than r_{MSY} because for any fishing fee that is smaller or equal to r_{MSY} a decrease in the fee will decrease both the revenue that is earned from the harvest and the share of the revenue that the owner retains. Therefore, r^* must be larger than r_{MSY}. One can solve for r_{MSY} by setting the derivative of H(r), equation (13), with respect to r equal to zero and solving for r.

$$(23) \qquad r_{MSY} = \frac{b(n-1) - 2cn}{b(n-1)}$$

The maximum sustainable yield fee may be positive or negative (which implies a subsidy). r_{MSY}, however, is always smaller than the socially optimal fee as can be seen by comparing (23) and (20). Therefore, as long as the concavity condition holds the following relationship must be true: $r^* > \hat{r} > r_{MSY}$. Since the total equilibrium effort is decreasing in r then if the concavity condition holds the following relationship must also be true: $E(r_{MSY}) > E(\hat{r}) > E(r^*)$.

These relationships are drawn in Figure 2, which shows the net return and the owner's revenue that result from different levels of total equilibrium effort. We elect to draw E(0), the total equilibrium effort that will be chosen when r = 0, as larger than $E(r_{MSY})$. However, E(0) can be either larger or smaller than $E(r_{MSY})$, depending on the values of the parameters. $E(r_{MAX}) = 0$ since none of the firms will exert any effort if $r = r_{MAX}$. Figure 2 is similar to the one developed by Schaefer (1957) but it also incorporates the fact that the total equilibrium effort is a function of the fishing fee that the owner chooses.

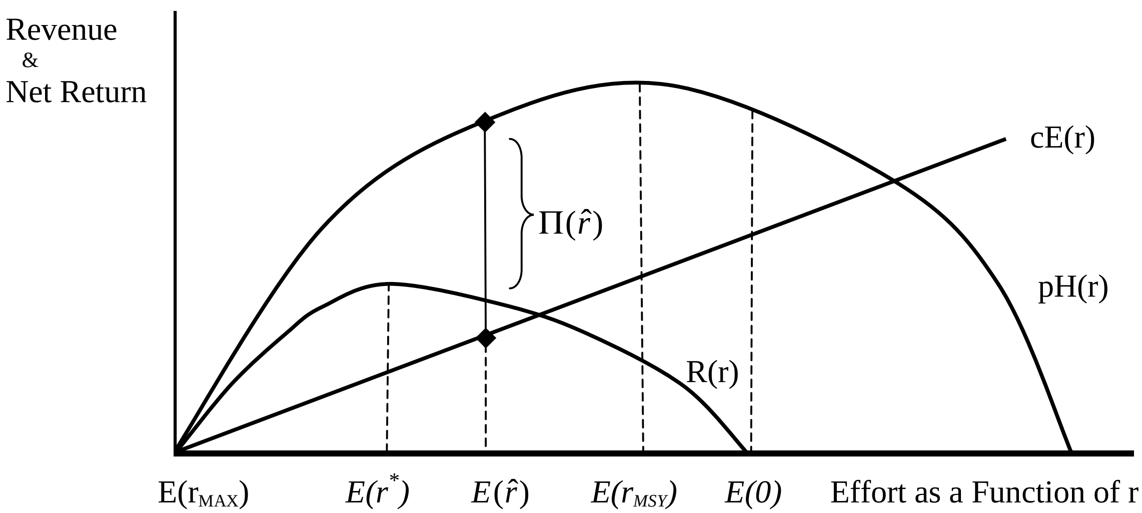

Figure 2 – Revenue & Net Return as a Function of r

The model suggests that when more than one fishing firm operates in a foreign fishery, the fishery owner can increase the net return from the fishery by charging the firms a fishing fee. The fee acts like an output tax and induces firms to reduce their fishing effort. However, if the goal of the owner is to maximize the revenue that it receives from the harvest it will probably select a fishing fee that is higher than socially optimal[10]

