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Bankruptcy of Fishing Resources: The Northern European Anglerfish Fishery

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Abstract *Since 1983 the Northern European anglerfish fishery, exploited by fleets of seven countries, has been regulated using a policy of Total Allowable Catch (TAC). In this paper, the strategy followed by the European Union (EU) in distributing the established TAC among the seven countries is explored. It is inferred that the EU has utilized a weighted proportional rule, taking the average catches for the period l973–78 as the reference point. On the other hand, given that the fishery situation for the years 1993, 1994, and 1995 can be characterized as a bankruptcy problem, this paper also explores, as possible means of enriching the Common European Fishery policy, alternatives to this rule. This work proposes the application of two additional rules derived from game theory, the nucleolus and the Shapley value, and studies their properties. The analysis suggests that it may be worth considering not only the proportional distribution, but also the alternative rules.*

Key words Fishing regulation, bankruptcy problem, Shapley value, nucleolus, proportional rule.

JEL Classification Codes Q20, Q22, Q28.

Introduction

One important consideration in the regulation of a fishery is the distribution of a Total Allowable Catch (*TAC*) among the different countries that are exploiting the species under control. This paper analyzes this issue on the Northern European anglerfish fishery in detail. The choice of this case study was based on several points.

The first motivating factor was the availability of detailed data. It was possible to obtain valuable information on the distribution of *TAC* among the countries exploiting the Northern European anglerfish fishery. This information allowed to infer the rule used by the EU in distributing the *TAC*. The sample has also shown the unfair treatment suffered by some of the countries involved.

The second motivation was that the size of the sample (which involves just

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seven countries) provided the opportunity to compare and contrast the traditional proportional rule with two of the rules most frequently studied in theoretical cooperative game literature: the Shapley value and the nucleolus. See Kaitala and Lindroos (1998) and Li (1999) for other applications of cooperative game theory to fishing problems.

Finally, given that the European Common Fishery Policy will soon be renewed, the considerations suggested in this paper could be useful for such a revision.

The paper is organized as follows. The second section looks, in detail, at the current state and management of the Northern European anglerfish fishery. The third section explores how the current quotas are allocated within the fishery. This is then followed, in the fourth section, by a formal representation of the fishing bankruptcy problem and three potential solutions: the proportional rule, the nucleolus, and the Shapley value. Included within this discussion is the analysis of the key desirable properties that any rule applied to this context should fulfill. The fifth section shows the application of the three rules to the data of the Northern European anglerfish fishery. Some closing comments and an explanatory appendix conclude the paper.

The Northern European Anglerfish Fishery

The Northern European anglerfish fishery was developed in the mid-70s from the bycatch of a fleet targeting hake. The fishery lies in the same International Council for the Exploitation of the Sea (ICES) administrative divisions as the European hake fishery, which according to the current divisions within the European Atlantic Fisheries, divides the fishery into two independent stocks: southern and northern. This paper focuses on the northern stock, which covers the ICES divisions VII b-k and VIII a, b, d and e, including western Ireland, the Bay of Biscay, and the Celtic Sea (see figure 1).

Anglerfish are properly divided into two sub-species, white anglerfish (*Lophius piscatorius*) and black anglerfish (*Lophius budegasa*). The latter has a southern geographical distribution, extending from Great Britain to Senegal, and lives in waters up to 500 meters deep, while the white anglerfish has a wider geographical distribution (extending from the Barents Sea to Spanish waters) and can be found in deeper waters. Landings of these species during the last six years have been composed of two-thirds white anglerfish and one-third black anglerfish, although a relative increase in the landings of black anglerfish has been observed over the last two years.

Anglerfish are harvested mainly by an otter trawl fleet, which is the most common type in French, Spanish, and Irish fleets. Some other gears, such as the beam trawl and gill nets, are also used, especially in the United Kingdom.

The European hake fishery has, in recent years, suffered from a stock collapse. This implies that the anglerfish fishery has grown in importance. There has been both a transfer of fishing effort from hake to anglerfish and a growth in the relative economic importance of the last species.

From data on harvests for this stock (see table 1) it is evident that seven countries operate within this fishery: France, the United Kingdom, Belgium, Spain, Ireland, Germany, and the Netherlands. Five of them are relatively important, while Germany and the Netherlands exploit a smaller proportion of the resource. Table 1 presents the average harvest rates of anglerfish for the periods 1973–78, 1982–85, and 1986–93. Note that the data for Spain is incomplete since it has only been a member of the EU since l986.

