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Centralised versus Decentralised Enforcement of Fish Quotas

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Abstract *The purpose of this article 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 the proportion of foreign fishermen in the domestic zone, the better the decentralised enforcement of quotas.*

Key words Quota enforcement policy, fisheries management.

JEL Classification Codes Q22, Q28.

Introduction

Despite the fact that the use of market solutions has increased in popularity in recent years, a need to impose governmental regulation exists. The exploitation of natural resources is an example of where markets are often absent (the common property problem). To achieve efficient exploitation of the resources, governmental regulatory goals are set in situations such as the international exploitation of fish resources. International agreements between states that exploit shared stocks are essential in order to avoid depleted fish stocks and dissipated rents. This type of international governance can be seen in the EU, where the regulation of fish quotas is decided at the international level (the EU level). However, the success of an imposed management strategy depends on whether the regulatory agencies are willing to spend sufficient money to catch and convict violators of regulations.

Further examples, including similar issues of centralised versus decentralised governance, include the analysis of the Regional Fisheries Management Organisations (RFMOs) in the context of high seas fisheries (Munro 2000). For

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these organisations, it is highly relevant to examine whether enforcement should be at the individual country level or at the RFMO level.

The purpose of this article is to address management and enforcement from an international perspective. This issue is relevant to the regulation of international pollution control (Silva and Caplan 1997; Harford 2000), forestry management (Clarke, Reed, and Shrestha 1993), and climate change enforcement (Chen 1997). The essence of the problem is that the single states joining the agreement have no incentive to apportion sufficient resources for monitoring and enforcement, and in a sense the situation can often be described by the classic "tragedy of the commons" problem (Hardin 1968).

The specific issue addressed in this article is to analyse the conditions under which it would be optimal to use additional funds for a centralised enforcement of the agreement. Centralised management is seen as an alternative to decentralised agencies, which may 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. It specifically addresses whether the task of enforcement and control can be conducted at a decentralised regional level, which due to information advantages may be less costly.

We study the problem in a two-stage game setting. In the first stage, the government(s) set their enforcement level, which has a direct impact on the probability of fishermen being caught illegally harvesting. In the second stage, fishermen maximise their expected profits, taking into account the enforcement of the government(s) and the actions of the other fishermen. We compare the cooperative (EU) case to a non-cooperative case with two Member States. In the cooperative case, only one central authority decides enforcement in the first stage. In the non-cooperative case, the two countries solve their equilibrium enforcement level in the first stage. In both cases, the fishermen play a non-cooperative game among themselves in the second stage.

For the two-country game, we make a distinction between two interesting special cases where the proportion of domestic and foreign fishermen varies in the domestic zone of the managing authority. We show how the proportion of foreign fishermen may affect the equilibrium of the two countries. From the analytical results we provide a numerical example where we discuss issues such as cost recovery. That is, we study whether the fishermen would be able to 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 carried out to escape the 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 and Lee (1986), and Kuperan and 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, to our knowledge no attempts have been made to construct a model with an international perspective. The current article contributes to the literature by analysing an enforcement game between two countries with a common fish stock.

The regulation of fisheries in the EU is described first. Second, we briefly describe the underlying Gordon-Schaefer model. Then the game with a single controller is established. The following section extends the analysis by allowing decentralised enforcement; that is, two countries. Simulations of these results are then conducted. Finally, the results are discussed.

The Management Problem of the European Union

As in most other fisheries around the world, an arsenal of different regulations is employed in the EU fishery.[1] However, the regulations have no influence on the efficiency of the fishery if the fishermen neglect them. In this sense it is important that the managing authority puts enough effort into monitoring and/or sets high enough penalties to secure compliance. As the cost of monitoring the industry is significant, it is reasonable that enforcement should be conducted at the most cost-efficient level (OECD 2003). On the other hand, it is important that the monitoring authority does not have conflicting interests that lead to a control policy that is insufficient or discriminatory.

EU common regulations (*e.g.*, the Total Allowable Catch [TAC]) are decided at the EU level. However, quota decisions are also often affected by advice from ICES (the International Council for the Exploration of the Sea), and in the case of shared stocks, they may be decided together with other countries. The competence to monitor regulations is typically placed at the level of the Member State.[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 its own fishing industries, fishing gear, and seasonal fishing patterns that are essential for detecting non-compliance.

Derivation of Sustainable Effort and Stock Levels

In this section, we briefly present the general model used in this article. The aim is to show the relationship between steady-state fishing effort and stock levels.