Under some circumstance the fee that the owner chooses reduces the net return from the fishery below the level that it were when the fishery was unregulated. The most obvious case occurs when only one firm operates in the fishery. As previously shown, if the fishery is unregulated (r = 0) then a single firm will select the level of effort that maximizes the net return from the fishery. However, since the owner charges the firm a fee (as it must to earn revenue) the firm will lower its effort below the socially optimal level resulting in a decrease in net return. Since H(r) and E(r) are both continuous in n, then the net return from the fishery, pH(r) – cE(r), must be continuous in n. Consequently, if n, which we assumed to be continuous, is sufficiently small then the owner reduces the net return from the fishery by charging a fishing fee.

If a coastal nation does not permit foreign firms to operate in its fisheries and exploits its fisheries using domestic firms instead, it has the incentive to maximize the net return from the fishery. The coastal nation can do so by allowing only one firm to operate in the fishery or by regulating the firms that operate in the fishery.[11] However, if the owner permits foreign firms to exploit the fishery in exchange for paying a fishing fee, the resulting outcome will not be socially optimal and in some cases will be socially inferior to not having the fishery regulated.

The owner may opt to allow exploitation by foreign firms if it does not have the necessary technology to exploit its fisheries or has an inferior technology compared to the foreign firms. Therefore, whether or not privatizing a certain fishery is socially optimal or not may depend on whether the fishery owner has the necessary technology to exploit the fishery and on the number of firms that operate in the fishery. The higher the number of firms the more likely it is that privatizing the fishery will result in an improvement in social welfare.

3. A Model with Endogenous Number of Firms

In the previous section we assumed that the number of firms that operate in the fishery is exogenous. However, the Extended Fisheries Jurisdiction gives coastal nations the right to determine the number of fishing firms that it admits into its EEZ. In this section we allow the fishery owner to choose both the number of firms and the fishing fee that each firm must pay. Consider the following two-stage game. In the first stage the owner determines the number of firms, n, and the fishing fee that they must pay, r. Since the firms are assumed to be identical there is no reason for the owner to levy a different fee on each firm. In the second stage the firms that are permitted to operate in the fishery, having observed the number of firms and the fishing fee, simultaneously choose their levels of effort in order to maximize their profit.

In this section we solve for the number of firms and the fishing fee that the owner selects in subgame perfect Nash equilibrium. Equation (9) shows the equilibrium effort that a given firm i selects in the second stage of the game, $e_i(n , r)$, given the n and r that the owner chooses in the first stage of the game. In this section we write the firms' equilibrium efforts and the owner's revenue as a function of n and r since both of these variables are assumed to be determined by the owner. An increase in the number of firms would reduce the effort that each of the firms exerts in subgame perfect Nash equilibrium as can be seen by taking the derivative of (9) with respect to n.

$$(24) \qquad e_n(r,n) = -\frac{\gamma}{q(n+1)^2}\left(1-\frac{c}{(1-r)b}\right) < 0$$

Although each firm reduces its effort as n increases, the total equilibrium effort, E(n ,r), increases as n increases. The increase in total equilibrium effort intensifies the strain that is placed on the stock. As a result, the bionomic equilibrium stock decreases as n increases as can be seen by taking the derivative of (12) with respect to n.

$$(25) \qquad \dot{x}_n(r,n) = -\frac{K}{(n+1)^2}\left(1-\frac{c}{(1-r)b}\right) < 0$$

By assumption the firms' harvest is determined by a CPUE production function, equation (3). Since an increase in n causes each firm to reduce its effort and leads to a reduction in the bionomic equilibrium stock, it must also reduce the harvests that each firm removes from the fishery. The net effect of an increase in n on the bionomic equilibrium harvest, however, depends on the values of the parameters. Taking the derivative of (13) with respect to n:

$$(26) \qquad H_n(r,n) = \frac{\gamma K\left(b(1-r)-c\right)\left[2cn-b(n-1)(1-r)\right]}{(1+n)^3 b^2}$$

