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Centralised versus Decentralised Enforcement of Fish Quotas

by

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Centralised versus Decentralised Enforcement of Fish Quotas

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Abstract: The purpose of this paper is to consider under what circumstances it is better to have centralised enforcement of catch quotas and when it is better to leave enforcement to the countries themselves. It is shown for a two-country case that a welfare gain is obtained under centralised enforcement at the federal level. The result depends critically on the difference in the unit cost of enforcement at the federal and the Member State (regional) level. If the Member States have a sufficiently large cost advantage in enforcing quotas they can be better off under decentralised enforcement. In addition, the result depends on the proportion of foreign fishermen in the domestic fishing zone. The higher is the proportion of foreign fishermen in the domestic zone the better is decentralised enforcement of quotas.

Keywords: Quota enforcement policy, fisheries management

JEL codes: Q22, Q28

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1 Introduction

Despite the fact that the use of market solution has increased in popularity during the recent years a need to impose governmental regulation exists. The exploitation of natural resources is one of such cases where market solution often proves to be insufficient to obtain an efficient exploitation of the resources. Therefore, governmental regulatory goals are set to correct the market failures, for example in international exploitation of fish resources. International agreements between States that exploit shared stocks are essential to avoid depleted fish stocks and dissipated rents. In such the EU forms an example of international governance, where the regulation such as the fish quotas are decided at the international level (EU level), and a strict management regulation of the resources should be secured. However, success of an imposed management depends critically on whether the regulatory agencies are willing to spend sufficient money to catch and convict violators of regulations.

The purpose in the following is to address the control and enforcement management in international perspective. This issue is relevant in accessing e.g., regulation of international pollution control (see e.g., Silva & Caplan 1997 and Harford 2000), forestry management (Clarke et al. 1993) and climate change enforcement (Chen 1997). The essence of the problem is that the single states joining the agreement have no incentives to employ cost for monitoring and enforcement, in the sense the situation can many times be described by the classical tragedy of the commons (Hardin 1968).

The specific issue addressed in the current paper is to analyse the condition under which it would be optimal to use additional cost to employ a centralised enforcement and monitoring of the agreement. The centralised management is seen as an alternative to decentralised agencies, which are cost efficient but have incentives to conduct insufficient enforcement.

In the present analysis the problem is considered in relation to the management of enforcement in the international shared fishery in the EU. Holden (1996) states that the Achilles heal of the Common Fisheries Policy is that the decentralised authorities (Member States) enforce quotas, leaving the federal level (the EU commission) an inferior role to play. It is specifically addressed whether the task of enforcement and control can be conducted at a decentralised regional level, which due to information advantages is the most cost efficient level to place the monitoring.

We study the problem in a two-stage game setting. In the first stage the government(s) set their enforcement / control effort level which has a direct impact on the fishermen's probability of getting caught in illegal harvesting. In the second stage the fishermen maximise their expected profits taking into account the control effort of the government(s) and the actions of the other fishermen.

We compare the cooperative (EU) case with the non-cooperative case when there are two Member States. In the cooperative case there is only one central authority that decides the control effort in the first stage. In the non-cooperative game two countries solve their equilibrium control efforts in the first stage. In both cases fishermen play a non-cooperative game among themselves in the second stage.

For the two-country game we separate between two interesting special cases where the proportion of domestic and foreign fishermen varies in the domestic zone of the controlling authority. We show how this proportion of foreign fishermen may affect the equilibrium control efforts of the two countries.

In addition, of the analytical results we provide a numerical example where we discuss, for example the issue of cost recovery. That is, we study whether the fishermen could afford to participate in the enforcement costs that could guarantee more efficient harvesting.

Sutinen and Andersen (1985) have studied the enforcement of fish quotas in a single-player model. Milliman (1986) has considered optimal enforcement in the presence of costly enforcement and avoidance activities to escape detection of illegal activities. Jensen and Vestergaard (2000) have studied the moral hazard problem when individual catches are unobservable to society. Further, Hatcher et al. (2000), Anderson & Lee (1986) and Kuperan & Sutinen (1998) have studied the problems of enforcement and compliance in fisheries. Although these examples show that there are many applications in the area of fisheries enforcement there have been no attempts to construct a model with international perspective. The current paper contributes to the literature by analysing an enforcement game between two countries with a common fish stock.

The outline of the paper is as follows. The regulation of fisheries in the EU is described in section 2. In section 3 we briefly describe the underlying Gordon-Schaefer model. The game with a single controller is established in section 4. Section 5 extends the analysis of section 4 by allowing decentralised control, that is, two controlling countries. In section 6 simulations of the results are conducted. Finally the results are discussed in section 7.

2 Control policy of the European Union

As in most other fisheries around the world an arsenal of different regulations that restrict catches is employed in the EU fishery.[1] However, regulations have no influence on the sustainability of the fishery, if the fishermen neglect them. In this sense it is important that the managing authority employs sufficient control/monitoring effort to secure compliance in the regulated industry. As there is significant cost to control/monitor the industry, it is reasonable that the control should be conducted at the most cost efficient managing level (Wallis and Flaaten, 2000). On the other hand it is important that the monitoring authority does not have conflicting interests that leads to a control policy that is either insufficient or discriminatory.

EU common regulations e.g. the TAC (=Total Allowable Catch) are decided at the EU level. The competence to monitor regulations is placed at the level of the Member State. The institutions at the EU level play only an inferior role in the control of the fishery.[2] The decentralised Member State level is presumably the most cost efficient place to put the competence of control. The reason is that the Member State's authority has the best knowledge of the national fishing industries, the fishing gears and seasonal fishing patterns that are essential for detecting non-compliance. Based on a cost minimisation criterion the handling of the control policy should be placed at the Member State level.

The core problem in the EU fishery is that the Member States are sharing a scarce common resource. The EU fishery is a non-cooperative game, where each Member State has an incentive to increase catches, which will happen at the expense of the other Member States in

[1] That is TAC, by-catch regulation, technical measures and so forth. (See the conservation regulation 3760/92 and later amendments) (O.J. L 389 31.12 1992.)

[2] The role of the Commission is mainly to make on the spot inspection of the monitoring in the Member States. (See the control regulation 2847/93 and later amendments (O.J. L 261 20.10 1993).

the EU. In this sense it might be problematic to decentralise the control at the Member State level, because the Member States might be tempted to manage the control policy based on national preferences, that is, to employ a control policy insufficient to secure EU regulations. In the non-cooperative game Member States maximise their individual economic earnings that flow from the activity of their national fishermen from the utilisation of the fish resources.[3] The Member State is put in a position of conducting a monitoring policy that is against the State's own interest, because it reduces the national earnings. The Member State has an incentive to implement a lower than optimal monitoring level that ignores when national fishermen try to increase their income by breaking the EU regulations. The individual Member State thus, has an incentive to implement a laissez faire control policy in the fishery to maximise the net national income. In this sense the self-interest of the Member States might be a problem that disqualifies the Member States to accomplish the necessary control precautions to secure the EU regulation. The EU institutions on the other hand would not be expected to have any self-interest to obtain an insufficient control policy. Based on a criterion to avoid disqualification that due to self-interest gives incentives to employ an insufficient control policy, the competence to monitor should be placed at the EU level.

