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Potential Gains from Cooperation for Vessels and Countries

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Abstract *In this paper, we consider a model in which fishing boats or firms share the stock of fish in a fishing ground. The catches made by each firm reduce the stock available for the rest of the firms, which directly affects their profits. We aim to quantify in a static framework the gain in welfare obtained by the firms if they decide to cooperate in order to attain an individually rational efficient outcome. One of the main results is that, both the incentives for the firms to cooperate and the minimum level of catches which permits any gain in welfare decrease as real wage increases. On the other hand, the greater the asymmetry among boats or firms, the more difficult it will be to reach any cooperative agreement.*

Key words Cooperation, economic theory, fishery.

Introduction

Even though there are some relevant exceptions, the main bioeconomic models used in the analysis of the management of fisheries usually suppose that the catches made by each firm or country affect the profit of other countries or firms only through the future variation in the size of the stock of fish in the grounds. In this way, the catches made by firms are not considered to be interdependent at the same moment, as the non-existence of congestion in using fishing resources is implicitly accepted. Interdependence among firms only occurs in the usual models as a factor which determines in part, the size of future available stock for them all, and therefore, their profits.[1]

In this paper, we consider the possibility that the catches made by each firm in period *t* affect the rest of the firms' profits also in *t*, that is to say, that the catches of each firm diminish the possibilities of exploitation of the resource by all the other firms at the same moment. In this manner, we will suppose that each firm does not consider the catches of rival firms to be insignificant, but that they take them into account and incorporate them into the problem of the firm's decision, precisely through their function of catches.

The objective of this paper is to quantify, in a static model, the potential gain in

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[1] See Clark (1976) or McKelvey (1983).

welfare of different boats competing for a stock of fish, if they decide to cooperate in order to reach an efficient solution which provides each boat a higher profit respect to a noncooperative situation, or in other words, a rational individually efficient solution or belonging to the core.[2] On the other hand, we calculate the interval within which the maximum number of allowable catches should be contained in order to maintain a biological equilibrium in such a way that there exist solutions, efficient or not, for which it is possible to reach greater individual profits as far as the noncooperative equilibrium is concerned.

In the following sections, we set out the general model of competition, when the players are boats, and we get the result that noncooperative catches exceed efficient ones, and even more so if there exist an effective restriction on maximum allowable catches. Subsequently, we set forth the problems involved if instead of considering the vessels as competitors, we regard countries or different groups of vessels taken by nationality, obtaining the result that the functions of national or aggregated catches undervalues the total number of catches carried out by the vessels of the country, to the effect that the national quotas laid down under an agreement differ from the efficient quotas. Finally, we put forward a concrete model and simulate the results for different values of real costs, as well as the rates of efficiency that may characterize the competitors, and compare the conclusions reached.

The Noncooperative Equilibrium

Let us suppose that there exist n vessels, or alternatively, n firms. Each of these aims to maximize its profit given a function of catches

$$\begin{gathered} \max\ B_i = ph_i - wE_i \\ \text{s.t.}\ \ h_i = f_i(E_i; X - \textstyle\sum_{i \neq j} h_j) \\ i, j = 1, 2, \ldots, n \end{gathered} \tag{1}$$

where p is the competitive price of the fish, w is the average competitive price of the inputs, E_i is the fishing effort of i (number of workers, number of boats, *etc.*), h_i are the catches of i, X is the stock of fish, and $\Sigma_{i \neq j} h_j$ are the catches of the competing firms.

Let us suppose that the catches of firm i increase with the fishing effort of i, in the same way as the difference between the stock of fish and the catches of rival firms. On the other hand, if $X = 0$ or $E_i = 0$, then $h_i = 0$. Let us also suppose that h_i is concave in its two arguments. It can be seen that the profit of i decreases with the catches of rivals, at an increasing rate. In this way, the catches of rival firms exert a negative effect on the profits of firm i. Besides this, i's profits, B_i, vary drastically when its rivals' catches are great in relation to the stock, X.