We follow the Gordon-Schaefer model with a single stock of size. The change of the stock in time t is given by:

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

where 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, the discount rate is equal to zero, and growth of fish, $G(x)$, is given by the logistic growth function:

$$G(x) = rx(1 - x / K), \tag{2}$$

where r is the intrinsic growth rate of fish and K is the carrying capacity. We have a linear production function (harvest for fisherman i):

$$h_i = qe_i x. \tag{3}$$

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

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[1] That is TAC, bycatch regulations, technical measures, and so forth (see conservation regulation 3760/92 and later amendments) (Official Journal of the European Communities L 389, 31.12 1992).

[2] The role of the Commission is mainly to conduct on-the-spot inspections of the monitoring in the Member States (see control regulation 2847/93 and later amendments) (Official Journal of the European Communities L 261, 20.10 1993).

The steady-state stock is derived by the use of equations (1), (2), and (3) when harvest equals growth:

$$x = \frac{K}{r}\left(r - q\sum_{i=1}^{n} e_i\right). \tag{4}$$

We see that for each level of fishing effort there is a corresponding 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.

Enforcement of the Fishery: The Case of a Single Central Authority (The EU)

In this section there is a single enforcing authority. The problem of the authority is to decide the level of enforcement given that enforcement is costly. The fishermen's problem 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 a sufficiently low level so that it restricts their fishing effort. Without regulation in the fishery, the open-access solution, or in our case the non-cooperative effort level, produces catches that exceed the TAC. This follows because it is not optimal for the central authority to choose perfect control since control is costly.

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

$$\underset{Z}{Max} \quad \pi_o = \sum_{i=1}^{2} P_i(o) - \frac{\gamma_1}{1 - Z}. \tag{5}$$

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

The government decides the level of the enforcement effort, *Z*, based on the objective function (5), 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 costs, which consist of the unit cost of enforcement, γ_1, and the level of enforcement, *Z*.

Note that the enforcement cost function implies: (*i*) diminishing returns in terms of enforcement effort with increasing expenditure and (*ii*) an infinite cost of perfect compliance. We have chosen this particular functional form for tractability of the model. It may well be that in some cases we would have to specify a very different form of enforcement cost function. Further, if enforcement 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:

$$E(P_i) = (1 - \Psi)ph_i - ce_i - \Psi\Omega \qquad \text{if } h_i > TAC_i. \tag{6}$$

The fishermen's profit depends on whether they decide on a strategy of compliance. The fishermen are assumed to be risk neutral. The expected returns under non-compliance are described in equation (6). 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 of the harvest. The second term denotes the cost of fishing effort, which is the 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. Note that we only consider the case in which the quota is non-binding.

The two decision problems in equations (5) and (6) 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 their fishing efforts in a non-cooperative Nash game that produces a subgame perfect equilibrium. The fishermen have the incentive to lower their fishing effort when the government increases the enforcement 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 enforcement effort is denoted by Z and the fishermen's risk of being caught, Ψ. Secondly, the decision on the level of enforcement is found for the central authority, which depends on the 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.

Optimal Fishing Effort of the Fishermen Facing a Centralised Authority

The maximisation problem of the fishermen is:

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

In our case, the relevant objective to maximise is the case where catches are above the 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 $(1 - \Psi)ph_i$ 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. The maximisation of this expression for both countries leads to an equilibrium where the reaction functions of the fishermen to each other's effort and the control policy of the EU are given in equation (7). See the appendix for the derivation.

$$e_i = \frac{1}{2q}\left[r(1-b) - q\sum_{k\neq i}^{n-1} e_k \right]. \tag{7}$$

We see that higher catchability coefficient, q; lower intrinsic growth rate, r; higher efficiency, b; and a larger number of fishermen imply a lower level of fishing effort for an individual fisherman. The term b equals $c/[(1 - \Psi)pqK]$ if catches exceed the TAC. In the case of catches within the permitted range, the reaction functions would be the same as equation (7), but with $b = c/pqK$. 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 (7) with b equalling $c/[(1 - \Psi)pqK]$.