The European Common Fisheries Policy relies mainly on *TAC* and quota regulation, and although these mechanisms can work well in some situations, there are two

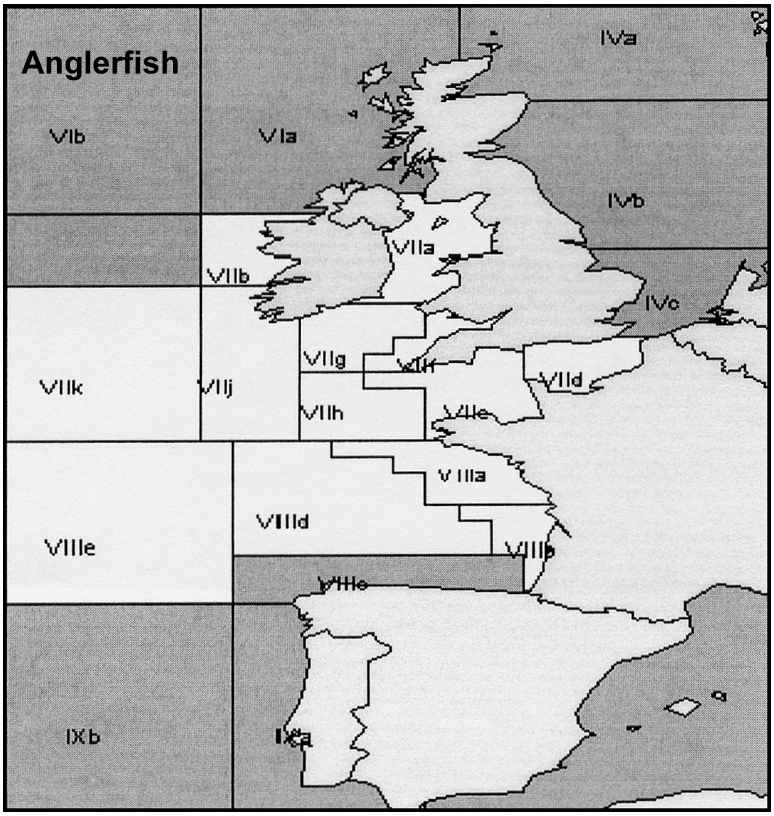

Figure 1. Area Studied (including ICES divisions)

Table 1
Historical Harvest Rates of Anglerfish in Tons and Percentage

Country	Average 1973–78		Average 1982–85		Average 1986–93	
Belgium	1,760	7%	2,087	8%	927	3%
Germany	203	1%	62	0%	158	1%
Spain	(n.a.)	(n.a.)	(n.a.)	(n.a.)	(n.a.)	(n.a.)
France	16,811	66%	18,717	71%	13,952	50%
Ireland	288	1%	1,522	6%	2,196	8%
The Netherlands	380	1%	180	1%	299	1%
U.K.	4,560	18%	3,941	15%	4,380	16%
TOTAL	25,474	100%	26,509	100%	28,120	100%

Source: ICES (several documents) and FAO statistics.

important problems that have to be resolved before implementing this policy. The first is deciding on the size of the *TAC*, and the second is determining what quotas to allocate to the different countries exploiting the fishery. The next section explores these problems in detail.

TAC Determination

The EU first introduced an anglerfish *TAC* in 1983. This *TAC* was “precautionary;” that is, it was based on general knowledge, not on scientific information about the condition of the stocks within the fishery. This procedure lasted until l993, when a lower *TAC*, based on scientific information, was approved.

At this stage, it makes sense to check whether the *TAC*s implemented after 1993 (the analysis of the Northern European anglerfish fishery bankruptcy is carried out on data post-1993) can be supported by bioeconomic models. The *TAC*s implemented by the EU for the period 1983–99 are reported in tables 2(a) and 2(b). Notice that these figures correspond to the sum of white and black anglerfish. On the other hand, in Prellezo (2000) the optimal harvest estimated for anglerfish is 14,507 tons. This estimation is only for the white stock; hence, it is not possible to make a direct comparison between them. During the last six years, landings have been composed of two thirds of white anglerfish and one third of black. Thus, it is possible to conclude that for l993–94 and l995 the established *TAC*s of 23,800 and 23,140 tons, respectively, were not far from the estimated optimal figure. After l995, this conclusion no longer holds because the *TAC*s are too large.

TAC Distribution

Prior to analyzing the problem of the distribution of the *TAC* among the countries involved, two key facets of *TAC* policymaking and implementation should be considered. Firstly, it is important to recognize that the EU relies principally on the *Relative Stability Principle*. This principle is a cornerstone of the Common European Fisheries Policy and it has a clear political aim: it guarantees each Member State a fixed percentage of each fish population subject to a *TAC* policy. Secondly, when the *TAC* policy was first implemented by the European Council of Ministers, the following variables were considered decisive in the calculation of the quotas corresponding to each member state: (*i*) the amounts fished by each national fleet from l973 to 1978; (*ii*) the requirements and needs of regions whose populations depended in a special manner on fishing activities; (*iii*) the loss of fishing possibilities in international waters.

For the case of the Northern European anglerfish fishery, the existence of seven countries exploiting the resource and stock deterioration led to the application of a *TAC* policy. In its implementation, the white and black anglerfish were considered as a single resource and the quota distribution was made geographically. Tables 2(a) and 2(b) show the agreed *TAC* and the assigned quotas for anglerfish from 1980 to 1999.

From tables 2(a) and 2(b), it is evident that France has received the greatest quota allocation, while the United Kingdom, Belgium, Ireland and Spain have received considerably smaller quotas. The last column of each table shows the percentage of the quota allocation obtained by each member state in all the periods that remains fixed. Hence, the *Relative Stability Principle* has been fulfilled. How these percentages are derived, however, is worthy of further consideration.