Obtaining L_i as a function of h_i and $X - \Sigma_{i \neq j} h_j$, the profit of firm i

$$ph_i - wg_i(h_i; X - \textstyle\sum_{i \neq j} h_j) \tag{2}$$

Let us suppose that B_i is strictly concave in h_i. In this case, in order that catches h_i should be a maximum of i's profits, it is a necessary and sufficient condition that the marginal profit of firm i should be equal to zero. From this condition we can ob-

[2] See Friedman (1991) and Shubik (1959).

tain the reaction function of firm i as a function of the rival firms' catches

$$\frac{\partial B_i}{\partial h_i} = 0 \Rightarrow h_i = R_i\left(\sum_{i \neq j} h_j\right) \tag{3}$$

In the same way we would obtain the reaction functions of the $n - 1$ remaining firms. Solving the system of n equations formed by the reaction functions of the firms, we would obtain the Nash equilibrium or noncooperative equilibrium in this model

$$(h_1^*; h_2^*; \ldots; h_n^*)$$

Under the considered assumptions concerning the profit functions, a unique equilibrium exists.[3] On the other hand, the equilibrium would give each firm an individual profit, B_i^*.

The Cooperative Solution

Let us now suppose the existence of a social planner that maximizes the sum of the individual profits weighted by a determined constant

$$\max \sum_{i=1}^{n} \alpha_i B_i \tag{4}$$
$$\text{s.t.} \sum_{i=1}^{n} \alpha_i = 1$$

Solving the problem we obtain the efficient combinations of catches $(h_1', h_2', \ldots, h_n')$, corresponding to the limit of possibilities of profits, varying the value of the weights of the firms.

Comparing the first order conditions of the problems of individual and social maximization, we can conclude that the Nash noncooperative equilibrium catches are excessive, as shown in figure 1, where B_i is the profit of firm i as a function of its catches h_i, and of the catches of its rivals, h_j in the figure. Thus, given a number of catches, h_j, the individual maximization by the firm would lead to a number of catches h_i^*, whereas the planner would dictate a number of catches h_i'.

In this way, in the noncooperative equilibrium, firms are not aware of the repercussions that their catches have on their rivals' profits. If such externalities were internalized through the joint maximization of profits, as done by the social planner, firms could place themselves at the limit of profit possibilities, and could obtain individual profits superior to those in the Nash equilibrium. This situation is shown in figure 2, for the case of two firms, where $(B_i'; B_j')$ are the profits of i, j in some efficient outcome $(h_i'; h_j')$.

In the model previously specified, the planner does not take into account the biological equilibrium. However, the stock of fish in a period t would be

$$X_t = X_{t-1} - \sum_{i=1}^{n} h_i^t + F(X) \quad t = 1, 2, \ldots \tag{5}$$

that is, X_t would coincide with the previous period's stock plus the natural growth of the stock $F(X)$, minus the total of catches carried out by firms in t.

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[3] See Friedman (1983), Friedman (1991), and Shapiro (1989).