For means of convenience in the symmetric case, $e(o)$ is defined from equation (7) as:

$$\sum_{i}^{n} e_i(o) = e(o) = \frac{r(1-b)}{q}. \tag{8}$$

Optimal Control Effort of the Central Authority

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

$$\underset{Z}{Max}\,\Pi = pqe(o)\left[K - \frac{Kqe(o)}{r}\right] - ce(o) - \frac{\gamma_1}{1-Z}.$$

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

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

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

$$Z^* = 1 - \frac{2c^2r}{pqKcr + c^2r - pq^2K\gamma_1}. \tag{9}$$

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

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

$$\frac{\partial Z^*}{\partial \gamma_1} = -\frac{2c^2r\,pq^2K}{(pqKcr + c^2r - pq^2K\gamma_1)^2} < 0. \tag{10}$$

A corner solution (no enforcement) will emerge when the enforcement costs are sufficiently high. In this case, the central authority does not find it profitable to enforce the fishery, since the additional value received from the fishery is less than the enforcement costs necessary to achieve a lower fishing effort. From equation (10) we see that $Z^* = 0$ if:

$$\frac{2c^2r}{pqKcr + c^2r - pq^2K\gamma_1} = 1. \tag{11}$$

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

$$\frac{\partial Z^*}{\partial \gamma_1} < 0 \quad \text{if } \gamma_1 < \hat{\gamma} \tag{12}$$

$$Z^* = 0 \quad \text{if } \gamma_1 \geq \hat{\gamma}.$$

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

Further, from equation (10) we see that increasing p and/or K leads to a higher optimal enforcement effort. See the appendix for the proof. The intuition behind the result is that if the resource is more valuable, the government has an increased incentive to monitor the exploitation. The effects of the remaining parameters are less obvious and may depend on the parameters of the fishery.

PROPOSITION 1: *For higher unit enforcement costs* γ_1; *lower price, p; and lower carrying capacity, K, of the fishery; the optimal enforcement effort level is always lower. Further, there exists a critical level of unit enforcement costs,* $\hat{\gamma}$*, which depends only on efficiency parameter b. If b is higher, then the critical level of unit enforcement costs is lower and vice versa. If unit enforcement costs are higher than* $\hat{\gamma}$*, then the optimal enforcement 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 $Z^*_{\max} = (2c^2r)/(pqkcr + c^2r)$. This is smaller than one only if $b < 1$.

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

Note also that unit enforcement costs must satisfy:

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

since $Z^* < 1$.

Management of the Fishery: The Case of Two Decentralised Authorities (Competing Countries)

In the game between two decentralised authorities, the decision on the level of enforcement effort is based on considerations of strategy, benefit to the fishery, and cost. This extends the problem of the single authority, which was purely based on cost and benefit considerations. In the first stage of the game, each authority will strategically let the level of enforcement depend on whether domestic or foreign vessels are monitored. This does not mean that the authority will impose different levels of enforcement over domestic and foreign vessels, rather that the authority will let the level of enforcement effort depend on the share of domestic and foreign vessels that are exploiting the fishery. In the second stage, the fishermen choose their fishing efforts based on the control decisions of the two authorities. The game is solved by backwards induction; that is, we first solve the second stage. After this, the authorities can, in the first stage, compute their optimal control efforts.

We assume that the authority monitors the vessels randomly. This implies that if 75% of the vessels operating in the fishery are domestic, then 75% of the time, on average, the authority monitors the domestic vessels. In other words, in the model the decentralised authority is by assumption not allowed to employ all its enforcement effort only to monitor the foreign vessels.

In our model, the decentralised authority monitors the fishing within its own zone. The variable S measures time spent monitoring 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 the enforcement effort. In this sense, $S = 1$ means that the decentralised authority only monitors the domestic fishermen because no foreign fishermen are fishing in the zone, whereas $S = 0$ means that only foreign fishermen are monitored because no domestic fleets fish in the zone. Note that we also assume that both countries have fleets of an equal size to the same fraction operating in the domestic zone.

We assume that the decentralised authority imposes similar management on domestic and foreign fishermen. In this sense, an incentive for the local authority to impose more severe control on foreign than domestic fishermen is not allowed in the model.[3] Secondly, the decision of the fishermen whether they want to fish in the domestic or foreign fish zones is exogenous.