Modelling the monitoring problem in a economic setting

From a policy point of view of it is interesting to analyse under what conditions it is feasible to place monitoring either at the Member State or the EU level. We analyse the problem of whether to centralise or decentralise enforcement in a game theoretical setting. This is accomplished by comparing the results of two different games. In the first game a single centralised controller (the EU) controls fishermen that are playing a non-cooperative game

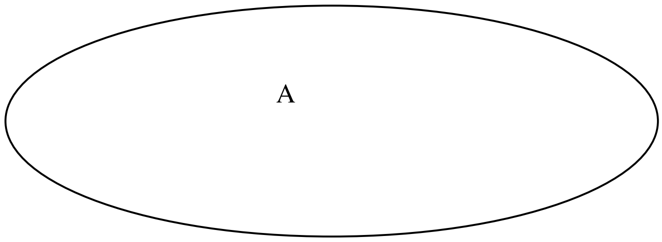
[3] The Member States gain will come in from income earnings by national fishermen, related economic activities, and tax payment from the fishing sector, etc.

over the resource. In the other game we have two decentralised controllers that are controlling the fishermen playing a non-cooperative game. In both cases the purpose of the control manager is to decide how much control effort to employ when confronted with fishermen that would utilise the resources to a very low level. It is assumed that control effort is costly, and that the control cost (γ_1) is higher for the centralised controller than the control cost (γ_2) of the decentralised controllers. This implies that we have a non-trivial problem to place the competence of control in a non-cooperative game.

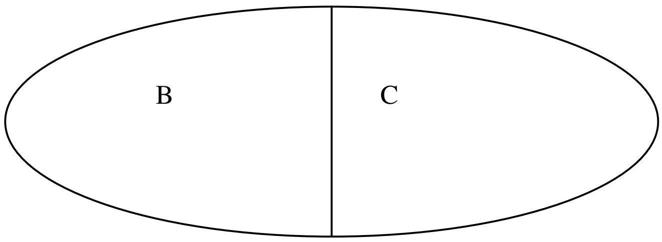
Figure 1 illustrates the two cases. In the first case a single authority controls the entire fishing area, denoted by A. The fishing area is exploited by fishing vessels from two different segments. It is assumed that the vessels have similar cost structure and same catchability coefficients. In the second case we have two decentralised authorities that each control the fishery in separate areas, B and C, and A = B + C. The biological and economic conditions in cases 1 and 2 are assumed to be the same except that in case 2 the fisheries are controlled by decentralised authorities. This latter condition adds an additional refinement to the model in the sense that the decentralised authorities will base their control effort, given costly enforcement costs, on the behaviour of the opponent controller.

Figure 1. The two case studies

Case 1: One Centralized Controller



Case 2: Two decentralized Controllers



In the present study it is emphasised that cost efficiency delegation of control would not necessarily be the economic optimum in a game theoretical setting where decentralised authorities minimise the control effort. Moreover, the centralised control of fisheries means that the problems of non-cooperative gaming are avoided. Finally, Member States that have to control a large share of domestic enterprise have incentives to impose a laissez faire control policy whereas this problem is avoided when the competence is delegated to the centralised authority.

3 Derivation of sustainable effort and stock levels

In this section we briefly present the general model that further sections of the current paper are based on. The aim is to show the relationship between sustainable fishing effort levels and the steady state stock level.

We follow the model used by e.g., Ruseski (1998), with a single stock of size x following the Gordon-Schaefer model,

$$\frac{dx}{dt} = G(x) - \sum_{i=1}^{n} h_i, \qquad (3.1)$$

the stock, x, is harvested by n fishermen of which n/2 belong to country 1 and the other half to country 2. In this model discount rate is equal to zero, growth of fish is given by logistic growth function,

$$G(x) = rx(1 - x/K), \qquad (3.2)$$

where r is the intrinsic growth rate of fish and K is the carrying capacity. We have a production function (harvest for fisherman i) of the Gordon-Schaefer type,

$$h_i = qe_i x \qquad (3.3)$$

Here x is the stock, e_i is fishing effort and q is catchability coefficient that is equal for all fishermen.

The steady state stock is derived by use of equations (3.1), (3.2) and (3.3) when harvest equals growth

$$x = \frac{K}{r}(r - q\sum_{i=1}^{n} e_i), \qquad (3.4)$$

We see that for each level of fishing effort there is a correspondent steady state stock level that can be sustained. For simplicity we approximate the number of fishermen by letting n approach infinity, which gives the open access case. In equilibrium there are thus no rents to be gained from the fishery.

4. Controlling the fishery: The case of a single central authority (The EU)

In this section we have a single controlling authority. The problem of the controller is to decide the level of control given control is costly. The problem of the fishermen is to decide the optimal fishing effort level; they play a Nash game in the exploitation of the fish resource. The fishery is managed by a TAC regulation. It is assumed that the TAC is set at sufficiently low level so that it restricts the fishing effort of the fishermen. Without regulation in the fishery the open access solution or in our case non-cooperative effort level produces catches that exceeds the TAC. This follows because it is not optimal for the central authority to choose perfect control since control is costly.

The control authority is assumed to maximise the economic surplus, which is given by the difference between fishermen profits and control costs:

$$\underset{Z}{Max}\ \pi_o = \sum_{i=1}^{2} P_i(o) - \frac{\gamma_1}{1-Z}. \qquad (4.1)$$

s.t. $0 \leq Z \leq 1$

The government decides the level of the control effort Z based on the objective function (4.1), where the first term is the sum of gross national income in the fishing sector denoted by $P_i(o)$. The second term indicates the governmental control costs, which consists of the unit cost of control γ_1 and the level of control effort Z. We see that if control effort is extensive the cost for control goes to infinity. On the other hand if control effort is zero then we still have a fixed management cost of the fishery worth γ_1. The fixed part of the management costs is due to e.g., research costs.