Table 2(a)
Agreed TAC and Quotas in Tons and Percentages from 1983 to 1985

Country	1983	1984	1985	% (83, 84, 85)
Belgium	2,500	2,750	3,060	7
Germany	500	560	630	1
France	23,000	25,930	28,930	66
Ireland	2,500	2,750	3,060	6
The Netherlands	500	560	630	1
U.K.	6,000	7,000	7,810	18
TOTAL	35,000	39,550	44,120	100

Source: Council Regulations. European Commission, DGXIV.

Table 2(b)
Agreed TAC and Quotas in Tons and Percentages from 1986 to 1999

Country	1986–87	1988–92	1993–94	1995	1996	1997–99	% (1986–99)
Belgium	2,780	3,060	1,710	1,660	2,180	2,460	7
Germany	310	340	190	190	240	270	1
Spain	2,460	2,720	1,490	1,440	1,900	2,140	6
France	25,480	28,020	15,460	15,030	19,670	22,290	65
Ireland	2,280	2,510	1,400	1,360	1,790	2,020	6
The Netherlands	360	390	220	220	280	320	1
U.K.	5,410	5,950	3,330	3,240	4,240	4,800	14
TOTAL	39,080	42,990	23,800	23,140	30,300	34,300	100

Source: Council Regulations. European Commission, DGXIV.

Calculus of the Quotas

The determination of quota allocation has no simple basis. The European Council of Ministers considers historical fishing rights, the requirements of regions, and the loss of fishing possibilities in international waters as the variables in calculating the quotas, but the importance assigned to each variable is not known.

In order to establish whether the EU has utilized the traditional proportional rule for the distribution of the *TAC*, it proceeds as follows. The proportion of the *TAC* assigned to each country is compared with the proportion between the historical catches of each country and the sum of all historical catches. From this comparison two periods can be clearly distinguished.

For 1983–85 it seems quite clear that if average catches for 1973–78 are used as a reference point, then the EU did not apply a "strict" proportional rule. The data suggests that the actual quotas can be better explained by the application of the proportional rule to a context in which the claims of Ireland are greater than their historical catches.[1] (Note that Irish fisheries organizations are currently demanding higher quotas, arguing that the reference period considered was a period of very low catches for the Irish fleet [COM 2000]).

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[1] Curiously, if the Irish's claims are taken as the amount of the historical catches of Belgium and the rest of the claims are maintained, the proportional rule replicates the current quotas exactly.

After 1985, Spain entered the EU with a large fleet, and a share of the *TAC* had to be assigned to the newcomer. The rule applied by the EU from l986 onward seems to be a recalculation of the percentages in a "political" manner. That is, there has been an adjustment of the percentages so that Spain could get a share of the *TAC*. This adjustment was apparently made at the expense of the United Kingdom, which saw a decrease of four points from its previous share. All these reflections give rise to the suggestion that the current quotas for anglerfish have been calculated using a "weighted" proportional rule.

The Fishing Bankruptcy Problem

Table 1 clearly illustrates that in 1993, l994, and l995 the EU confronted what can be defined as a bankruptcy of the Northern European anglerfish fishery. The agreed *TAC* for 1993 and 1994 amounted to 23,800 tons, while the claims (the average catches for l986–93) amounted to 28,120 tons. In l995, the *TAC* was set at 23,140 tons, an amount again lower than average catches for the period considered as the reference point. Total claims were higher than the *TAC*, and this type of situation can be characterized as a bankruptcy problem. Formally, this bankruptcy problem can be formulated in the following way.

> Let $N = \{1,...,n\}$ be a set of countries involved in the distribution of a given *TAC*. Each country claims a share of the *TAC* equivalent to its historical fishing rights, which are denoted by $d_i \geq 0$. The vector of claims against the *TAC* is denoted by $d = \{d_1,\ldots,d_n\}$, and the sum of all claims is $D = \Sigma_{i\in N}\, d_i$. A fishing bankruptcy problem emerges when the *TAC* cannot give away the summation of the country claims; *i.e.*, $\Sigma_{i\in N}\, d_i > TAC$. The pair (TAC, d) is called a fishing bankruptcy problem, and B_f^N denotes the set of all fishing bankruptcy problems with N country claimants.
>
> A *division rule for a bankruptcy problem* is a function $f\colon B_f^N \to R^N$, which assigns to each $(TAC, d) \in B_f^N$ a vector $f(TAC, d)$ representing a distribution of the *TAC* between countries. Hence, $f_i(TAC, d) \geq 0$ is the quota assigned to country *i*. Only *efficient* division rules are considered; that is, $\Sigma_{i\in N}\, f_i(TAC, d) = TAC$ for all fishing bankruptcy problems.

In this paper, three efficient division rules are considered: the traditional proportional rule, the nucleolus, and the Shapley value. The last two come from cooperative game theory.

The Proportional Rule[2]

Proportional division was already a favored rule of distribution among philosophers of ancient Greece, and even now this rule is widely used in distribution problems. The proportional rule for a fishing bankruptcy problem allocates the *TAC* proportionally in accordance with the historical rights of the countries, and this seems to be the principal rule behind the EU distribution of fishing *TAC*s. The formal definition of this rule is as follows.