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

Optimal Fishing of the Fishermen Facing Decentralised Authorities

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

$$\text{From zone } i\text{: } (1-\Psi_i)(pqSe_ix - cSe_i) + \Psi_i(-cSe_i - \Omega) \tag{14a}$$

$$\text{From zone } j\text{: } (1-\Psi_j)\left[pq(1-S)e_ix - c(1-S)e_i\right] + \Psi_j\left[-c(1-S)e_i - \Omega\right]. \tag{14b}$$

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

The expected income of fishermen, i, can now be separated between the two fishing zones that are the domestic and the foreign zones, respectively. The expected profit of fishermen i of operating in the fishing zone is denoted in equation (14a), where the first term is the expected income of non-compliance in the 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 (14b). The total expected income of the fishermen operating in both fishing zones is expressed in (14c), which follows by adding (14a) with (14b).

$$\text{Total } E(P_i) = S(1-\Psi_i)pqe_ix + (1-S)(1-\Psi_j)pqe_ix - ce_i - (\Psi_i + \Psi_j)\Omega. \quad (14c)$$

The reaction functions of the fishermen are now a modified version of equation (9) above (see appendix for derivation):

$$e_i = \frac{1}{q}\left[r(1-b_i) - q\sum_{k\neq i}^{n-1} e_k \right]. \quad (15)$$

The efforts can be calculated explicitly as:

$$e_i(o) = \frac{r}{q}\left[\frac{1}{2} - b_i + \frac{b_j}{2}\right]. \quad (16)$$

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

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

which is the efficiency parameter showing how profitable the fishery is.

The result is that we have two opposite effects, which are shown in equation (16). The first effect implies that an increase in the enforcement from 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 (16). According to the second effect, an increased enforcement effort from the foreign state means a decreased fishing effort by foreign fishermen, and this means that the domestic fishermen will increase their fishing effort (given that $S \in [0.5, 1]$).

Optimal Control Effort of the Decentralised Authorities

We will 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, $S = 1$, is the case where all domestic vessels harvest within the domestic zone and where each country controls its own vessels.

The countries then maximise the following:

$$\underset{Z}{Max} \quad \Pi = pqe_i(o)\left[K - \frac{Kqe(o)}{r}\right] - ce_i(o) - \frac{\gamma_2}{1-Z_i}. \quad (17)$$

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 the derivation of implicit reaction functions in the appendix).

The case where $S = 0.5$ leads to $b_i = b_j$, since half of the enforcement of the fishermen comes from the home country and half from the foreign country. Differentiating equation (17) with respect to Z_i leads to first-order conditions and a subgame perfect Nash equilibrium:

$$Z_i^{S=0.5} = Z_j^{S=0.5} = 1 - \frac{c^2 r}{2pq^2K\left[\frac{cr}{4q} + \frac{c^2 r}{4pq^2K} - \gamma_2\right]}. \tag{18}$$

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 the control costs of the Member State are low enough.

Comparing the EU optimum Z^* [equation (9)] 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:

$$-\frac{1}{\frac{cr}{2q} + \frac{c^2 r}{2pq^2K} - \frac{\gamma_2}{2}} + \frac{1}{\frac{cr}{2q} + \frac{c^2 r}{2pq^2K} - \gamma_1} > 0. \tag{19}$$

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 enforcement costs. Further, if the Member States are exactly 50% more efficient in controlling the fishery, the solutions are identical since expression (19) then equals zero.

Proposition 3: *When S = 0.5 (meaning that half of the enforcement effort is directed towards domestic and the other half towards foreign fishermen), the decentralised enforcement game has a lower equilibrium enforcement level than the EU optimal enforcement if the enforcement costs are equal. If the Member States have 50% lower enforcement costs, then the equilibrium enforcement is higher than the EU enforcement 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 enforcement only affects domestic fishermen. Differentiating equation (17) with respect to Z_i leads to the following symmetric equilibrium:

$$Z_i^{S=1} = Z_j^{S=1} = 1 - \frac{5c^2 r}{4pq^2K\left[\frac{cr}{4q} + \frac{c^2 r}{pq^2K} - \gamma_2\right]}. \tag{20}$$

We have that the enforcement effort, Z, must be lower in the case when $S = 1$. Given that there is no enforcement cost difference between the EU and the two-country cases, we can also state that enforcement 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 enforcement costs) yields a condition that should hold if the EU optimum is higher than the non-cooperative solution:

$$\gamma_1 < \frac{3cr}{q} + \frac{13c^2r}{pq^2K}. \quad (21)$$

If inequality (21) is not satisfied, then clearly this is a violation of condition (13). This means that if condition (21) holds, enforcement effort is larger in the EU case than in the non-cooperative game between two countries that both enforce their own fishermen ($S = 1$).

Numerical Example

We use the following numerical example to illustrate the main results based on the model developed in previous three sections.