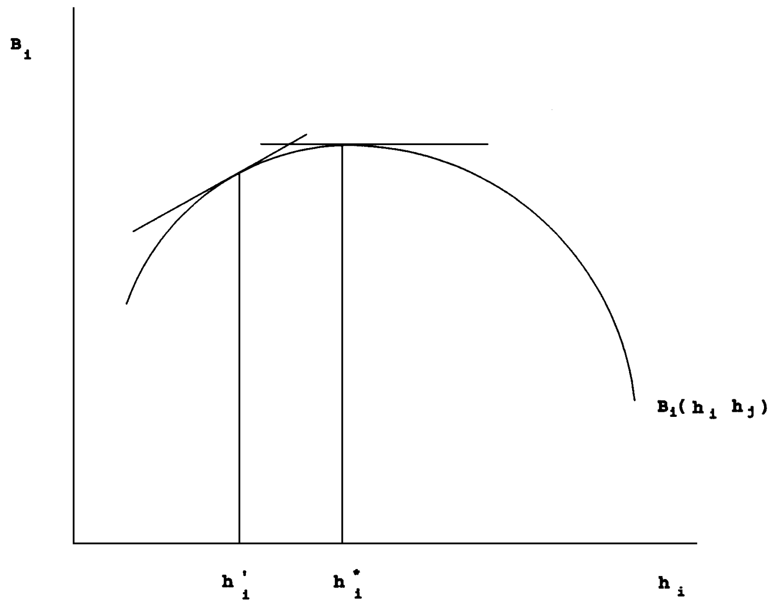

Figure 1. Noncooperative and Cooperative Equilibria

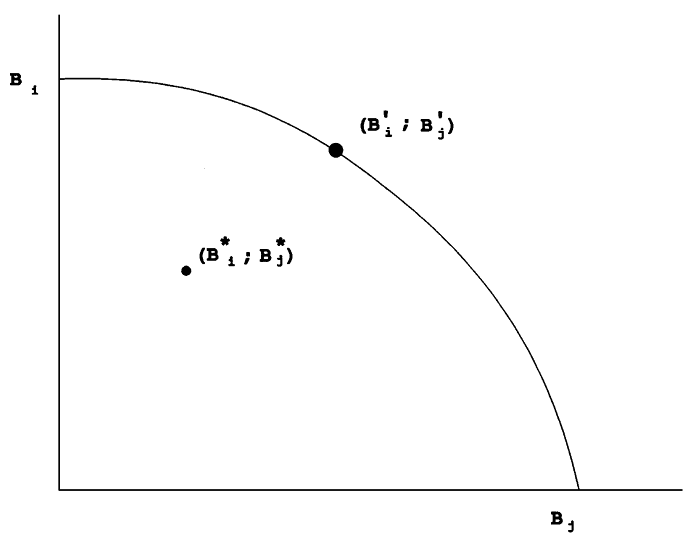

Figure 2. Firms' Profits in Efficient and Inefficient Outcomes

In a biological equilibrium, the stock of fish is invariable throughout time, that is, $X_t = X_{t-1}$ and therefore

$$F(X) = \sum_{i=1}^{n} h_i^t \qquad t = 1, 2, \ldots \tag{6}$$

This restriction should be incorporated into the problem to be solved by the planner if it is logically desired that the stock of fish does not diminish with time.

On the other hand, and as reflected in figure 2, not all the efficient combinations of catches imply a gain in welfare for all the firms simultaneously, with regard to the profits obtained in the Nash equilibrium. Therefore, in order to reach a cooperative agreement it could be necessary, as a starting point in negotiations, to obtain individual profits superior to the corresponding ones in the Nash equilibrium: to obtain an individually rational solution for all the firms. Accepting this fact, the planner should incorporate in the problem n restrictions of the type

$$B_i \geq B_i^*$$

Quantity B_i being the profits of firm i corresponding to efficient catches.

In this case, it can be assured that the individual catches, the solution to the planner's problem, would be even less than the catches corresponding to the problem of the planner without restrictions. That is to say, the marginal profit of firm i in the restricted optimum would be positive and greater than the marginal profit in the optimum without restrictions (as represented in figure 3), where h_i'' is the catch of firm i, the solution to the planner's problem with restrictions.

Once we have solved the problem of the planner, we will have at our disposal, for different combinations of weights, the individual efficient catches (h_1'', h_2'', ..., h_n''). If the vessels belong to a group m of countries, the international distribution of quotas resulting from an agreement is obvious: each country could benefit from a quota equal to the sum of the efficient catches of its vessels. Apart from this, the problem of the redistribution of the quota among the national firms is already solved.

Competition and Cooperation When Competitors are Countries

If the competition is between m countries, the logical method would be to start from national functions of catches like the following

$$h^i = f^i(E^i; X - \sum_{j \neq i}^{m} h^j) \qquad i, j = 1, 2, \ldots, m \tag{7}$$

where the superscripts refer to the country in question. Thus, h^i would be the total number of catches of country i; the first argument of the function would be the total of the variable factors used in country i; the second argument of the function would be the total stock of fish minus the catches of rival countries.

The step from considering firms as competitors, to considering their countries of origin as being so, presents a series of problems difficult to solve.

The function of catches of each country depends on the stock of fish minus the total number of catches of the other countries. In this way, it is supposed that the vessels of the same country do not compete among themselves, but rather would have a reaction function not on rival vessels in general, but only on those of other countries. This would mean that we suppose that each vessel of one country calcu-