The proportional rule for a fishing bankruptcy problem $(TAC, d) \in B_f^N$ is:

[2] See Chun (1988) for a detailed analysis of this rule for bankruptcy problems.

$$P_{S_i}(TAC, d) = \frac{d_i}{\sum_{i \in N} d_i} TAC, \text{ for all } i = 1, ..., n. \tag{1}$$

The Shapley Value

The Shapley value is a well-known solution concept for cooperative games (Shapley 1953), whose standard formulation for a game (N, v) is the following:

$$Sh_i(N, v) = \sum_{S \subset N} \frac{(s - 1)!\,(n - s)!}{n!}\left[v(S) - v(S/\{i\})\right] \text{ for all } i = 1, ..., n, \tag{2}$$

which implies that the payoff to a player is his average marginal worth to all the coalitions in which he might participate. For bankruptcy games, the Shapley value can be easily computed according to the following procedure. Line up the country claimants in some random order. Then, starting with the first country, give each of them their entire claim until the *TAC* is exhausted. All orders are equally likely, and the Shapley value provides each country with the average payment over all possible orders.

Let us illustrate this interpretation with the numerical example used by Young (1994). Three fishing countries, A, B, and C, have claims of 100, 200, and 300 against a given *TAC* of 400. There are six possible lineups (table 3). In the ordering ABC, claimant A withdraws its full claim of 100 from the *TAC*, then B withdraws its full claim of 200, and C gets the remaining 100. The amount that each claimant receives under each ordering is then considered, and the average over the six possible orderings is 66.6 for A, 116.6 for B, and 216.6 for C, which stands for the Shapley value solution.

The Nucleolus

As previously noted, there are arguments in favor of rules other than proportional division. Aumann and Maschler (1985), for instance, argue that if the estate does not exceed the smallest claim, then equal division among creditors makes good sense. In this paper, the proposal of Aumann and Maschler that embodies this last idea is con-

Table 3
The Shapley Value

Ordering	A	B	C
ABC	100	200	100
ACB	100	0	300
BAC	100	200	100
BCA	0	200	200
CAB	100	0	300
CBA	0	100	300
Total	400	700	1,300
Average	66.66	116.6	216.66

sidered. They consider the bankruptcy problem as sharing a variable estate among a set of fixed claimants and propose a division of the estate for each possible case. It just so happens that their proposal coincides with the nucleolus (Schmeidler 1969). When applied to bankruptcy problems, the idea behind the nucleolus is that claimants tend to focus on their gains when the *TAC* to be shared is small, and on their losses when it is large.

When this solution is presented for a fishing bankruptcy problem, the country claimants are first ordered so that $d_1 \leq \ldots \leq d_n$. It will be seen that the nucleolus, denoted by η, is a solution whose formula varies depending on the relationship between the sum of claims and the estate. There are four cases. In the first two cases, the *TAC* to be distributed is small in relation to the claims ($TAC \leq D/2$).

Case 1a: $TAC \leq D/2$ and $TAC \leq nd_1/2$.

In this case, the nucleolus provides each country i with the following quota:

$$\eta_i(TAC, d) = \frac{TAC}{n}, \quad \text{for all } i = 1, \ldots, n. \tag{3}$$

Notice that the *TAC* is *so* small in relation to the sum of the claims, $TAC \leq nd_1/2$, that the nucleolus divides the *TAC* equally between the claimants.

Case 1b: $TAC \leq D/2$ and $TAC \geq nd_1/2$.

The *TAC* in this case is greater than $nd_1/2$, and the nucleolus follows this process of division: The amount $d_1/2$ is first provided to all countries and country 1 is left with $\eta_1 = d_1/2$. The remaining *TAC* is equally divided between all countries (excluding country 1) until they obtain $d_2/2$. Country 2 is left with $\eta_2 = d_2/2$, and again the remaining *TAC* is divided between the countries, excluding countries 1 and 2, until all of them obtain $d_3/2$ and so on.

In the last two cases, the *TAC* to be distributed is large in relation to the claims $TAC \geq D/2$.

Case 2a: $TAC \geq D/2$ and $TAC \leq (D - nd_1/2)$.

Here, the *TAC* is not so large, $TAC \leq (D - nd_1/2)$, and the nucleolus for this case adopts the following process of division: All claimants first receive $d_i/2$. At this time, the first creditor will have the smallest loss, $d_1/2$ (the difference between the claim and $d_1/2$). The remaining *TAC* is set aside and used to equalize the losses of the remaining claimants. The aim is to put each creditor's loss as close to $d_1/2$ as the *TAC* allows. To do this, the following procedure is used: the claimant with the greatest loss (claimant n) is awarded until its loss equalizes the loss of the $n - 1$ claimant; then, the loss of the n and $n - 1$ claimants is equalized with the loss of the $n - 2$ claimant and so on, until the *TAC* is exhausted.

Case 2b: $TAC \geq D/2$ and $TAC \geq (D - nd_1/2)$.

In this last case, the *TAC* is large enough to equalize the loss of all claimants. If some remains, then it will be equally distributed among all the claimants. This can be summarized by the following expression:

$$\eta_i(TAC, d) = \frac{TAC - D + nd_i}{n}, \text{ for all } i \in N. \tag{4}$$

This nucleolus proposal is illustrated below with a numerical example.