$H_n(r, n)$ is positive as long as $2cn > b(n-1)(1-r)$, a condition that will hold true for any feasible values of n and r if $b/c < 2$. The owner's revenue equals $rp \times H(n, r)$. Therefore, in order to maximize its revenue the owner will select the number of firms that will maximize the bionomic equilibrium harvest. If $b/c < 2$ then the owner would admit as many firms into the fishery as possible. The owner can do so by not placing any restrictions on entry to the fishery. From (9) as long as $(1-r)b > c$ it is profitable for firms to operate in the fishery regardless of what n is. Thus, if the owner does not restrict entry to the fishery then the number of firms would become infinitely large. Hereinafter, we shall refer to the outcome in which the owner does not restrict entry as the open access solution.

As n approaches infinity the profit that each of the firms makes will approach zero. Therefore, none of the firms' will earn any profit under open access as is asserted by Gordon (1954) and others.[12] We solve for the profit of firm i, Π_i, by substituting (9) for e_i and (11) for Σe_i into the firm's profit function. Note from (27) that as n approaches infinity Π_i approaches zero.

$$(27) \qquad \Pi_i(n,r) = \begin{cases} \dfrac{\left[b(1-r)-c\right]^2 \gamma}{bq(n+1)^2(1-r)} & \text{if } (1-r)b > c \\ 0, & \text{otherwise} \end{cases}$$

The owner will not restrict entry to the fishery if b/c < 2. But will the owner restrict entry to the fishery if b/c ≥ 2? To answer this question, consider the owner's objective function. The owner maximizes its revenue by choosing n and r. Equation (15) gives the owner's revenue in subgame perfect Nash equilibrium for any choice of n and r.

$$(28)\qquad \underset{n,r}{MAX}\quad R(n,r) = rp \times K\gamma\left(\frac{n}{(n+1)}\right)\left(1-\frac{c}{(1-r)b}\right)\left[1-\left(\frac{n}{(n+1)}\right)\left(1-\frac{c}{(1-r)b}\right)\right]$$

The first order conditions of the owner's maximization problems are:

$$(29)\qquad R_n(n,r) = \frac{[b(1-r)-c][2cn-b(n-1)(1-r)]r\gamma}{qb(1+n)^3(r-1)^2} = 0$$

$$(30)\qquad R_r(n,r) = \frac{[b^2(r-1)^3 + c^2 n(1+r) - bc(n-1)(1-r)]n\gamma}{qb(n+1)^2(r-1)^3} = 0$$

If 2c > b(1 – r) then the derivative of the revenue function with respect to n is positive for any level of n, which implies that the owner would choose the open access solution. Rearranging (29) to solve for n:

$$(31)\qquad n(r) = \begin{cases} \dfrac{b(1-r)}{b(1-r)-2c} & \text{if } 2c < b(1-r) \\ \infty & \text{if } 2c \geq b(1-r) \end{cases}$$

Consider the possibility that the n that maximizes the owner's revenue is some finite number. If such a case existed we could solve for the n and r that the owner would choose in subgame perfect Nash equilibrium by simultaneously solving the first order conditions. Substituting (31) into (30) yields several possible values for r.

$$(32)\qquad r = 0,\ \frac{b-c}{b},\ \frac{b-c+\sqrt{2}c}{b},\ \frac{b-c-\sqrt{2}c}{b},\ \frac{b-c}{b+c}$$

Consider which one of these values of r maximizes the owner's revenue. Clearly r can not equal zero. If it did the owner would not earn any revenue. (b – c)/b equals r_{MAX} and (b – c + $2^{.5}$c)/b is larger than r_{MAX}. If the owner selects either of these values for r firms will not exert any effort and the owner will not earn any revenue. Let r' = (b – c – $2^{.5}$c)/b and r_{OA} = (b – c)/(b + c). As we shall soon show, r_{OA} is the fee that the owner select under open access. The only possible values of r in subgame perfect Nash equilibrium are r` and $r_{OA}$. We determine the number of firms that the owner would select when choosing r', n', by substituting r` for r in (29) and simplifying.