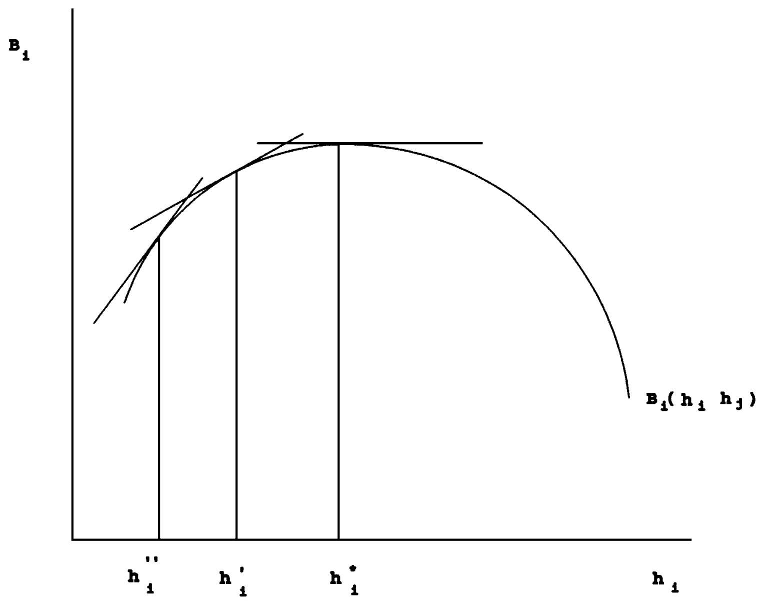

Figure 3. Solution to the Planner's Problem with Restrictions

lates the catches of the other vessels of that country as zero, which is quite doubtful, especially if the dimension of the rest of the national vessels is not insignificant, or if the grounds are small in area.

The function of national catches also depends on the variable factors used in the country, E^i. However if all vessels had the same technology, if the running costs of the firms are strictly convex, or, what comes to the same thing, if for each firm there are decreasing marginal returns on the variable factor, then the first argument of f^i should be different from the sum of the variable factor used by all the firms in the country.

For example, let us say that there are two vessels in country j, each with a function of catches:

$$h_1^j = (E_i^j)^{1/2} \, (X - \textstyle\sum_{i \neq j}^m h^i)^{1/2} \tag{8}$$

where the unrealistic assumption that each vessel only competes with foreign firms has been incorporated. Then,

$$\begin{aligned} h_1^j = h_2^j = h^j &= (E_1^j)^{1/2} \, (X - \textstyle\sum_{i \neq j}^m h^i)^{1/2} + (E_2^j)^{1/2} \, (X - \textstyle\sum_{i \neq j}^m h^i)^{1/2} \\ &= (X - \textstyle\sum_{i \neq j}^m h^i)^{1/2} \left[(E_1^j)^{1/2} + (E_2^j)^{1/2} \right] > (E_1^j + E_2^j)^{1/2} \, (X - \textstyle\sum_{i \neq j}^m h^i)^{1/2} \end{aligned} \tag{9}$$

The national catches are greater than those established by the "aggregated" function.

On the other hand, if each vessel presents constant marginal returns on the variable factor, the first argument of f^i would be, in fact, the sum of the variable factors used by all the vessels of the country, although in this case each firm's problem would not have a defined solution.

Therefore, if the planner maximizes the weighted sum of the profits of the m countries, based on functions of national catches as previously designed, in general the solutions (h^1, h^2, …, h^m) will differ from the first-best solutions ($\Sigma h_i^{1\prime\prime}$, $\Sigma h_i^{2\prime\prime}$, …, $\Sigma h_i^{m\prime\prime}$).

Simulation of the Model

In this section we shall set forth concrete functional forms for the agents' catches, and calculate the Nash equilibrium, h^*, as well as the ideal points for each firm or extremes of the core, that is to say, those combinations of efficient catches which provide each firm with the maximum possible profit if its rivals maintain their Nash profits. We will also calculate the minimum combination of quantities which will provide each firm with the noncooperative profit, h^-. In this way, the dimension of the area of cooperation is quantified and an interval of maximum allowable catches which respects a biological equilibrium may be obtained, while maintaining welfare profits for all firms. In the case of two firms, the area of cooperation is shown in figure 4.

The curves described in figure 4 are isoprofit curves for the firms. Thus, the curve marked B_1^* represents all the combinations of catches, (h_1, h_2), which provide the firm 1 with the Nash, or noncooperative profit. The curve marked B_1' shows all the combinations of catches, (h_1, h_2), which provide firm 1 a B_1' profit. On the other hand, with the functions we will use, $B_1^G > B_1' > B_1^*$. For firm 2, we use $B_2^F > B_2' > B_2^*$.

Point h^* represents the Nash equilibrium, where each firm receives a profit, B_i^*. Point h' is an efficient combination of catches, as would be that which, for example, maximizes the sum of the profits of both firms, each obtaining B_i'. Point F is the ideal point for firm 2—it is the combination of catches which offers firm 1 the Nash profit, B_i^*, and firm 2 the maximum possible profit compatible with an efficient situation, B_2^F. Point G is the ideal point for firm 1. The combination of catches h^- marks the lowest extreme of the lens, and in this case, the firms obtain the noncooperative profit.