The fishermen choose the level of fishing effort e_i based on expected profit maximisation:

$$E(P_i) = (1-\Psi)ph_i - ce_i - \Psi\Omega \qquad if\ h_i > TAC_i \quad (4.2a)$$

$$E(P_i) = p\,h_i - ce_i \qquad if\ h_i \leq TAC_i \quad (4.2b)$$

The profit of the fishermen depends on whether they decide a strategy of compliance. The fishermen are assumed to be risk neutral. The expected returns under non-compliance are described in equation (4.2a). The first term is the expected individual income, where Ψ is the risk of being caught in non-compliance, h is the quantity harvested and price is the unit price on the harvest. The second term denotes the cost of fishing effort that is unit cost of cost effort, c, times units of employed fishing effort, e_i. The third term is the expected penalty of being caught, which is the risk of being caught (Ψ) times the penalty, Ω. Equation (4.2b) indicates the profit in the case of compliance equal to the gross income minus the cost of fishing effort. Clearly, if the expected profit of non-compliance is larger than compliance then the fishermen find non-compliance optimal.

The two decision problems in (4.1) and (4.2) are solved by backward induction, where we first solve the problem of the fishermen. This is done based on information of the announced TAC regulation, the level of control effort Z, and a fixed penalty Ω, where Z is the decision variable of the central authority. The fishermen of the two countries decide the fishing efforts in a non-cooperative Nash game that produces a subgame perfect equilibrium. Basically the fishermen have an incentive to lower their fishing effort when the government increase the control effort. This follows since it is costly for the fishermen to be caught harvesting more than the TAC. We assume a linear relation between the control effort and the risk of being caught, denoted by $\Psi = Z$, where control effort is denoted by Z and the fishermen's risk of being caught, Ψ. Secondly, the decision on the level of control is found for the central authority, which depends on level of fishing effort decided by the fishermen under all possible TACs.

Solving the fishermen game produces the non-cooperative effort levels $e_i(o)$ and profit levels $P_i(o)$ for the fishermen.

4.1 The optimal fishing effort of the fishermen facing a centralised authority

The maximisation problem of the fishermen is

$$\underset{e_i}{Max}\ E(p) = \begin{bmatrix} \underset{e_i}{Max}\ ((1-\Psi)ph_i - ce_i - \Psi\Omega & \mid h_i > TAC_i) \\ \underset{e_i}{Max} \qquad ph_i - ce_i & \mid h_i \le TAC_i) \end{bmatrix}$$

In our case the relevant objective to maximise is the case where catches are above TAC, that is, there is non-compliance (see above). The objective function of the fishermen given non-compliance (upper equation) means that the fishermen have an expected penalty of $\Psi\Omega$ and in addition to this the expected value of the catch $(1\text{-}\Psi)ph_i$ is confiscated. We assume that the penalty Ω is exogenous and low. Kuperan and Sutinen (1998) argue that courts often are reluctant to penalize overfishing significantly. Maximisation of this expression for both countries leads to an equilibrium where the reaction functions of the fishermen to each other's effort and control policy of the EU is given as in equation (4.3). See appendix for derivation.

$$e_i = \frac{1}{q}\left[r(1-b) - q\sum_{j \neq i}^{n-1} e_j \right] \qquad (4.3)$$

We see that higher catchability coefficient q, lower intrinsic growth rate r, higher efficiency b and larger number of fishermen imply a lower level of fishing effort for an individual fisherman. The term b equals $\dfrac{c}{(1-\Psi)pqK}$ if catches exceed TAC. In the case of catches within the permitted range the reaction functions would be the same as (4.3) but with

$b = \dfrac{c}{pqK}$. Note that we assume that the EU sets the TAC so low that the fishermen are catching more than the TAC in their non-cooperative equilibrium without control. Therefore, the relevant reaction functions are given by equation (4.3) with b equals $\dfrac{c}{(1-\Psi)\,pqK}$.

Figure 2: Effect of control policy Z on the fishermen game

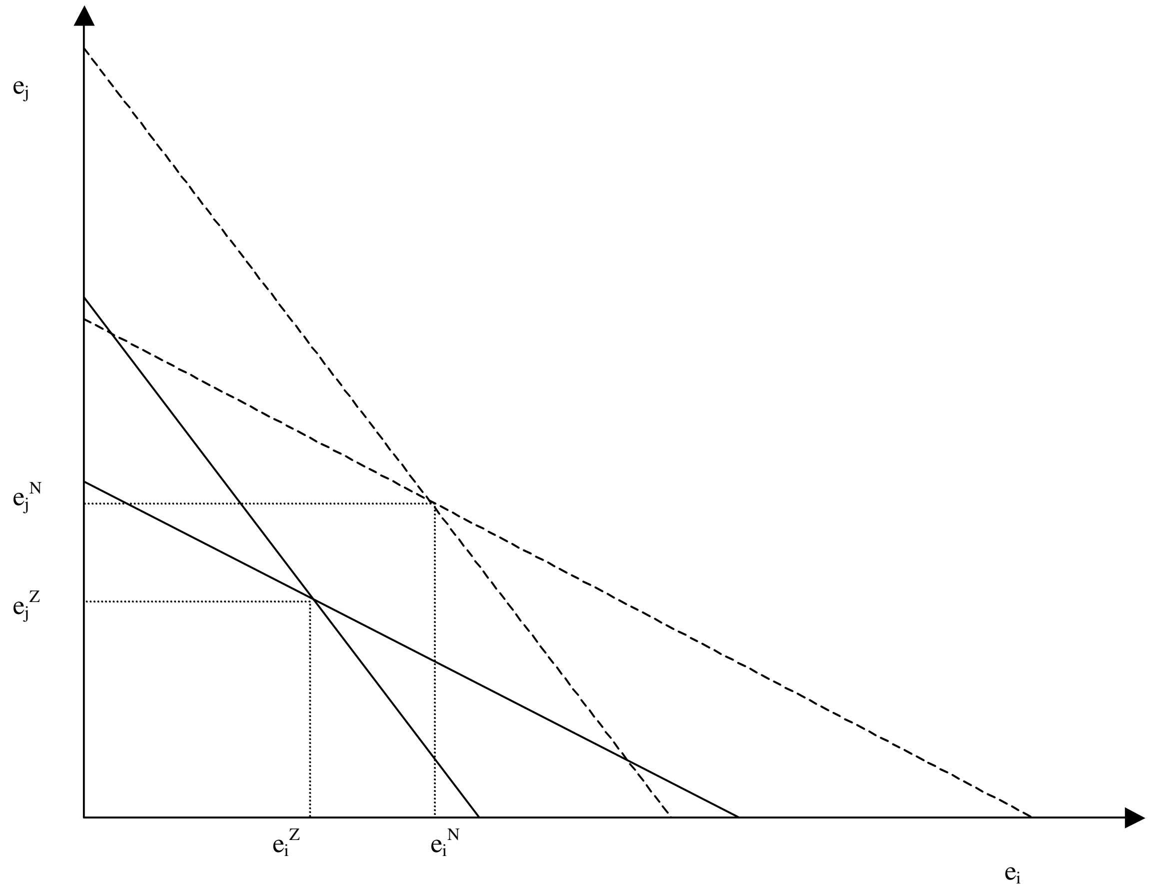


Figure 2 shows how the control policy (probability of getting caught) affects the equilibrium fishing effort. The term e_j^N denotes the Nash equilibrium level of fishing effort. When control increases the probability of getting caught increases and the equilibrium fishing effort decreases to e_j^Z .

