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APPLICATIONS OF GAME THEORY TO NATURAL RESOURCE MANAGEMENT: THE CASE OF HIGH SEAS FISHERIES

COELHO, Manuel Pacheco, (P), FILIPE, José António, (P), FERREIRA, Manuel Alberto, M. (P)

Abstract: Property rights are in the center of fisheries management difficulties. The problem becomes more complex when fisheries are transboundary by nature. Extended Fisheries Jurisdiction gave the coastal states property rights and the potential of a sustainable management of fisheries resources. But, the High Seas remain with a statute where the principle of the "freedom of the seas" is in force. The imprecise definition of use rights in the areas of High Seas adjacent to the EEZs and the consequent difficulties in the management of the straddling stocks, made the origins of a lot of "fish wars", in the 90s. The U. N. Agreement (1995) on Transboundary Stocks and Highly Migratory Species pretended to be a formula of cooperation among interested states. The purpose of this paper is to survey the important contribution of Game Theory to study this problem of fisheries management and to highlight the possible routes for further research.

Keywords: Fisheries, Straddling Stocks, Game Theory, Optimal Control Theory

Introduction

Since the seminal papers of GORDON, SCHAEFER and SCOTT, in the 50s, the central idea in the Fisheries Economics is that, in conditions of free access and competition, the market leads to non - optimal solutions in the use of the resources. The "common property" nature of fisheries and the presence of externalities in the capture lead to market equilibrium solutions that implicate the overexploitation of the resources and overcapacity in the industry. That is, we're in the presence of Hardin's metaphor of "The Tragedy of the Commons" (HARDIN, 1968).

The property rights are in the core of fisheries management and the problem becomes more complex when fisheries are transboundary by nature. Extended Fisheries Jurisdiction gave the coastal states property-rights and the potential of a sustainable management of fisheries. However, the general evolution towards more exclusive rights didn't mean the exclusion of free access in international fisheries. The Law of the Sea (1982) doesn't exclude the principle of the "freedom of the seas" that remains in force in the High Sea.

One of the most penetrating subjects that emerge as a consequence of this statute is the management of straddling stocks. Given that the fish are endowed with mobility, it was inevitable that the coastal states, after the establishment of Economic Exclusive Zones (EEZs), verified that they were sharing some of those resources with neighbouring countries. Many coastal countries also verified that some of the acquired stocks passed the border of EEZ to the High Sea, where they were subject to the exploitation of distant waters fishing fleets from other countries. Some of those stocks moved at great distances, passing successively in EEZs of several countries and in areas of High Sea. There is no rigorous typology; we can designate the first ones as transboundary resources, the seconds as straddling stocks and the last ones as highly migratory species.

It is the second case that interests us, particularly. The development of a theory for these cases is still a work in progress, in spite of Economists and Mathematicians efforts to seek, from the end of the 70s, answers for these situations. The problem can be stated as the following:

The Law of the Sea attributes to the coastal states almost exclusive property rights on the fisheries to the 200 miles. The fundamental article (art. 56) reflects these sovereign rights to explore, to manage and to conserve the resources in EEZs.

One subject that was inconclusive, in 1982, concerned “transzonal” species. It rested for a clear debate the subject of who should be entitled management on these resources. During the Conference, the distant waters fishing nations argued that, given the mobility of those stocks, management should not be under jurisdiction of coastal states but under the competence of the Regional Fisheries Organisations. This position had the vigorous opposition of many coastal countries.

The debate took a commitment (established in the art. 64) that ended for being the focus of subsequent controversy. Art. 64 count two paragraphs seemingly contradictory. In the paragraph 1 it is said that, where International Organisation exist, coastal states should cooperate with the countries of distant fishing. For these countries it means, obviously, that, inside those Organisations, they can influence the regulation of the resources. The paragraph 2 says that the art. 64 should be applied “in addition to the other provisions of the part V of the Convention". Coastal states interpret this paragraph as implicating that the art. 56 should be applied integrally in (and out) their EEZs; that is, also to the migratory species.

An area of potential conflict grew up. The high negotiation costs implicated in the problem resolution were enough to maintain this vague stance situation. But the problem arose strongly, in the context of straddling stock fisheries. The consideration of the small importance of the highly migratory resources and the reasonable conjectures of certain coastal countries, who believed that the long distance fisheries fleets could only explore the resources of High Seas adjacent areas if it was guaranteed the access to EEZs, all showed to be wrong. Straddling stocks management was in the root-causes of serious “fish-wars” in the 90s.

In the essence, it is a problem of property rights. The conviction of coastal states, that they would be entitled “de facto" property rights on the transboundary resources, was wrong. These virtual rights ended for showing emptiness. Actually, these resources remain as “international common property" and the usual “tragedy of the commons” is well reflected in the overexploitation of these resources. The vague, imprecise form as they are defined in the Convention of 82 is in the origin of the problem. So, they can be called the" unfinished business" of the Law of the Sea (KAITALA e MUNRO (1993)).

The purpose of this paper is to survey the important contribution of Game Theory to study this problem of fisheries management and to highlight the possible routes for further research.

Shared Resources Management: Review of the Literature

The common analytical proposal has been the one that takes the basic model of the Fisheries Economics and combines it with Game Theory. In the core, the Theory grew for the transboundary resources. The importance of the straddling stocks is more recent. There is, however, a common trunk that we'll refer as Shared Resources Management.

The starting point is the Gordon–Schaefer model. We are confronted with two essential issues: the nature of free access of the resource and the consequent effect of total dissipation of rents, and the exercise of inter-temporal management of the resource, implicating a trade-off among present sacrifices and future gains.