For the sake of comparison, the results outlined in table 1 are normalised, which means that the results for the EU case are set to unity so that numerical figures for other incidents can be directly compared numerically. This means, for example, that a 0.94 enforcement effort implies a 6% reduction in the enforcement effort compared to the case of EU enforcement.

The cases of one central authority (EU) and decentralised enforcement undertaken by two countries are outlined in the table. In the case of decentralised enforcement, we calculate different numerical values depending on the values for S and γ. The enforcement cost for the EU is set to γ_1. For the decentralised authorities, we simulate two cases. In the first case, the enforcement cost of the decentralised authorities is 25% less than the enforcement cost of the EU. In the second case, we

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

		Enforcement Effort	Fishing Effort/ Steady-state Stock/Harvest	Government Surplus	Expected Fishermen Profit/Enforcement Costs
EU		1	1/1/1	1	1/1
No Enforcement		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

Parameter values: $\gamma_1 = 2$ and $\gamma_2 = 1.5$ when $\gamma_1 > \gamma_2$; otherwise $\gamma_1 = \gamma_2 = 1.5$.
Other parameter values: $p = 1$, $r = 0.8$, $K = 100$, $q = 0.8$, $c = 7$, $\Omega = 0.22$.

assume that the enforcement costs of the EU and decentralised authorities are equal. For the share of national fishermen, *S*, we employ two values $S = 0.5$ and $S = 1$, which imply that the proportion of domestic fishermen is 50% and 100% of the total population of monitored fishermen, respectively.

A general result that is seen in the table is that it is Pareto optimal to leave the competence to enforce the fishery to the EU. This follows because both the government and the fishermen will be better off in terms of government surplus and profits for the fishermen. The result depends critically on the level of enforcement cost, and we have assumed that the cost advantage of decentralised enforcement is 25% of the cost of EU enforcement. However, as indicated in the previous section, a cost advantage of 50% is needed to secure that the enforcement 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 enforcement 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 the choice of centralised and decentralised enforcement.

Another result revealed by the simulations is that under a regime of no enforcement, the profits of the fishermen are zero. This follows from the results of familiar literature on open access fishery (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 enforcement effort, assuming the enforcement cost of the EU and decentralised states are the same $\gamma_1 = \gamma_2$, it is seen that the enforcement effort of the decentralised states varies between 56% and 85% of the 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 the 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 incentive to increase their enforcement levels, thereby decreasing their foreign fishing effort in the domestic zone. It is also interesting to note that although there is only a minor difference in the enforcement 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 fewer harvests and the stock level will be smaller. The expected profits of the fishermen are not affected dramatically, as was the case with government surplus. This is because less enforcement effort also means a lower probability of being caught illegally harvesting. The fishermen's 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 enforcement effort of the decentralised states is 67% and 94%, respectively, of the EU effort level. Moreover, the surplus of the government and the expected profits of the fishermen are higher than for the case of equal enforcement costs. This follows because the 25% reduction in the enforcement cost of the decentralised states implies a more cost-efficient enforcement that allows the countries to monitor their fishing zone with less cost.

When comparing the income of the fishermen under centralised and decentralised enforcement, we extend the discussion to the possibility of the cost recovery of enforcement costs, as emphasised by Arnason, Hannesson, and Schrank (2000), OECD (2003), and Andersen and Sutinen (2003). 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 a higher profit under a regime of high enforcement effort than under a regime of less effort, the regulator could use this difference in the fishermen's profits as an argument for requiring the fishermen to finance some of the enforcement cost. In considering the possibility of cost recovery, we look 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 enforcement cost is $\gamma_1 = \gamma_2$, by requiring the fishermen pay the 1% cost difference, we move to a situation when $\gamma_1 > \gamma_2$, and the expected profits of the fishermen increase from 44% to 69% of the EU solution.

However, the fishermen cannot afford to pay the difference between centralised and decentralised enforcement costs in any of the cases. This is due to the high costs of enforcing the cooperative solution. For example, with the enforcement 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 cost (57%). A limitation of the present model is that it is static, which 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 fishing capacity. This might prove to be 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.

Discussion

In the management of international shared resources, economic rents are obtained by coordinating the exploitation of the resources. The management of 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) emphasise that essential elements in the management of a regulated industry are implementation and enforcement. Enforcement is essential in order to ensure that imposed regulations are not neglected. The present article has addressed the employment of enforcement policy in an international context. We have focused on whether the management of enforcement should be conducted at the centralised (federal) or decentralised (regional) level. This has been accomplished by the use of a two-country model that describes the 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 the proportion of foreign fishermen in the domestic zone, the better decentralised enforcement of quotas is compared to centralised enforcement.