For means of convenience in the symmetric case e(o) is defined from (4.3) as,

$$\sum_i^n e_i(o) = e(o) = \frac{r(1-b)}{q} \tag{4.4}$$

4.2 The optimal control effort of the central authority

The EU maximises the net present value of harvesting less the control costs:

$$\underset{Z}{Max}\ \Pi = pqe(o)(K - \frac{Kqe(o)}{r}) - ce(o) - \frac{\gamma_1}{1-Z}$$

s.t. $0 \leq Z \leq 1$

The objective function of the EU does not include the penalties paid by fishermen ($\Psi ph_i + \Psi\Omega$) because this is exactly offset by the income received by the EU from the penalties.

The optimal control policy is found by taking the first order condition:

$$Z^* = 1 - \frac{2c^2 r}{pqKcr + c^2 r - pq^2 K\gamma_1} \tag{4.5}$$

s.t. $Z^* \geq 0$

It is clear that higher control costs imply a lower level of optimal control effort. To see this we differentiate Z* with respect to γ_1.

$$\frac{\partial Z^*}{\partial \gamma_1} = -\frac{2c^2 r\, pq^2 K}{(pqKcr + c^2 r - pq^2 K\gamma_1)^2} < 0 \qquad (4.6)$$

A corner solution (no control) will emerge when the control costs are sufficiently high. In this case the central authority does not find it profitable to control the fishery since the additional value received from the fishery is less than the control costs to achieve a lower fishing effort. From (4.5) we see that Z* = 0 if

$$\frac{2c^2 r}{pqKcr + c^2 r - pq^2 K\gamma_1} = 1. \qquad (4.7)$$

From this expression we have that $\gamma_1 = \frac{1}{2b} + \frac{1}{2} = \hat{\gamma}$. Therefore, the relationship between optimal control effort and control cost can be characterised in the following way.

$$\begin{aligned} &\frac{\partial Z^*}{\partial \gamma_1} < 0 \quad if\ \gamma_1 < \hat{\gamma} \\ &Z^* = 0 \quad if\ \gamma_1 \geq \hat{\gamma} \end{aligned} \qquad (4.8)$$

Here $\hat{\gamma}$ denotes a critical level of control cost above which control is not profitable. The critical level is higher for lower efficiency of the fishery and vice versa.

Further, from (4.5) we see that increasing p and/ or K leads to higher optimal control effort. See appendix for proof. The intuition behind the result is that if the resource is more valuable the government has increased incentive to control the exploitation. The effects of the remaining parameters are less obvious and may depend on the fishery parameters.

PROPOSITION 1: *For higher control costs γ_1, lower price p and lower carrying capacity K of the fishery the optimal control effort level is always lower. Further, there exists a critical level of control costs $\hat{\gamma}$, which depends only on the efficiency parameter b. If b is higher then the critical control cost level is lower and vice versa. If control costs are higher than $\hat{\gamma}$ then optimal control effort is always zero.*

Further, note that Z values greater than or equal to one are impossible since we assume that harvesting is profitable for which it is necessary that b < 1 (see e.g. Mesterton-Gibbons 1993). To prove this let us denote the maximum control effort by $Z^*_{\max} = \dfrac{2c^2r}{pqkcr + c^2r}$. This is smaller than one only if b < 1.

PROPOSITION 2: *An optimal control effort is strictly less than one, which follows from the profitability condition b <1.*

Note also that therefore, control costs must satisfy

$$\gamma_1 < \frac{cr}{q} + \frac{c^2r}{pq^2K} \qquad (4.9)$$

since Z* < 1.

5 The Management of the fishery: The case of two decentralised authorities (Competing Countries)

In the game between two decentralised control authorities the decision of control effort is based on strategic as well as fishery benefit and control cost considerations. This represents an extension of the control problem of the single controller, which was purely based on cost and benefit considerations. In the present context each authority will strategically let the level of control depend on whether domestic or foreign vessels are controlled. This does not mean that the controller will impose different control of domestic and foreign respectively, but rather that the controller will let the level of controlling effort depend on the share of domestic/foreign vessels that are exploiting the fishery. It is assumed that the controller controls the vessels randomly. This implies that if 75% of the vessels operating in the fishery are domestic then on average 75% of the time the controller monitors the domestic vessels. In other words in the model the decentralised controller is by assumption not allowed to employ all its control effort only to monitor the foreign vessels.

We assume that the decentralised control authority monitors the fishing within its own zone. The variable S measures time spent controlling the domestic fishermen in the national fishing zone. In this sense S=1 implies that the national fishermen fish entirely in the national zone, whereas S=0.5 means that they only fish half of the time in the national zone. The level of S is critical, because it is crucial for the calculation of the national income and thereby for the decentralised authority in the decision on the level of the control effort. In this sense S=1 means that decentralised authority only control the domestic fishermen, because no foreign fishermen are fishing in the zone, whereas S = 0 means that only foreign fishermen are controlled because no domestic fleets fish in the zone.

It is assumed that the decentralised authority imposes a similar control on the domestic and foreign fishermen. In this sense incentives of the local authority to impose a more tough control on foreign than domestic fishermen is not allowed in the model.[4] Secondly, the decision of the fishermen whether they want to fish in the domestic or the foreign fish zones is exogenous. The decentralised authorities will let the optimal control effort depend of the share of domestic and foreign fishermen operating in the fishing, and analysis of this specific issue is addressed by studying to which extent the solution will change domestic/foreign fishermen share, denoted by S. The gain of specifying S is that this allows us to analyse whether the result would change in S.

We assume that each country is responsible for the control of its own national zone with sum of control costs γ_2 (γ_i control cost of country i). This means that the country is handling the control on both the domestic and foreign vessels within its zone. The game proceeds in similar way as in section 4. The difference to the earlier analysis is now that the efforts chosen by fishermen in country i are also a function of control policy of country j since this control policy affects fleet j's decision and this is the fleet that the fishermen in country i have to compete against. Thus, also in the governments maximisation of their choice of Z_i depends of Z_j.