Let A+ be the sum of catches taken by the firms in h^*, and A– be the sum of

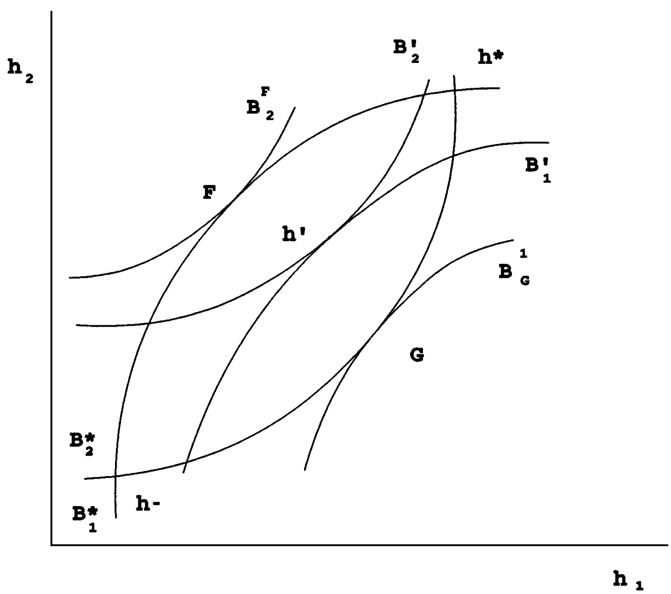

Figure 4. Two Firms Cooperation Area

catches in h^{-}. If the allowable maximum number of catches exceeds A+ , the firms may reach either the Nash equilibrium or any individually rational efficient solution either belonging to the core like h', F, G, or some other combination of catches within the lens. If the allowable maximum number of catches is inferior to A+ and superior to A–, the firms still have incentives to cooperate if they agree to stay in the interior of the lens. If the maximum number of allowable number of catches is inferior to A–, there are no incentives to cooperate, let alone accept restrictions since the profits obtained in this case are inferior to those of the noncooperative equilibrium.

We propose to quantify figure 4 in the following pages.

Following the specified model, let there be n firms competing in grounds with X stock of fish. Let us suppose that the function of catches for vessel i is the following

$$h_i = a_i E_i^{1/2} (X - \textstyle\sum_{i \neq j}^{n} h_j)^{1/2} \qquad a_i > 0 \tag{10}$$

The catches for each boat depend positively on the fishing effort, E_i, as well as the stock of fish available. In addition, the function of catches is concave in both its arguments.

Parameter a_i differentiates the boats as to their efficiency in catches, so that if a_i is greater than a_j, firm i makes greater catches than firm j for the same amount of variable factors and stock. In this way, the parameter a_i reflects the possible differentiation of technology among firms.

The function of catches used in the simulation is relatively simple and includes those desirable assumptions which ensure the existence and uniqueness of equilibrium. However, the calculation, especially of efficient allocations, is very difficult, so we have simplified the simulation using only two firms, 1 and 2, with parameters of efficiency a_1 and a_2, respectively.

In the absence of cooperation, each firm maximizes its profits, given the catches of the rival firm. The reaction functions and the equilibrium quantities have the following expressions

$$h_i = \frac{a_i^2 p(X - h_j)}{2w} \tag{11}$$

$$h_i^* = \frac{a_i^2 pX(2w - a_j^2 p)}{4w^2 - a_i^2 a_j^2 p^2} \qquad i, j, = 1, 2 \tag{12}$$

For strictly positive values of a_i, p, and X, the quantities of equilibrium will be positive if

$$a_i^2 p < 2w \qquad i = 1, 2 \tag{13}$$

These are conditions which we shall impose in the simulation and which also guarantee the stability of the Nash equilibrium.

It can be seen as in symmetric cases, where $a_1 = a_2$, the individual catches in equilibrium diminish with the increase of real wage.[4] On the other hand, given a level of prices, the individual noncooperative profits also diminish as w/p increases.

[4] w is the average competitive price of factors included under the fishing effort variable. For simplicity, we will use the word “wage” to name w.