The results are derived in a game theoretical setting by comparing 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 setting a sustainable TAC is not sufficient to avoid an overexploitation of the resources. The reason is that the 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 sufficient management of enforcement. If the Member State level is the most cost efficient one through which to conduct enforcement management, a higher level of enforcement could be achieved using a federal level subsidy. An advantage to this is that the efficiency gain of enforcement is realised. Federal subsidising of enforcement by Member States is actually employed as part of the EU fishery policy.[4] Our model has shown that these subsidies may be justified in two 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 to decrease the problem of the commons by increasing control effort but leaving the level of control costs practically unchanged. The second case in which EU subsidies would be appropriate is where the control costs are very high. Enforcement subsidies might induce a change from no enforcement 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 fishery management is 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 up some interesting dimensions in the present analysis. The implications of employing a user charge at the Member State and federal levels 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 a 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 would give a higher level of enforcement than the case where the proportion of domestic fishermen is high.

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

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Appendix

Derivation of equation (7): Fishermen's Reaction Functions of the EU Case

$$\max \ E(P_i) = (1 - \Psi) p q e_i \left(K - \frac{Kqe_i}{r} - \frac{Kq \sum e_k}{r} \right) - c e_i - \Psi \Omega$$

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

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

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

$$\Rightarrow$$

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

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 (9): The Interior Optimum in the EU Case

$$\max \quad pqe(o)\left[K - \frac{Kqe(o)}{r}\right] - ce(o) - \frac{\gamma_1}{1-Z}.$$

Insert equation (8), *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 enforcement effort Z^* by multiplying all through by $(1-Z)^3$.

Effect of Price and Carrying Capacity

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

Derivation of equation (15): Fishermen's Reaction Functions of the Two-player Case

$$\max \; E(P_i) = (1-\Psi_i)pqSe_i\left[K - \frac{Kqe_i}{r} - \frac{Kq\sum e_k}{r}\right]$$

$$+ (1-\Psi_j)pq(1-S)e_i\left[K - \frac{Kqe_i}{r} - \frac{Kq\sum e_k}{r}\right] - ce_i - (\Psi_i + \Psi_j)\Omega$$

$$\text{FOC:} \; (1-\Psi_i)pqSK - \frac{2(1-\Psi_i)pq^2Se_iK}{r} - \frac{(1-\Psi_i)pq^2SK\sum e_k}{r}$$

$$+(1-\Psi_j)pq(1-S)K - \frac{2(1-\Psi_j)pq^2(1-S)e_iK}{r} - \frac{(1-\Psi_j)pq^2(1-S)K\sum e_k}{r} - c = 0$$

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

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

$$1 - \frac{2qe_i}{r} - \frac{q\sum e_k}{r} - b_i = 0$$

$$\Rightarrow$$

$$e_i = \frac{r(1-b_i) - q\sum e_k}{2q}$$

Applying symmetry:

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

Derivation of equation (18): Countries' Reaction Functions and Equilibrium of the Two-player Case when S = *0.5*

$$\max \; pqe_i(o)\left[K - \frac{Kqe(o)}{r}\right] - ce_i(o) - \frac{\gamma_2}{1-Z_i}$$

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

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

$$\text{FOC: } -\frac{rc^2}{2pq^2K}\frac{1}{\left[\frac{1-Z_i}{2} + \frac{1-Z_j}{2}\right]^3} + \frac{1}{\left[\frac{1-Z_i}{2} + \frac{1-Z_j}{2}\right]^2}\left(\frac{cr}{4q} + \frac{c^2r}{4pq^2K}\right)$$

$$-\frac{\gamma_2}{(1-Z_i)^2} = 0$$

Applying symmetry $Z_i = Z_j$ yields the equilibrium:

$$Z_i^{S=0.5} = Z_j^{S=0.5} = 1 - \frac{c^2 r}{2pq^2K\left[\frac{cr}{4q} + \frac{c^2 r}{4pq^2K} - \gamma_2\right]}.$$

Derivation of equation (20): Countries' Reaction Functions and Equilibrium of the Two-player Case when S = *1*

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

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

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

Applying symmetry again yields the equilibrium:

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