[4] In the EU report on fisheries it is noted that there might be discrimination involved in the control of the domestic and foreign fishermen (see Report on Monitoring of the Common Fisheries Policy: Commission document SEC (92) 394 final).

5.1 The optimal fishing of the fishermen facing decentralised authorities

The expected profits of the fishermen in the case of illegal catches is now:

From zone i: $(1-\Psi_i)(pqSe_i x - cSe_i) + \Psi_i(-cSe_i - \Omega)$ (5.1a)

From zone j: $(1-\Psi_j)(pq(1-S)e_i x - c(1-S)e_i) + \Psi_j(-c(1-S)e_i - \Omega)$. (5.1b)

The expected income of the fishermen *i* can now be separated between the two fishing zones that are respectively the domestic and the foreign zones. The expected profit of fishermen *i* of operating in fishing zone is denoted in (5.1a), where the first term is the expected income of non-compliance in zone. The second term is the expected term of compliance in zone i. The expected profit of operating in zone j is likewise outlined in (5.1b). The total expected income of the fishermen operating in both fishing zones is expressed in (5.1c), which follows by adding (5.1a) with (5.1b).

$$Total\ E(P_i) = S(1-\Psi_i)pqe_i x + (1-S)(1-\Psi_j)pqe_i x - ce_i - (\Psi_i + \Psi_j)\Omega. \qquad (5.1c)$$

The reaction functions of the fishermen are now a modified version of equation (4.4) above (see appendix for derivation):

$$e_i = \frac{1}{q}\left[r(1-b_i) - q\sum_{j \neq i}^{n-1} e_j \right] \qquad (5.2)$$

The efforts can be calculated explicitly as:

$$e_i(o) = \frac{r}{q}(\frac{1}{2} - b_i + \frac{b_j}{2}) \tag{5.3a}$$

$$\sum_i^n e_i(o) = e(o) = \frac{r}{q}(1 - \frac{b_i}{2} - \frac{b_j}{2}) \tag{5.3b}$$

We notice that the effort in country i is a function of control in country j since

$$b_j = \frac{c}{\left[S(1-\Psi_j) + (1-S)(1-\Psi_i)\right]pqK},$$

which is efficiency parameter showing how profitable the fishery is.

There result is that we have two opposite effects, which in equation (5.3a). The first effect implies that an increase in the control of country i will decrease potential income and thereby decreases effort in country i. The second effect is half of the magnitude of the first effect and is given by the last term of equation 5.3. According to the second effect increased control effort of the foreign state means decreases fishing effort of the foreign state and this means that the domestic fishermen will increase their fishing effort (given that S lies between 0.5 and 1).

5.2 The optimal control effort of the decentralised authorities

We compare two cases. The first case is S = 0.5 where half of the fishing effort of the domestic fleet is directed to the foreign zone. The second case S = 1 is the case where all domestic vessels harvest within the domestic zone. Thus, this is the case where each country controls its own vessels.

The countries then maximise the following:

$$\underset{Z}{Max}\ \Pi = pqe_i(o)(K - \frac{Kqe(o)}{r}) - ce_i(o) - \frac{\gamma_2}{1-Z_i} \qquad (5.4)$$

Since e_i is a function of e_j and Z_j, Z_i is also a function of these. In the following the subgame perfect equilibria are solved (see derivation of implicit reaction functions in the appendix):

The case where S = 0.5 leads to $b_i = b_j$ since half of the control of the fishermen come from home country and half from the foreign country. Differentiating equation (5.4) with respect to Z_i leads to first order conditions and a subgame perfect Nash equilibrium:

$$Z_i^{S=0.5} = Z_j^{S=0.5} = 1 - \frac{c^2 r}{2pq^2 K(\frac{cr}{4q} + \frac{c^2 r}{4pq^2 K} - \gamma_2)} \qquad (5.5)$$

The solution of the two-player game when S = 0.5 looks very much like the solution to the one player game and may even coincide if control costs of the Member State are low enough.

It is again straightforward to show that increase in control costs leads to lower control effort. Further, from (5.5) we see that increasing p and/or K leads to higher equilibrium control efforts.

Comparing the EU optimum Z* (equation (4.5)) and the non-cooperative equilibrium with S = 0.5 shows that whether the EU optimum Z* is higher than the equilibria levels of control depends only on control costs. To see this we manipulate $Z^* - Z_i^{S=0.5}$ to be

$$-\frac{1}{\frac{cr}{2q}+\frac{c^2r}{2pq^2K}-\frac{\gamma_2}{2}}+\frac{1}{\frac{cr}{2q}+\frac{c^2r}{2pq^2K}-\gamma_1}>0 \qquad (5.6)$$

Thus, for any given fishery parameters when S = 0.5 and $\gamma_1 = \gamma_2$ the difference between the EU optimum and the non-cooperative control game between two Member States depends only on control costs. Further, if the member states are exactly 50 % more efficient in controlling the fishery the solutions are identical since expression (5.6) then equals zero.

PROPOSITION 3: *When S = 0.5 (meaning that half of the control effort is directed towards domestic and the other half towards foreign fishermen) the decentralised control game has a lower equilibrium control level than the EU optimal control if the control costs are equal. If the Member states have 50% lower control costs then the equilibrium control is higher than EU control level.*

Let us next proceed to the other case where S = 1. Here we see that b_i is only a function of Z_i since control only affects domestic fishermen. Differentiating equation (5.4) with respect to Z_i leads to the following symmetric equilibrium:

$$Z_i^{S=1} = Z_j^{S=1} = 1 - \frac{5c^2r}{4pq^2K(\frac{cr}{4q}+\frac{c^2r}{pq^2K}-\gamma_2)} \qquad (5.7)$$

We have that the control effort Z must be lower in the case when S = 1. Given that there is no control cost difference between the EU and the two-country cases, we can also state when control effort in the two-player case when S = 1 is lower than in the EU case.

Comparing the solutions with $Z^* - Z_i^{S=1}$ (equal control costs) yields a condition that should hold if the EU optimum is higher than the non-cooperative solution:

$$\gamma_1 < \frac{3cr}{q} + \frac{13c^2 r}{pq^2 K} \tag{5.8}$$

If inequality (5.8) is not satisfied then clearly this is a violation of condition (4.9). This means that if condition (5.8) holds control effort is larger in the EU case than in the non-cooperative game between two countries who both control their own fishermen (S = 1).

When control costs of the Member states approach zero, we see that fisheries that have low unit effort costs, low intrinsic growth rate, high price, high catchability or high carrying capacity may produce outcomes where decentralised control increases control effort.