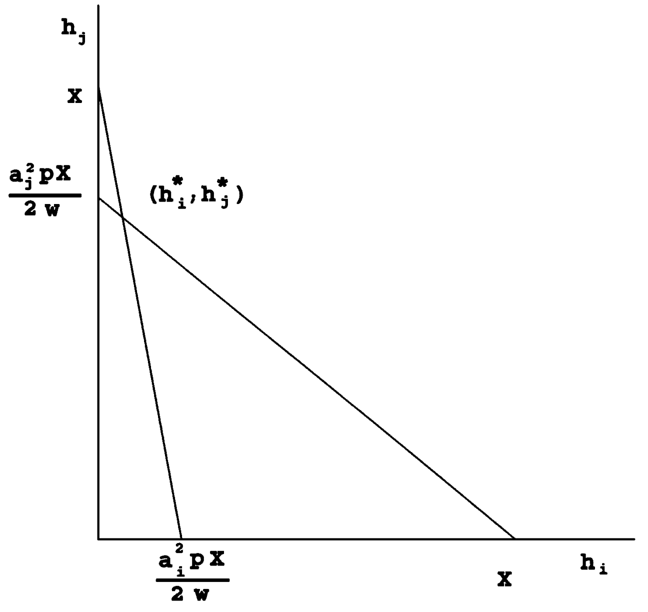

Figure 5. Noncooperation Catches in an Asymmetric Case

Besides this, given a wage and a price level, the Nash profits and the individual catches in equilibrium increase with the parameter of efficiency of the firms. In the asymmetric cases, these results are only obtained by determined values of the considered variables.

Furthermore, in equilibrium the catches and profits of each vessel depend positively on its own efficiency parameter and negatively on that of the rival vessel. On the other hand, the asymmetry of catches and profits of the vessels will be greater the greater the difference between a_i and a_j. On the contrary, if $a_i = a_j$, the two vessels will have equal catches and profits in equilibrium. In figure 5, the reaction functions and the Nash equilibrium for the case $a_i < a_j$ are shown.

Let us examine in some detail the results of the simulation.

We have observed two symmetric cases, ($a_1 = 1$, $a_2 = 1$), ($a_1 = 2$, $a_2 = 2$) and three asymmetric cases: ($a_1 = 0.5$, $a_2 = 1.5$), ($a_1 = 0.5$, $a_2 = 2$), ($a_1 = 0.5$, $a_2 = 3$), but for simplicity, we will only show one symmetric case and one asymmetric case. All the values of catches appear in function of the stock, X. On the other hand, the catches depend on the real wage, w/p, but not on the value of the wage and the prices separately. For this reason, the real wage is used as a variable in the simulation. The profits depend on the values reached by w, y, and p, although the foreseen profit increase only depends on the real wage.

In table 1 it is supposed that $a_1 = a_2 = 1$ and for different values of the real wage, w/p, the Nash equilibrium, h^*, is obtained, as well as the ideal points for the firms, points F and G. In the symmetric cases, point F, or the efficient point where firm 2 has the maximum profit since firm 1 reaches the noncooperative profit, is exactly the opposite of point G, that is, $h_1^F = h_2^G$, $h_2^F = h_1^G$. The lowest extreme of the lens, h^-, is also obtained; that is the combinations of catches that, without being an equilibrium, gives each firm the Nash profit. The gain in welfare is also quantified, as firm 1 goes from point F, with B_1^* profit, to point G at percentage terms, which is identical to the gain of firm 2 as it goes from G to F.

Table 1
Upper and Lower Points of the Lens, Ideal Points and Gains from Cooperation ($a_1 = a_2 = 1$)

w/p	h_i^*	$(h_1^G; h_2^G) = (h_2^F; h_1^F)$	h_i^-	$(B_1^G - B_1^*)/B_1^* \cdot 100 = (B_2^F - B_2^*)/B_2^* \cdot 100$
1	0.3333X	(0.3068X; 0.2788X)	0.2500X	5.7734
2	0.2000X	(0.1882X; 0.1784X)	0.1667X	1.9710
3	0.1429X	(0.1363X; 0.1314X)	0.1250X	0.9893
5	0.0909X	(0.0880X; 0.0861X)	0.0833X	0.3959
10	0.0476X	(0.0468X; 0.0462X)	0.0455X	0.1075
100	0.004975X	(0.004965X; 0.00496X)	0.004950X	0.0011

In table 2, the values of weights of firm 1, which should be included in the Welfare Function of the planner to reach points F and G, alternatively, are related.

In table 3, the levels of maximum allowable catches which permit any gain in welfare appear. Thus, if the maximum allowable catches exceed A+, any individually rational solution, efficient or not, may be reached in a cooperative way. If the allowable catches are inferior to A–, cooperation is not possible.

It can be observed how, given a value of $a_1 = a_2$, the greater w/p, the smaller h_i^* and h_i^-. The coordinates of points F and G are also smaller. In this way, we could say that the zone of cooperation moves toward the origin of coordinates. Logically, both A+ and A–, and also the percentage difference between them, are smaller the greater the real wage.