Example: Let d_1 = 100, d_2 = 200 and d_3 = 300, and d_4 = 400 be the country claimants. With a *TAC* = 60, *Case 1a* applies and the nucleolus provides 15 for each country. With a *TAC* = 400, *Case 1b* applies and the nucleolus is η_1 = 50, η_2 = 100, η_3 = 125, η_4 = 125. With a *TAC* = 700, *Case 2a* applies and the nucleolus provides η_1 = 50, η_2 = 116.6, η_3 = 216.6, η_4 = 316.6. Finally, with a *TAC* = 850, *Case 2b* applies and the nucleolus is η_1 = 62.5, η_2 = 162.5, η_3 = 262.5, η_4 = 362.5.

Desirable Properties for Division Rules

In this subsection, the discussion moves on to compare the three division rules considered above according to certain desirable key properties. Of course, some properties may be desirable in one context and not in another. However, this paper targets those properties believed by the authors to be relevant to the distribution of a given *TAC* between a set of country claimants. The key properties are introduced formally following Thompson (1995), preceded by a brief explanation of their contents.

No country should receive more than its claim.
This property, called *claim boundedness*, can be formulated as follows:

$$\text{For all } (TAC, d) \in B_f^N \text{ and } i \in N, f_i(TAC, d) \le d_i.$$

Two countries with equal claims should be equally awarded.
This property, called *symmetry*, is formulated as follows:

$$\text{For all } (TAC, d) \in B_f^N \text{ and all } i, j \in N, \text{ if } d_i = d_j, \text{ then } f_i(TAC, d) = f_j(TAC, d).$$

An obvious generalization of symmetry is that the rule should respect the ordering of claims. If agent *i*'s claim is at least as large as agent *j*'s claim, it should receive at least as much. Here, this property is presented as adapted to the context of the paper.

One country with a greater claim than another should not be awarded a smaller quota.
The rationality of this property, called *order preservation*, is obvious: the rule should respect the ordering of claims. That is, if country *i's* claim is greater than country *j's* claim, then the former should receive at least as much as the latter.[3]

$$\text{For all } (TAC, d) \in B_f^N \text{ and all } i, j \in N, \text{ if } d_i > d_j, \text{ then } f_i(TAC, d) \ge f_j(TAC, d).$$

Notice that these three properties imply requirements that are so obvious that one might consider only rules that satisfy them.

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[3] A stricter version of this property can be formulated. That is, any country with a greater claim than another should be awarded with a greater payoff.

If the TAC increases no country should receive less.

This property, called *net worth monotonicity*, is particularly interesting in the context of fisheries regulated via *TAC*s, since the size of each *TAC* may vary depending on the biological conditions of the resource. See, for example, the case for the anglerfish presented in table 1.[4] Formally, let $(TAC, d) \in B_f^N$ and $TAC' \in R$,

$$\text{if } \sum_{i \in N} d_i > TAC' > TAC, \text{ then } f(TAC', d) \geq f(TAC, d).$$

Historical overexploitation should not be rewarded.

Recent biological research has shown that many fish stocks are overexploited and a quota system may be established in order to rectify this situation. Some quota distribution is principally based on the historic catches of each country claimant, implying that those countries capturing more in the past are receiving greater quotas. However, are not these countries responsible for the greater part of fish stock overexploitation? One would presume so. Taking into account this observation, it seems natural to introduce an additional property that limits the claims of the countries. The understanding being that claims greater than the *TAC* will mean that a country has overexploited the fish stock. This property, called *invariance under claims truncation*, is formally defined as follows:

$$\text{For all } (TAC, d) \in B_f^N, f(TAC, d) = f(TAC, dTAC)$$
$$\text{where } dTAC = \min\{TAC, d_i\}.$$

The minimum rights of countries should be respected.

A country claimant has a *minimal right* if the difference between the *TAC* and the sum of the claims of the remaining countries is positive. The minimum right for each country is exactly this difference. It seems desirable to select a division rule that respects these minimum rights. In this case, each country would first receive the amount defined as its minimum right, and second, the quantity that results of distributing the remaining amount as in a bankruptcy problem. A numerical example may clarify the content of this property. Let $d_1 = 100$, $d_2 = 200$, $d_3 = 300$, and $d_4 = 400$ be the country claimants. With a $TAC = 700$, the last country will have 100 as its minimum right. The bankruptcy problem now is transformed into: $d_1 = 100$, $d_2 = 200$, $d_3 = 300$, and $d_4 = 300$, with a *TAC* of 600.

Thus, any difficulty in agreement between claimants can be reduced to that part of the *TAC* left after the minimum rights have been distributed. This idea is summarized in a property called *composition up from minimal rights*[5] (Thomson 1995), and it can be defined formally as follows:

$$\text{For all } (TAC, d) \in B_f^N, f(TAC, d)$$
$$= m(TAC, d) + f\left[TAC - \sum_{i \in N} m_i(TAC, d_i), d - m(TAC, d)\right].$$

[4] Once more, a stricter version of this property can be formulated. That is, if the fishing resource increases, every country should receive a greater quota.

[5] This property is called v-separability in Dagan (1996).

The rule should not be manipulable.