To see this let control costs of the decentralised case approach zero. Then (5.8) becomes:

$$\gamma_1 < \frac{3cr}{5q} + \frac{13c^2 r}{5pq^2 K} \tag{5.9}$$

It is then straightforward to show that with $b < 1/9$ and condition (5.9) we may have that there is a positive equilibrium control effort higher than the optimal EU control effort level.

PROPOSITION 4: *When $S = 1$ (meaning that the Member states only control their domestic fishermen) the decentralised control game has a lower equilibrium control effort level than the EU optimal control if the control costs are equal. If the EU has high control costs relative to the fishery parameters (e.g., low unit cost of fishing effort, high price) then the equilibrium control effort is higher than EU control level for strictly positive control costs of the Member States.*

6 Numerical example

We use the following numerical example to illustrate the main results. To obtain the results we exploit the model developed in sections 3 to 5.

Table 1. Overview of the Results following the Cases of Centralised and Decentralised Control (EU, Member State)

		Control effort	Fishing effort/ Steady state stock / harvest	Surplus of the government	Expected profit of fishermen / control costs
EU		1	1 / 1 / 1	1	1 / 1
No control		0	1.52 / 0.22 / 0.33	-0.25	0 / 0
Two countries					
S = 0.5	$\gamma_1 > \gamma_2$	0.94	1.13 / 0.81 / 0.91	0.92	0.93 / 0.57
	$\gamma_1 = \gamma_2$	0.85	1.23 / 0.65 / 0.80	0.53	0.84 / 0.55
S = 1	$\gamma_1 > \gamma_2$	0.67	1.37 / 0.46 / 0.62	0.39	0.69 / 0.23
	$\gamma_1 = \gamma_2$	0.56	1.40 / 0.39 / 0.55	0.13	0.44 / 0.22

*) Assuming that $\gamma_1 = 2$ and $\gamma_2 = 1.5$

**) Other parameters used are: $p = 1$, $r = 0.8$, $K = 100$, $q = 0.8$, $c = 7$, $\Omega = 0.22$.

For sake of comparison the results outlined in Table 1 is normalised, this means that the results for the EU case is set to unity that numerical figures for other incidents can directly compared numerically. This means for example that a control effort 0.94 means that the case would imply a 6% reduction in the control effort compared to the case of EU control.

In the Table is distinguished between the cases of one central controller (EU) and decentralised controlling undertaken by two countries. In the case of decentralised enforcement we calculate different numerical values depending on the values for S and γ control costs. The control cost of EU is set to γ_1. For the decentralised controllers we simulate two cases. In the first case the control cost of the decentralised controllers is 25% less than control cost of the EU. In the second case we assume that the control costs of EU and decentralised controllers are equal. For the share of national fishermen S, we employ two values S = 0.5 and S = 1 that imply that the proportion of domestic fishermen is half and 100 % of the total population of controlled fishermen, respectively.

A general result that is enfolded by the Table is that it is Pareto optimal to leave the competence to control the fishery by the EU. This follows because both the government and the fishermen will be better off in terms of government surplus and profits to the fishermen. The result depends critically on the level of control cost, we have assumed that cost advantage of the decentralised control is be 25% of the cost of EU. However, as indicated in section 5 a cost efficiency of 50 % is needed to secure that the control effort is at the same level in the EU cooperative case and in the two-country non-cooperative game. Note however, that for achieving a welfare gain an efficiency difference of strictly less than 50 % is sufficient. This is because the control effort is the same when the cost difference is 50 % and clearly the countries are then strictly better off in the non-cooperative game as compared with the EU case. Therefore, a smaller cost difference is sufficient to make the countries indifferent between centralised and decentralised enforcement.

Another result enfolded by the simulations is that under a regime of no control, the profits of the fishermen are zero. This follows from the results of the familiar literature on open access fishery (see e.g. Mesterton-Gibbons 1993). In addition to this we see that under open access the government has a negative surplus because we assume that the government has some fixed management cost.

When looking at the control effort, assuming the control cost of the EU and decentralised states are the same $\gamma_1 = \gamma_2$, it is seen that control effort of the decentralised states varies between 56% and 85% of the control effort employed by the EU. This follows because in the non-cooperative solution the countries are only concerned about their national income and the obtained equilibrium is a typical example of tragedy of the commons. The negative externality problem is less severe when there are also foreign fishermen in the national zones (S = 0.5). This is because the countries then have more incentives to increase enforcement level thereby decreasing foreign fishing effort in the domestic zone. It is also interesting to note that although there is only minor difference in the control effort there will be a dramatic difference in the obtained surplus to the government, only 53% and 13 % relative to the cooperative game for S = 0.5 and S = 1, respectively. The reason is that the fishermen employ much more fishing effort in the non-cooperative game, and as they do so there will be less harvests and the stock level is smaller. The expected profits of the fishermen are not affected dramatically as was the case with government surplus. This is because less control effort also means lower probability of getting caught in illegal harvesting. Fishermen expected profits are 84 % and 44 % of the EU case for S = 0.5 and S =1, respectively.

For cases where enforcement cost differs between the EU and the Member States, $\gamma_1 > \gamma_2$, the control effort of the decentralised states is, respectively 67% and 94% of the EU control effort level. Moreover the surplus of the government and expected profits of the fishermen are higher than for the case of equal control costs. This follows because the 25% reduction in the control cost of the decentralised states implies a more cost efficient enforcement that allows the countries to control their fishing zone with less cost.

When comparing the income of the fishermen under centralised and decentralised enforcement, we extend the discussion with the possibility of cost recovery of the enforcement costs emphasised by Arnason *et al.* (2000), Wallis and Flaaten (2000) and Andersen and Sutinen (2000). The cost recovery concerns the extent to which it is possible that the users of the resource cover some of the enforcement costs. In this respect the government might charge the fishermen for participating in the fishery. This implies that if the fishermen obtain higher profit under regime of high control effort than under regime of less control effort, the regulator could use this difference in fishermen profits as an argument to let the fishermen finance some of the control cost. The argument for charging the fishermen follows because they benefit economically from the employed control effort. Stating the possibility of cost recovery we are looking at the expected profit of the fishermen. In Table 1 it is outlined that cost recovery is possible under decentralised enforcement. For example when S = 1, assuming that control cost is $\gamma_1 = \gamma_2$, then by letting the fishermen pay the 25% control cost difference moving to situation when $\gamma_1 = \gamma_2$, the expected profits of fishermen increase from 44% to 69% of the EU solution.