$$(33) \qquad n' = \frac{b\left(1+\sqrt{2}\right)+c\left(7+5\sqrt{2}\right)}{b\left(\sqrt{2}-1\right)+c\left(\sqrt{2}+1\right)}$$

Substituting n' and r' back into the owner revenue function, equation (28), and simplifying:

$$(34) \qquad R(n',r') = \frac{\left[b\left(1+\sqrt{2}\right)+c\left(7+5\sqrt{2}\right)\right]\left[b-\left(1+\sqrt{2}\right)c\right]\gamma}{2\sqrt{2}\left[\left(2+\sqrt{2}\right)b+\left(10+7\sqrt{2}\right)c\right]q}$$

Substituting r_{OA} into (29) yields that n equals infinity. From (28) we determine the limit of the owner's revenue function as n approaches infinity, R(∞, r).

$$(35) \qquad R(\infty,r) = rp \times K\gamma\left(1-\frac{c}{(1-r)b}\right)\left(\frac{c}{(1-r)b}\right)$$

Substituting r_{OA} for r in (35) gives the owner's revenue when n = ∞ and r = r_{OA}.

$$(36) \qquad R(\infty,r_{OA}) = \frac{(b-c)^2 b\gamma}{4b^2 q}$$

Proposition 3: When the fishery owner can determine both the fishing fee and the number of firms that operate in the fishery it will always choose a fishing fee of r_{OA}, where $r_{OA} = (b - c)/(b + c)$, and will not restrict access to the fishery.

Proof: Suppose that the owner selects the open access solution by setting n = ∞. Equation (35) shows the owner's revenue as a function of r as n converges to infinity. Taking the derivate of (35) with respect to r and setting it equal to zero shows that the fishing fee that maximizes the owner's revenue under open access is r_{OA}, where $r_{OA} = (b - c)/(b + c)$. Therefore if the owner selects the open access solution it will set $r = r_{OA}$. We previously determined that if an interior solution exists than the only feasible solution is for the owner to set r = r' and set n = n'. However selecting the open access solution will always yield more revenue for the owner than selecting (n', r') as can be seen by subtracting R(n', r') from R(∞, r).

$$(37) \qquad R(\infty, r_{OA}) - R(n', r') = \frac{bc\left[\sqrt{2}b^2 + 2\left(3 + 2\sqrt{2}\right)bc + \left(10 + 7\sqrt{2}\right)c^2\right]\gamma}{4b^2\left[\left(\sqrt{2} + \sqrt{2}\right)b + \left(10 + 7\sqrt{2}\right)c\right]q}$$

The right-hand side of (37) is positive for any feasible values of c, p, q, K and γ. Therefore, selecting the open access solution yields more revenue for the owner than selecting (n', r') regardless of the values of the exogenous parameters. Since (n', r') is the only feasible interior solution then setting n = ∞ and $r = r_{OA}$ must yield more revenue to the owner than any other combination of n and r.

The fishing fee that the owner selects under open access, r_{OA}, will increase with increases in either the price of the species, the carrying capacity of the fishery or the catchability coefficient (recall that b = pqK) and decrease with increases in the marginal cost of effort. Proposition 3 states that the owner will maximize its revenue by selecting the open access solution. But is the open access solution optimal from a social perspective?

Proposition 4: The open access solution, in which the owner does not restrict entry to the fishery and chooses a fishing fee of r_{OA}, is socially optimal since it maximizes the net return from the fishery.