This property, also called strategy-proofness (O'Neill 1982) or non-manipulability by merging or splitting agents (Chun 1988; De Frutos 1999) implies that no claimant country should obtain a higher total fishing quota by consolidating its claim with other country claimants or by splitting its claim into two or more claims. Formally, it can be stated as follows:

$$\text{For all } M,T \subset N, \text{ all } (TAC, d) \in B_f^M \text{ and all } (TAC, d') \in B_f^T \text{ if } M \subset T$$
$$\text{and there is } i \in M \text{ such that } d_i' = d_i + \textstyle\sum_{j \in T \setminus M} d_j, \text{ and for all } j \in M \setminus \{i\} d_j' = d_j,$$
$$\text{then } f_i(TAC, d') = f_i(TAC, d) + \textstyle\sum_{j \in T \setminus M} f_j(TAC, d).$$

To conclude this subsection, table 4 shows which of these desirable properties are satisfied by the three rules defined. See the appendix for formal justifications.

The Bankruptcy Problem of the Northern European Anglerfish Fishery

In this section, the three division rules discussed above are applied to the Northern European anglerfish fishery. As mentioned previously, the EU has not always faced a bankruptcy situation in this fishery. In fact from 1983 to 1993, when precautionary *TAC*s were adopted, they were large enough to allocate quotas that were respectful with historical catches. However, for the years l993–94 and 1995, the bankruptcy problem was very evident. In this application, l994 is the focus of analysis to which the three division rules are applied, on the understanding that the claims of each country are the average records for the period 1986–93.

The choice of the average records for 1986–93 can be justified on two accounts. On the one hand, it makes use of historical fishing rights for a period relatively close to the target year (1994) and on the other, it captures the fact that Spain is also fishing the resource. On this basis, the bankruptcy problem to be solved is: (*TAC* 94*;* *d* = average 1986–93).

The fishing quotas obtained for this bankruptcy problem using the proportional rule, the nucleolus, and the Shapley value are presented in table 5. From this table it can be seen that there are many differences between the actual distribution and those obtained by applying the Shapley value, the nucleolus, and the proportional rule.

Considering the ranking of countries in terms of quota size the following observations can be drawn. First, in 1994 Spain was ranked fourth, whereas it would have been ranked second if any of the three alternative rules were used. Furthermore, if the ranking for the 1994 quotas and the theoretical ones are compared, Ireland and

Table 4

Properties of the Quota Division Rules Proposed

Property	Proportional	Nucleolus	Shapley Value
Claim boundedness	yes	yes	yes
Symmetry	yes	yes	yes
Order preserving	yes	yes	yes
Minimal rights	no	yes	yes
Monotonicity	yes	yes	yes
Invariance	no	yes	yes
Manipulability	yes	no	no

Table 5
TAC Distributions in Tons

Country	Proportional	Nucleolus	Shapley Value	1994 Quotas
France	12,077	13,041	12,805	15,460
Spain	5,552	5,345	5,109	1,490
U.K.	3,442	3,437	3,201	3,330
Ireland	1,571	1,285	1,647	1,400
Belgium	836	463	695	1,710
The Netherlands	204	150	224	220
Germany	117	79	119	190

Note: (*TAC* 94; *d* = average 1986–93)

Belgium swap their positions. Second, if the *TAC* distribution obtained using the proportional rule is compared with the *TAC* distribution obtained from the nucleolus, it can be seen that France receives more with the latter rule, while the remaining countries receive less. On the other hand, the Shapley value assigns a greater quota to France, the Netherlands, and Germany, while the remaining countries obtain lower amounts. Notice that comparing with the actual quotas, the three rules used in this exercise give the same ordering for the countries although the differences in the quantities assigned to each country are not negligible.

Analysis of the Properties of the Northern European Anglerfish Fishery

Now, the desirable properties satisfied by each of the three division rules are analyzed. The first property, formulated as *no country should receive more than its claim*, refers to a natural upper bound on the quota and is satisfied by all the division rules. Table 6 shows the fulfillment of the property for the bankruptcy problem solved.

A second requirement imposed on the division rules is that two or more countries with equal claims should be awarded equal amounts. This is certainly not the case in the Northern European anglerfish fishery (all countries have different claims) but, as shown in Appendix B, all the distribution rules analyzed fulfill this property. The same occurs for the property formulated as *a country with a greater claim will not be awarded a smaller amount*. Table 6 is just an example of how all the rules analyzed satisfy this property.

The next set of properties refers to upper and lower bounds for fishing quotas. The first property (a natural upper bound) is that *historical overexploitation should not be rewarded*; that is, the rule should not depend on that part of a claim that is greater than the *TAC*. To see what this property implies in the quota distribution problem, let us suppose that the EU, due to the overexploitation of stock, decides to reduce the *TAC* for anglerfish to 13,500 tons/year.[6] Assume also that the EU assigns the *TAC*, taking into account the historical harvest records of the member states for 1986–93. The three distribution rules proposed give the results presented in table 7.

Assuming that no country's claim can be higher than the *TAC*, the French claim will change to 13,500 tons, while the remaining countries, given that their claims are lower than the *TAC*, will maintain their full claims. The implementation of the three divisions rules for this new problem is shown in table 8.

[6] This quantity is selected in order to make the illustration easier.