However, the fishermen cannot afford to pay the difference between centralised and decentralised control costs in any of the cases. This is due to the high control costs needed to enforce the cooperative solution. For example, having control cost difference and S = 0.5 the non-cooperative game produces nearly as much government surplus (92 %) and expected fishermen profit (93 %), but at a much lower control cost 57 %. A limitation of the present model is that is static that implies that the cost of excess fishing capacity in a dynamic context is not addressed. By allowing capacity dynamics cost recovery induces taxation that would impact the employed fishing capacity. This might prove to the right context to evaluate the impact of cost recovery. In the present static context, the simulations indicate that complete cost recovery is not obtained.

7 Discussion

In management of international shared resources economic rents are obtained by coordinating the exploitation of the resources. The management of the fishery resources in the EU is an interesting case of international cooperation because the Member States have committed principal elements of the conservation policy to the federal level.

Sutinen and Andersen (1985) emphasize that an essential element in the management of a regulated industry is the implementation and the enforcement policy. Enforcement is essential to order to ensure that imposed regulations are not neglected. The present paper has addressed the employment of enforcement policy in an international context. We have focused on whether the enforcement management should be conducted at the centralised (federal) or decentralised (regional) level. This has been accomplished by use of a two-country model that describes enforcement of international shared resources.

The result indicates that a welfare gain is obtained under centralised enforcement at the federal level. The result depends critically on the level of enforcement costs at the federal and the Member State (regional) levels. If the Member States have a sufficiently large cost advantage in enforcing fishing quotas then welfare gains under decentralised enforcement could be obtained. In addition, the result depends on the proportion of foreign fishermen in the domestic fishing zone. The higher is the proportion of foreign fishermen in the domestic zone the better is decentralised enforcement of quotas compared to centralised enforcement.

The results are derived in a game theoretical setting by comparing the cooperative and non-cooperative solutions. The cooperative solution is obtained under federal enforcement where overall welfare is maximised. The non-cooperative solution follows under decentralised enforcement, where the level of enforcement is based on individual optimisation. The latter case implies that a regime that sets a sustainable TAC is not sufficient to avoid an overexploitation of the resources. The reason is that management of enforcement is decided strategically.

The fact that it is relatively expensive to undertake enforcement in the fishery is an important reason that many states are reluctant to undertake the sufficient enforcement/control management. If the Member state level is the most cost efficient level to conduct the enforcement management, one way to get a higher level of enforcement would be that the federal level subsidises enforcement of the Member States. An advantage by leaving the enforcement management at the Member State is that the efficiency gain of enforcement is realised. Federal subsidising of enforcement in Member States is actually employed as part of the EU fishery policy.[5] Our model has shown that these subsidies may be justified in two

[5] O.J. L 154 , No.431/2001, 9.6 2001.

cases. The first case is when there is a large proportion of domestic fishermen in the Member States fishing zone (high S). In this case it is clear that subsidising enforcement costs would help in decreasing the problem of the commons by increasing control effort but leaving the level of control costs practically unchanged. The second case where EU subsidies would be appropriate is where the control costs are very high. Enforcement subsidies might induce a change from no-control to a reasonable degree of enforcement and thus, higher economic viability of the fishery.

Another way that the Member State could obtain funds to finance their enforcement/management goes through user payment. The fishermen as the main user group of the fishery resources could be charged for the enforcement. This is called cost recovery and has been employed in Australia, Canada and New Zealand. The use of cost recovery has not been considered in the EU, but opens for some interesting extensions on the present analysis. The implication of employing the user charge at the Member State and Federal level should be studied in the future.

A further EU policy that would seem reasonable would be to allow fishermen to harvest in the waters of the foreign Member State. This would reduce the problem of non-cooperative behaviour (national interests) by decreasing S, the proportion of domestic fishermen. Following the model a decrease in S, the proportion of domestic fishermen, would give higher level of enforcement than the case where the proportion of domestic fishermen is high.

The current paper has also opened a number of avenues for further research. The trade-off between complete compliance and costly enforcement could be studied taking into account several features. First, the asymmetry between countries and fishermen could be analysed when countries may have different fleet sizes and cost structures. Second, the effect of having more than two countries and possible groups of Member States could be studied. Finally, the problem could be studied in a dynamic setting.

REFERENCES

Andersen, P. and J. Sutinen (2001). Financing Fishery Management: Principles and Economic Implications. In *The Cost of Fisheries Management*, Editors: W. Schrank, R. Arnason and R. Hannesson. Ashgate.

Anderson, L.G. and D.R. Lee (1986). Optimal Governing Instrument, Operating Level, and Enforcement in Natural Resource Regulation: the case of the fishery. *American Journal of Agricultural Economics* 68:678-690.

Arnason, R., R.Hannesson and W.E Schrank (2000). Costs of Fisheries Management: the Cases of Iceland, Norway and Newfoundland. *Marine Policy* 24: 233-243.

Chen, Z. (1997). Negotiating an Agreement on Global Warming: A Theoretical Analysis, *Journal of Environmental Economics and Management*, 32:170-188.

Clarke, H.R., W.J. Reed and R.M. Shrestha. Optimal Enforcement of Property Rights on Developing Country Forests subject to Illegal Logging, *Resource And Energy Economics*, 15: 271-293.

Hardin, G. (1968). The Tragedy of the Commons. *Science,* 162: 1243-1248.

Harford, J. (2000). Initial and Continuing Compliance and the Trade-Off between Monitoring and Control Cost, *Journal of Environmental Economics and Management*, 40: 151-163.

Hatcher, A.; S. Jaffry; O. Thébaud and E. Bennett (2000). Normative and Social Influences Affecting Compliance with Fishery Regulations. Land Economics 76: 448-461.

Holden, M. (1996) *The Common Fisheries Policy*: Origin, Evaluation and Future. Oxford: Fishing News Books.

Kuperan, K. and J.G. Sutinen (1998). Blue Water Crime: Deterrence, Legitimacy, and Compliance in Fisheries. *Law & Society Review* 32: 309-337.

Jensen F. and Vestergaard N. (2000). Moral Hazard Problems in Fisheries Regulation: The Case of Illegal Landings. Working Paper, No. 9/00. Department of Environmental and Business Economics, University of Southern Denmark.

Milliman, S. (1986) Optimal Fishery Management in the Presence of Illegal Activity. *Journal of Environmental Economics and Management* 13: 363-381.

Mesterton-Gibbons, M. (1993). "Game-Theoretic Resource Modeling". *Natural Resource Modeling*, 7: 93-146.

Ruseski, G. (1998) International Fish Wars: The Strategic Roles for Fleet Licensing and Effort Subsidies. *Journal of Environmental Economics and Management* 36: 70-88.

Silva, E. and A. Caplan (1997). Transboundary Pollution Control in Federal Systems, *Journal of Environmental Economics and Management*, 34: 173-186

Sutinen, J. G. and P. Andersen (1985) The Economics of Fisheries Law Enforcement. *Land Economics* 61: 387- 397.