On the other hand, the distance[5] between points F and G diminishes as w/p increases, that is to say, the lens narrows. The distance between points h^* and h^- is also reduced when the real wage is greater (the lens shortens). In this way, the dimensions of area of cooperation are reduced as the real wage increases.

As the welfare gains of the firms reach their ideal point, they are reduced as w/p increases (these gains are recorded in the last column of table 1). Therefore, the Nash profits of the firms decrease as the real wage increases, so that the difference between noncooperative profit and profit corresponding to the ideal point of each firm is reduced; that is, the combination of noncooperative profits is nearer and nearer to the limit of profit possibilities. Therefore it can be said that the incentives for the firms to cooperate depend negatively on real wage.

Moreover, given a real wage, the greater the efficiency parameter of the firms, the greater are h^* and h^- and also F and G (the lens moves in the opposite direction to the origin of the coordinates). The distance between h^* and h–, and between F and G, also increases (the lens lengthens and widens, the dimension of the area of cooperation is greater).

The limits of the interval of total catches which would permit any cooperation gain, A+ and A–, increase with the efficiency parameter. So, for example, at a real wage 3, with efficiency parameter equal to 1, and the permitted catches equal to 28.58% of X, the firms could obtain cooperative gains simultaneously. However, if the parameter of efficiency is 2, the total number of catches to ensure any cooperative gain would have to be 80.00% of X.

Finally we may conclude that the greater the efficiency parameter of the firms, the farther from the profit possibilities limit are the allocations of noncooperative

[5] The distance between two points with coordinates $(x_1; x_2)$ and $(y_1; y_2)$ has the following expression $d = \sqrt{(x_1 - y_1)^2 + (x_2 - y_2)^2}$.

Table 2
Weights of Firm 1 in F and G ($a_1 = a_2 = 1$)

w/p	1	2	3	5	10	100
α_1^F	0.4802	0.4648	0.4582	0.4523	0.4475	0.4430
α_1^G	0.5198	0.5352	0.5418	0.5477	0.5525	0.5570

Table 3
Total Allowable Catches, A+ and A– ($a_1 = a_2 = 1$)

w/p	1	2	3	5	10	100
A+	$0.6666X$	$0.4000X$	$0.2858X$	$0.1818X$	$0.0952X$	$0.00995X$
A–	$0.5000X$	$0.3334X$	$0.2500X$	$0.1666X$	$0.0910X$	$0.0099X$

Table 4
Upper and Lower Points of the Lens ($a_1 = 0.5$, $a_2 = 1.5$)

w/p	$(h_1^*;\ h_2^*)$	$(h_1^-,\ h_2^-)$
2	$(0.0283X;\ 0.5466X)$	$(0.0220X;\ 0.5059X)$
3	$(0.0264X;\ 0.3651X)$	$(0.0223X;\ 0.3429X)$
5	$(0.0195X;\ 0.2206X)$	$(0.0176X;\ 0.2113X)$
10	$(0.0111X;\ 0.1113X)$	$(0.0105X;\ 0.1086X)$
80	$(0.00154X;\ 0.01403X)$	$(0.001532X;\ 0.014X)$

profit, so that the incentives for the two firms to cooperate increase with the parameter of efficiency. In this way, the Nash profits grow with the firms' productivity, so that the difference between the noncooperative profit and the profit which corresponds to the ideal point of each firm should increase with the parameter of efficiency.

Tables 4 to 7 show the results obtained for the asymmetric case. It can be seen that, given a_1 and a_2, the greater w/p the less the distance between h^* and h– (the lens shortens). Also, the differences between h_1^* and h_2^*, and h_1^- and h_2^- are reduced, with a tendency towards a greater symmetry in the allocations which provide the noncooperative profits. Moreover, the distance between F and G also diminishes, so that the lens narrows. Besides this, there is again a tendency towards a smaller difference between individual catches corresponding to each ideal point.

As to the maximum gains in welfare attainable by the firms if they decide to cooperate, the gains of firm 2 (the more efficient), when situated in its ideal point, are reduced in general as w/p increases. The Nash profit of firm 2 decreases in w, given a price level p, for which the last column of table 5 shows how, as w/p increases, the allocation of noncooperative profits is nearer and nearer to the allocation of profits corresponding to the ideal point of firm 2. In this way, the incentives for firm 2 to cooperate diminish. In the case of firm 1, given p and with the increase of w, its noncooperative profits may increase, or on the contrary, descend, so that the incentives for its cooperation do not have a clear relation with real wage.