Table 6
Claim Boundedness

Country	Proportional	Nucleolus	Shapley Value	Claim
France	12,077	13,041	12,805	13,952
Spain	5,552	5,345	5,109	6,256
U.K.	3,442	3,437	3,201	4,348
Ireland	1,571	1,285	1,647	2,196
Belgium	836	463	695	927
The Netherlands	204	150	224	299
Germany	117	79	119	158

Table 7
Solutions for (*TAC* = 13,500; *d* = average 1986–93)

Country	Proportional	Nucleolus	Shapley Value
France	6,694	6,408	6,530
Spain	3,002	3,128	3,101
U.K.	2,086	2,174	2,147
Ireland	1,054	1,098	1,071
Belgium	445	463	437
The Netherlands	143	150	140
Germany	76	79	74

Table 8
Solutions for (*TAC* = 13,500; *d* = average 1986–93)
France's claim changes to 13,500

Country	Proportional	Nucleolus	Shapley Value
France	6,583	6,408	6,530
Spain	3,050	3,128	3,101
U.K.	2,120	2,174	2,147
Ireland	1,071	1,098	1,071
Belgium	452	463	437
The Netherlands	146	150	140
Germany	77	79	74

If tables 7 and 8 are compared, it is evident that the quota obtained by each country using the nucleolus and the Shapley value is exactly the same, while the proportional rule gives a higher quota to France for the case in which its total claim is taken into account. The reverse is true for the remaining countries. This implies that the proportional rule weights positively the entire claim of France, which is above the *TAC*, whereas the Shapley value and the nucleolus do not.

The next property refers to a natural lower bound: *The minimum rights of the countries should be respected*. To see the performance of this property, consider the bankruptcy problem in two parts. Firstly, the minimum right of each country is computed as explained earlier (see table 9).

Once this minimum right is assigned to each country, a new bankruptcy problem can be defined. In the new problem, the total amount to be shared is the initial *TAC* less the sum of the minimum rights (11,548 tons) and the claims are the initial ones adjusted downwards by the amounts already obtained. Using these new claims (d' in table 9), the new bankruptcy problem is solved. The results for each rule are shown in the columns (TAC', d') of table 10. The three other columns (Total) of this table show the final amounts when the minimum rights are added. Comparison of these (Total) columns with the results presented in table 5 shows that the nucleolus and the Shapley value provide exactly the same final distribution, respecting the minimum rights property, while the proportional rule gives a different share.

Finally, the problem of the *manipulability* of the solutions is analyzed. A simulation has been conducted under the assumption that all the fishing countries, except France, consolidate their claims. The results for this case are shown in table 11.

Comparing tables 11 and 5, it can be seen that the nucleolus and the Shapley value are manipulable in the sense that all countries, except France, can obtain a higher share by consolidating their claims. Table 11 also shows that the proportional rule gives exactly the same results as before.

Table 9

Minimum Rights (mr) and New Claims (d')

Country	mr	d'
France	9,616	4,336
Spain	1,920	4,336
U.K.	12	4,336
Ireland	0	2,196
Belgium	0	927
The Netherlands	0	299
Germany	0	158
Total	11,548	16,588

Table 10

Minimum Rights

	Proportional		Nucleolus		Shapley	
Country	(TAC', d')	Total	(TAC', d')	Total	(TAC', d')	Total
France	3,205	12,821	3,425	13,041	3,189	12,805
Spain	3,205	5,125	3,425	5,345	3,189	5,109
U.K.	3,205	3,217	3,425	3,437	3,189	3,201
Ireland	1,623	1,623	1,285	1,285	1,647	1,647
Belgium	685	685	463	463	695	695
The Netherlands	221	221	150	150	224	224
Germany	116	116	79	79	116	116

Table 11
Manipulability

Country	Proportional	Nucleolus	Shapley Value
France	12,077	12,129	12,129
Rest	11,723	11,671	11,671

Closing Comments

Even though fisheries regulated via a *TAC* policy show, in some cases, the characteristics that define a bankruptcy problem, the use of these types of models is not common in the fisheries literature. In fact, to our knowledge, it is the first time that such an application has been carried out. In this paper, it is shown that the use of bankruptcy models to characterize a fishery regulated via *TAC* is a useful approach. This is made evident from the results obtained with the case study, the Northern European anglerfish fishery.

First, tables 1, 2(a), and 2(b) show that given the *TAC*s imposed by the EU for the years l993, 1994, and 1995 (taking as claims the average catches for 1986–93), the Northern European anglerfish fishery is a bankruptcy problem since total historical catches were higher than the *TAC*. Second, data analysis allows us to infer that the first distribution of the *TAC* for 1983–85 has been derived by using a sort of a "weighted" proportional rule. Although the prescribed quotas for France, the United Kingdom, the Netherlands, Germany, and Belgium, when the average catches for the period 1973–78 are taken as the reference point, approximate to the outcome given by the proportional rule, this is not the case for Ireland, which was treated differently. Moreover, the rule followed from l986 (once Spain entered the EU) onwards can be considered as a modification of the "weighted" proportional rule previously used. That is, the EU adjusted the quotas so that Spain could get a part of the *TAC*. This adjustment was made at the expense of the United Kingdom. Third, the division rules considered in this exercise were the proportional rule, the Shapley value, and the nucleolus. As expected, these rules are sensitive to the definition of the claims and give quite different outcomes.