Wallis & Flaaten (2000) Fisheries Management Costs: Concepts and Studies. OECD.
http://www.oecd.org/agr/fish/publications.htm

APPENDIX

Derivation of equation (4.3): fishermen's reaction functions of the EU case

$$\max \ E(P_i) = (1-\Psi)pqe_i(K - \frac{Kqe_i}{r} - \frac{Kq\sum e_j}{r}) - ce_i - \Psi\Omega$$

$$\text{FOC:} \ \ (1-\Psi)pqK - \frac{2(1-\Psi)pq^2 e_i K}{r} - \frac{(1-\Psi)pq^2 K\sum e_j}{r} - c = 0$$

Divide both sides by $pqK(1\text{-}\Psi)$ and note $b = c/pqK(1\text{-}\Psi)$.

$$1 - \frac{2qe_i}{r} - \frac{q\sum e_j}{r} - b = 0$$

$\Rightarrow$

$$e_i = \frac{r(1-b) - q\sum e_j}{2q}$$

Applying symmetry and letting n approach infinity.

$\Rightarrow$

$$\sum_i^n e_i = \frac{n}{n+1}\frac{r(1-b)}{q} = \frac{r(1-b)}{q}$$

Derivation of equation (4.6): the interior optimum in the EU case

$$\max \ \ pqe(o)(K - \frac{Kqe(o)}{r}) - ce(o) - \frac{\gamma_1}{1-Z}$$

Insert equation (4.4), i.e., e(o) to yield

$$\max \; -\frac{c^2 r}{(1-Z)^2 pq^2 K} + \frac{1}{1-Z}\left(\frac{cr}{q} + \frac{c^2 r}{pq^2 K} - \gamma_1\right) + \frac{cr}{q}$$

The first-order conditions are:

$$-\frac{2c^2 r}{pq^2 K(1-Z)^3} + \left(\frac{cr}{q} + \frac{c^2 r}{pq^2 K} - \gamma_1\right)\frac{1}{(1-Z)^2} = 0$$

From this equation we can solve for optimal control policy Z* by multiplying all through by $(1-Z)^3$.

(ii) Effect of price and carrying capacity

$\frac{\partial Z^*}{\partial p} > 0$ if $qKcr - q^2 K\gamma_1 > 0$. This holds if $\gamma_1 < \frac{cr}{q}$. However, Z* = 0 if $\frac{2c^2 r}{pqKcr + c^2 r - \gamma_1} > 1$ and this condition is always satisfied if $\gamma_1 \geq \frac{cr}{q}$. Therefore, it is always true that $\frac{\partial Z^*}{\partial p} > 0$. Analogous proof for K.

Derivation of equation (5.1): fishermen's reaction functions of the two-player case

max

$$E(P_i) = (1-\Psi_i)pqSe_i(K - \frac{Kqe_i}{r} - \frac{Kq\sum e_j}{r}) + (1-\Psi_j)pq(1-S)e_i(K - \frac{Kqe_i}{r} - \frac{Kq\sum e_j}{r})$$
$$-ce_i - (\Psi_i + \Psi_j)\Omega$$

FOC:
$$(1-\Psi_i)pqSK - \frac{2(1-\Psi_i)pq^2Se_iK}{r} - \frac{(1-\Psi_i)pq^2SK\sum e_j}{r}$$
$$+(1-\Psi_j)pq(1-S)K - \frac{2(1-\Psi_j)pq^2(1-S)e_iK}{r} - \frac{(1-\Psi_j)pq^2(1-S)K\sum e_j}{r} - c = 0$$

Divide both sides by $pqK\left[(1-\Psi_i)S + (1-\Psi_j)(1-S)\right]$ and note

$$b_i = \frac{c}{pqK\left[(1-\Psi_i)S + (1-\Psi_j)(1-S)\right]}.$$

$$1 - \frac{2qe_i}{r} - \frac{q\sum e_j}{r} - b_i = 0$$
$$\Rightarrow$$
$$e_i = \frac{r(1-b_i) - q\sum e_j}{2q}$$

Applying symmetry:

$$\sum_i^n e_i = \frac{r(1-b_i)}{q}$$

Derivation of equation (5.5): countries reaction functions and equilibrium of the two-player case when S = 0.5

$$\max \quad pqe_i(o)(K - \frac{Kqe(o)}{r}) - ce_i(o) - \frac{\gamma_2}{1-Z_i}$$

$$= \frac{prK(1-b)}{2} - \frac{prK(1-b)^2}{2} - \frac{cr(1-b)}{2q} - \frac{\gamma_2}{1-Z_i}$$

where $b = b_i = b_j = \dfrac{c}{pqK\left[\dfrac{1-Z_i}{2} + \dfrac{1-Z_j}{2}\right]}$

FOC:

$$-\frac{rc^2}{2pq^2K}\frac{1}{\left[\dfrac{1-Z_i}{2}+\dfrac{1-Z_j}{2}\right]^3} + \frac{1}{\left[\dfrac{1-Z_i}{2}+\dfrac{1-Z_j}{2}\right]^2}\left(\frac{cr}{4q} + \frac{c^2r}{4pq^2K}\right) - \frac{\gamma_2}{(1-Z_i)^2} = 0$$ Applyi

ng symmetry $Z_i = Z_j$ yields the equilibrium

$$Z_i^{S=0.5} = Z_j^{S=0.5} = 1 - \frac{c^2r}{2pq^2K(\frac{cr}{4q} + \frac{c^2r}{4pq^2K} - \gamma_2)}$$

Derivation of equation (5.7): countries reaction functions and equilibrium of the two-player case when S = 1

$$\max \quad pqe_i(o)(K - \frac{Kqe(o)}{r}) - ce_i(o) - \frac{\gamma_2}{1-Z_i}$$

$$= pr(\frac{1}{2} - b_i + \frac{b_j}{2})(K - K(1 - \frac{b_i}{2} - \frac{b_j}{2})) - \frac{cr}{q}(\frac{1}{2} - b_i + \frac{b_j}{2}) - \frac{\gamma_2}{1 - Z_i}$$

FOC: $$-\frac{rc^2}{pq^2K}\frac{1}{(1-Z_i)^3} + \frac{1}{(1-Z_i)^2}(\frac{cr}{4q} + \frac{crb_i}{4q} + \frac{c^2r}{pq^2K} - \gamma_2) = 0$$

Applying symmetry again yields the equilibrium:

$$Z_i^{S=1} = Z_j^{S=1} = 1 - \frac{5c^2r}{4pq^2K(\frac{cr}{4q} + \frac{c^2r}{pq^2K} - \gamma_2)}$$