Table 5
Ideal Points and Gains from Cooperation ($a_1 = 0.5$, $a_2 = 1.5$)

w/p	$(h_1^F;\ h_2^F)$	$(h_1^G;\ h_2^G)$	$(B_1^G - B_1^*)/B_1^* \cdot 100 = (B_2^F - B_2^*)/B_2^* \cdot 100$
2	(0.0241X; 0.5318X)	(0.0261X; 0.5216X)	3.809 0.342
3	(0.0237X; 0.3567X)	(0.0249X; 0.3512X)	1.569 0.212
5	(0.0183X; 0.2170X)	(0.0188X; 0.2148X)	0.550 0.095
10	(0.0107X; 0.1102X)	(0.0109X; 0.1100X)	0.137 0.028
80	(0.001534X; 0.014023X)	(0.001536X; 0.014013X)	0.013 0.001

Table 6
Weights of Firm 1 in F and G ($a_1 = 0.5$, $a_2 = 1.5$)

w/p	2	3	5	10	80
α_1^F	0.5974	0.6098	0.6163	0.6199	0.6226
α_1^G	0.6677	0.6902	0.7049	0.7147	0.7229

Table 7
Total Allowable Catches, A+ and A– ($a_1 = 0.5$, $a_2 = 1.5$)

w/p	2	3	5	10	80
A+	0.5749X	0.3915X	0.2401X	0.1224X	0.01557X
A–	0.5279X	0.3652X	0.2289X	0.1191X	0.01553X

The conclusions drawn from the symmetric cases about A+ and A– are the same.

As to the weights of firms in their ideal points, we observe that the weights of firm 1 (the less productive), both in F or G, increase with the real wage. In this way, the importance that the planner must give this firm is greater and greater if a solution in the core is desired. On the contrary, the weights corresponding to firm 2 (or the more efficient), being situated in the ideal point F, or alternatively in G, decrease with the real wage. Furthermore, notice how the weight of firm 1 always exceeds 0.5, while those of firm 2 never reach this value, so the efficient solutions which would result in identical weights for the firms do not belong to the core.

Moreover, given w/p, the greater a_2, the greater are the equilibrium catches of firm 2, the same as A+ and A–. Also it can be shown that, given w/p, the greater a_2 the higher is the noncooperative profit of firm 2 and the lower the profit in equilibrium of firm 1. The welfare gains of firm 1 increase with a_2, but the gains of firm 2 increase in some cases and decrease in others. The incentives to cooperate, measured as the difference between the Nash profit and the ideal profit, do not have a clear connection with the differences of efficiency between firms.

Conclusion

The principal aim of this paper has been to quantify the area of cooperation and the welfare gains to be obtained by firms if they decide to cooperate, reducing their catches with the object of individually increasing their profits. To this end, we have used determined functions of catches and we have analyzed two cases: one symmetrical and one asymmetrical. The results depend, obviously, on the functions used, and this should be taken into account when making any normative consideration.

As was to be expected, the results in the symmetrical case showed greater consistency than in the asymmetrical one. Therefore, we have been able to observe how, in the symmetrical case, the lower the real wage, the greater the incentive for firms to cooperate. Although in the symmetrical case, the minimum number of total catches A+, which guarantees any individually rational efficient solution, could be very high. What is more, the greater the firms' productivity, the greater the incentives to cooperate, but again in this case, A+ may be very high. We can then conclude that there is a negative relation between the incentives for firms to cooperate and the level of the total number of catches which would allow any individually rational efficient allocation. Therefore, if the limitations on catches are great, cooperation may lack adequate incentives for firms.

In the asymmetrical case, our results indicate that the incentives to cooperate for the firm with most catches are fewer, when the real wage is greater. In all the cases we examined, however, the maximum gains in cooperation for the most productive firm are very low (never reaching 0.5%) because the asymmetry of catches situates such a firm very near the limit of possible profits. In the asymmetrical cases, therefore, and the greater the asymmetry among the firms, it could be very difficult to establish any kind of agreement, especially if it is costly.

Summing up, the incentives for firms to cooperate may be very small, especially if real wage is high. If, besides this, the restrictions on catches are heavy, there could be no incentive to cooperate. Thus, to reach an agreement to limit catches would require, in a large number of situations, another type of argument to incorporate in the objective functions of the agents implied.

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