Finally, the behavior of the division rules in relation to a set of desirable key properties has been illustrated. All of the rules considered satisfy the obvious requirements of *claim boundedness, symmetry,* and *order preservation*. However, the property *historical overexploitation should not be rewarded*, discriminates between the rules. While the Shapley value and the nucleolus satisfy it, the proportional rule does not. The same happens with the *minimum rights* property. The question of the *manipulability* of the solutions has been also analyzed, revealing that only the proportional rule is not manipulable.

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Appendix

The purpose of this rather technical appendix is to provide some theoretical results and references that exist in the literature of cooperative games. These results are concerned with the verification by the proportional rule, the Shapley value, and the nucleolus of the properties that are considered desirable. See Thompson (1995) for a survey of the literature devoted to the axiomatic analysis of bankruptcy problems.

In order to formally justify the mentioned verification, it is necessary to formulate a bankruptcy problem as a game in a characteristic function form, since this type of modeling shows whether the Shapley value and the nucleolus satisfy the set of desirable properties.

Following O'Neill (1982) a bankruptcy problem is a pair (E, d) where E is the estate and d is the vector of claimants. This problem can be defined as an n-person cooperative game (N, v), where N is the set of claimants and the characteristic function is defined as:

$$v_B(S) = \max\{0, E - d(N - S)\} \text{ for all } S \subseteq N,$$

where $d(N - S) = \sum_{i \in N \setminus S} d_i$.

In other words, the worth of a coalition S, denoted by $v_B(S)$, represents the maximum amount that coalition S can get by accepting either nothing, or what is left of E after paying the claim of the members outside its coalition. It is well known that a bankruptcy cooperative game is convex. Now, let us present the results concerned with the verification of the properties by the proportional rule, the Shapley value and the nucleolus:

Claim boundedness: Curiel, Maschler and Tijs (1987) have proved that a division rule for a bankruptcy problem selects a core allocation if, and only if, it satisfies claim boundedness. Given that the nucleolus always provides a core allocation (see Schmeidler 1969) and that the Shapley value of a convex game is also a core allocation (see Shapley 1971), both solutions must satisfy claim boundedness. Additionally, in the same paper, it has also been proven that the proportional rule (proportional to the claims) in a bankruptcy problem satisfies claim boundedness. Therefore, the three division rules satisfy claim boundedness.

Symmetry and order preservation: It is easy to see how the proportional rule satisfies symmetry. Moreover, for the case of the Shapley value and the nucleolus, these solutions have been "characterized" using this property by Shapley (1953) and Schmeidler (1969), respectively. (Notice that if a solution is characterized using a property, then this solution satisfies this property.) On the other hand, from the application of the Shapley value, the nucleolus, and the proportional rule to any bankruptcy problem, it is clear that all three satisfy the property of order preservation.[7]

Monotonicity: Young (1985) has proven that the Shapley value satisfies net worth monotonicity. Besides, considering the four-case procedure that defines the nucleolus for a bankruptcy problem, it is easy to see that this solution satisfies this property.[8] It is also immediate that the proportional rule satisfies net worth monotonicity.

Invariance under claims truncation: In order to see how the nucleolus and the Shapley value satisfy this property, let us proceed as follows. For any bankruptcy problem with claims greater than the *TAC*, it is possible to consider a new associated bankruptcy problem in which these "claims" have been substituted exactly by the *TAC*. The two problems, if different, give the same cooperative game. Hence, the nucleolus and the Shapley value will provide the same outcome for the two problems, implying that they are invariant under claims truncation. Additionally, in the main text there are examples that illustrate that the proportional rule does not satisfy this property (see tables 7 and 8).

Composition up from minimum rights: In Dagan (1996) it can be seen how any rule that is invariant under claims truncation and self-dual[9] will satisfy composition up from minimum rights. The nucleolus and the Shapley value satisfy both properties; hence, they will also satisfy composition up from minimum rights. In contrast, the application given in the main text shows an example of how the proportional rule does not satisfy this property (table 10).

Manipulability: O'Neill (1982), Chun (1988) and de Frutos (1999) have shown that the proportional rule is the *only* non-manipulable rule. Therefore, the nucleolus and the Shapley value cannot satisfy this property.

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[7] Note that the Shapley value and the nucleolus do not satisfy strict order preserving, as can be seen in the following example: Let $d_1 = 100$, $d_2 = 200$, $d_3 = 300$, and $E = 100$. In this case, both the Shapley value and the nucleolus give the same payment to all claimants, $Sh_i = \eta_i = 33.3$ for $i = 1,2,3$. On the other hand, it is easy to see how the proportional rule satisfies strict order preserving.

[8] Note that the Shapley value and the nucleolus do not satisfy strict monotonicity, as can be seen in the following example: Let $d_1 = 100$, $d_2 = 200$, $d_3 = 300$. It is easy to check that claimant d_1 receives the same payment if $E = 400$ or if $E = 450$ using both the Shapley value and the nucleolus.

[9] A self dual rule implies that awards and losses in the nucleolus are allocated in the same manner. See Dagan (1996) for a formal statement of this property.