Proof: A socially optimal solution will induce firms to select the socially optimal effort, $\hat{E}$, as defined in (19). From (11) the total equilibrium effort will converge to $[\gamma(1 - r)b - \gamma c]/[(1 - r)bq]$ when n converges to infinity. If the owner charged a fee of r_{OA} then the total equilibrium effort exerted by the firms under open access, $E(\infty, r_{OA})$, equals:

$$(38) \qquad E(\infty, r_{OA}) = \frac{\gamma(b-c)}{2qb}$$

The total equilibrium effort under the open access solution with $r = r_{OA}$ is identical to the socially optimal effort, $E(\infty, r_{OA}) = \hat{E}$. Therefore, under the open access solution firms select the level of effort that maximizes the net return from the fishery.

If the fishery owner has the ability to determine the number of firms that operate in its fishery it would always select the open access solution and will charge the firms a fishing fee of r_{OA}. Under open access the fishing firms do not earn a positive economic profit. Firms earn just enough revenue, after paying the fishing fee to the owner, to cover their cost. The owner collects all the return from the fishery net of cost via a fishing fee.

Since the owner collects all the net return from the fishery under the open access solution, it has the incentive to maximize the net return from the fishery. The owner does so by selecting a fee that induces firms to choose the socially optimal total equilibrium effort. Therefore, if the owner can choose the number of firms that operate in the fishery and the fishing fee that the firms must pay it will simultaneously maximize its own revenue and the net return from the fishery.

4. Discussion and Concluding Remarks

We use non-cooperative game theory to model the strategic interaction between a fishery owner and the foreign fishing firms that operate in its fishery. In the base model we assume that the number of firms is finite and exogenous. The assumption that n is finite implies that there is some constraint that prevents additional firms from entering the fishery such as an international agreement, high travel cost to the fishery, or high cost of fishing capital.[13] Otherwise, additional firms will enter the fishery until the firms' economic profit is driven to zero.

Since firms exert more fishing effort than is socially optimal when the number of firms is larger than one, the fishery owner can potentially increase the net return from the fishery by charging firms a fishing fee. However, if the owner is only concerned with maximizing its revenue it will not charge the socially optimal fee. If the owner's revenue function is globally concave with respect to r (and in most cases even if it is not) the owner will charge a fee that is higher than socially optimal inducing firms under-fish the stock. Furthermore, if the number of firms is sufficiently small then the revenue-maximizing fee decreases the net return from the fishery below the level that it would have been if the fishery was unregulated.

Our paper questions the wisdom that nationalizing international fisheries will reduce the inefficiencies that exist under open access. Nationalizing international fisheries can potentially eliminate the over-fishing that occurs under open access. There are some evidences that efficiency increases under the management of developed nations (e.g. Bulte et al, 1995). However, when developing nations permit an exogenous number of foreign firms to operate in their EEZ they will charge a fishing fee that induces under-fishing and in some cases even reduces social welfare. Furthermore, McKelvey (2002) finds that when distant water fishing nations (DWFNs) have to compete with a coastal nation over a straddling (migrating) stock they may harvest the stock more intensely then if they did not have to compete with the coastal nation. More empirical studies are needed to determine the effect of nationalizing various fisheries on the exploitation of marine resources and on social welfare.

In section 3 we consider an extension of the base model in which the owner can determine both the number of fishing firms and the fishing fee that each firm must pay. We conclude that the owner does not restrict entry to the fishery thus allowing the number of firms to converge to infinity. Under open access the firms do not earn any profit and all the net return from the fishery is collected by the owner. Therefore, the owner has the incentive to maximize the net return from the fishery and will do so by setting the fishing fee equal to (b – c)/(b + c). We concur with Clarke and Munro (1991) assertion that the owner can not simultaneously maximize its revenue and the net return from the fishery when the number of fishing firms is fixed. However, we assert that if owner can choose the number firms that operate in its fishery it can simultaneously maximize its revenue and the net return from the fishery.

We conclude that when a fishery owner can determine the number of firms it would not place any restrictions on entry. However, coastal nations usually restrict the number of vessels that utilize their fisheries. For instance, the Parties to the Nauru Agreement (a group of island nations in the South West Pacific Ocean) supply a limited number of licenses for each DWFN that operates vessels within their EEZs and contiguous areas (Lodge, 1998).

There are several reasons why a coastal nation may wish to restrict that number of fishing firms that operate in its fisheries even when it can increase its revenue by admitting more firms. The owner may engage in domestic exploitation of the fishery. If the domestic firms possess the same fishing technology as foreign firms then there is little reason for the owner to admit any foreign firms into its fisheries. However, if the domestic firms use an inferior technology it may make sense for the owner to allow for both domestic and foreign exploitation. In such a case the owner will limit the number of foreign firms in order to provide domestic firms with some protection from foreign competition. Even if the owner is currently not engaging in domestic exploitation, it may limit foreign competition in order to allow its domestic fleet to develop (Charles, 1986).

The coastal nation may also restrict access to its fishery out of political or environmental considerations. For instance, the owner may form an agreement with a DWFN to limit the competition that that nation’s firms face in exchange for financial aid or technology. Moreover, the owner may be concerned about spillover and production externalities that may occur if it admits a large number of fishing vessels into its EEZ. Finally, the owner's monitoring and enforcement costs may increase as the number of fishing firms increases.

Since the open access solution reduces firms' profit to zero, DWFNs may have the incentive to limit the number of firms that travel to a foreign fishery even if the owner does not restrict the number of firms that may enter the fishery. If the number of firms is finite each firm will earn a positive profit. Therefore, DWFNs may voluntarily restrict the number of vessels that can operate in certain foreign fisheries. Future research can further examine the extensions discussed here.

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[1] See Koh (1983) for particular on the United Nations Conference on the Law of the Sea.

[2] See Charles (1986) for more examples.

[3] Lodge (1998) notes that several fishing firms from the United States, Japan, Taiwan and South Korea operate in the South West Pacific Ocean, a tuna fishery that is jointly managed by a group of island nations.

[4] A negative biological externality (such as mutual competition between the target species over food) will cause fishermen to under-fish both species in the absence of dynamic externalities. However, Fischer and Mirman (1996) show that when both firms harvest both species the dynamic externality between them dominates the biological externality.

[5] For examples of dynamic models see Kamien et al (1985) and Clark and Munro (1975). Munro (1982) provides a brief discussion on the use of static and dynamic models.

6 All the aforementioned papers on foreign fisheries (Clark and Munro 1987, 1991; Raissi, 2001 and others) assume that the price of the species is constant and that the marginal cost of effort is constant and identical for all the firms.

[7] Solving for the revenue-maximizing fishing fee yields a system of one real root and two complex roots. The real root is:

$$r = 1 - \frac{3^{2/3} c[b(n-1)+cn]}{3[-9b^4c^2n+\phi]^{1/3}} - \frac{3^{1/3}[-9b^4c^2n+\phi]^{1/3}}{3b^2}$$

Where $\phi = \sqrt{3}\sqrt{b^6c^3\left[27b^2cn^2 + (b(n-1)+cn)^3\right]}$

[8] See Rosenman (1986) for a discussion on optimal taxation in fisheries exploitation.

[9] If the revenue function is not globally concave with respect to r it may be possible that the socially optimal fee is lower than some other local maximum fee but higher than the revenue-maximizing fishing fee (the global maximum fee).

[10] Although we can not prove that the revenue-maximizing fee is higher than the socially optimal fee when the concavity condition does not hold, after comparing r^* and $\hat{r}$ under many different feasible values of the parameters we are convinced that this is always the case.

[11] See Hanley et al (1997, pp. 298-302) for summary of policies that governments can use to regulate the behavior of fishing firms.

[12] Berck and Perloff (1984) show that a fishery will converge to the same equilibrium under rational expectations then under myopic expectations, which were considered by Gordon (1954); although, the path of adjustment will differ.

[13] Firms may under-invest in capital in a stochastic environment when the cost of capital is high and the growth rate of the stock is low (Charles and Munro, 1985). See Sumaila (1995) for an example of a game-theoretical model of fisheries conflicts with non-malleable capital.

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