The Game Theory, understood as an instrument of applicable analysis to situations in which a player is influenced not only for his decision and actions, as for those taken by the other players of the economic game, has an obvious value in this case.

2.1 Prisoner's Dilemma Or Cooperation?

The first subject to discuss is*: Is the cooperation worthwhile*? And one finds several alternative analysis: Colin CLARK (1980) and LEVHARI and MIRMAN (1980) classic approaches, and the developments of the Group of Helsinki (see, for example, KAITALA (1986)). The general conclusion is that the non-cooperation leads to inferior performances. The authors predict that the non-cooperation translates in results very similar to the non-regulated, free access fisheries case, that is, the dissipation of the rents.

CLARK (1980) combines the basic model of the fisheries with the Theory of Nash of non-cooperative Games, with two players (NASH, 1951).

1 THE GORDON-SCHAEFER MODEL

Consider a given country 1. The conditions of the basic model are assumed in:

$$\dot{x} = F(x) - h_{(t)}$$

$$h(t) = qE^{v}(t).x^{\phi}(t)$$

The first equation represents the dynamics of the resource as a function of the natural growth of the species and of the capture. The function of natural growth of the species, F(x), is given by a differential equation that relates the growth of the stock with the dimension of the biomass in every moment. In the model of Schaefer, a quadratic function is used that, integrated, drives to the popular logistic curve of Lotka/Volterra.

The second equation can be identified as the production function of the fishery, the capture depending on the stock dimension, on the level of applied effort and on a capture-ability coefficient specific for each species.

x represents the biomass*, h(t)* the capture, *q* the capturability coefficient and E(t) the measure of effort. The exponents *v* and *ø* are, for hypothesis, same to 1.

Supposing that the fishery is made by the country 1 alone:

The function of total cost is

$$C(t) = a_1 E(t),$$

a_1 is the unit cost of the effort, constant. This implies that the supply of effort is perfectly elastic. The same condition is put as for the demand, being *p* the fixed, constant, price of the fish.

The country 1 objective is the maximisation of the liquid benefits along the time:

$$\text{Max} \quad PV_1 = \int_0^{\infty} e^{-\delta_1 t}\left(p - c_1(x)\right)h(t)\, d_t$$

δ_1 is the social discount rate in the country 1 and $c_1(x)$ it is the capture unit cost.

The Optimal Control Theory problem can be solved using the Maximum Principle of Pontryagin. The solution is the modified Golden Rule

$$F'(x*1) - \frac{c'\left(x*_1\right)F\left(x*_1\right)}{p - c_1\left(x*_1\right)} = \delta_1$$

This equation establishes the rule of resource use, the way as the society owes to invest/ disinvest in the resource along the time. The right side of the equation can be interpreted as the sustained marginal income of investing in an additional unit of the resource, divided by the cost of the investment, for that can be identified as the "rate of interest" of the resource. It is divided in two components. The first corresponds to the instantaneous marginal productivity of the resource. The 2nd term is the Marginal Stock Effect (EMS) that reflects the impact in the capture costs of the dimension of the biomass.

The approach to the optimal solution will be the fastest and we'll have a "bang-bang" result

$$h*_1(t) = \begin{cases} h_1 \text{ Max} & \text{se} \quad x_{(t)} > x*_1 \\ F(x) & \text{se} \quad x_{(t)} = x*_1 \\ 0 & \text{se} \quad x_{(t)} < x*_1 \end{cases}$$

h_1 Max is the maximum, arbitrary, capture rate.

The argument of the traditional model is that, in conditions of free access, the solution will be driven to the" bionomic equilibrium", where the rent is totally dissipated. The resource would be led to a level $x(t)=x_1$, in such a way that $c_1(x(t)) = p$.

MODEL WITH 2 PLAYERS

Supposing now the existence of a co-user 2 that shares the resource:

If the country 2 was the only user of the resource we could define the optimal biomass, according to the perspective of 2, x^*_2, in the same way we did for 1. Therefore, the "bionomic equilibrium" would be at the level x_2 in that $c_2(x_2) = p$

Supposing that there is no cooperation between the two countries and there is no communication among the managers, we are in presence of a non-cooperative game that leads us to the Prisoner's Dilemma. We fell back upon the Theory of Nash of no-cooperative games with two players.

The nature of the solution of Nash is that each player doesn't have incentive to alter his strategy given the other player's strategy. So, in the context of a fishery shared by two countries, the balance of Nash implicates, for both, capture rates (h1**(t), h2**(t)) stable.

These rates should satisfy the inequalities:

$$PV1(h1^{**}, h2^{**}) \geq (PV1(h1, h2^{**}) \quad \text{for any } h1$$

$$PV2(h1^{**}, h2^{**}) \geq (PV2(h1^{**}, h2) \quad \text{for any } h2$$

Supposing, for instance, that the costs of effort in the two countries are different and that barriers exist to the mobility of the labour and capital that perpetuate the inequality; and that $a_1 < a_2$ (the country 1 has low capture costs).

CLARK (1980) proves that, in these circumstances, supposing that Maxh1 and Maxh2 are sufficiently big, the solution for the no-cooperative game of Nash should satisfy

$$h1^{**}(t) = \begin{cases} h1\ Max & \text{if} \quad x > \min(x_1^*, x_2\infty) \\ F(x) & \text{if} \quad x = \min(x_1^*, x_2\infty) \\ 0 & \text{if} \quad x < \min(x_1^*, x_2\infty) \end{cases}$$

$$h2^{**}(t) = \begin{cases} h2\ max & \text{if} \quad x > x_2\infty \\ 0 & \text{if} \quad x < x_2\infty \end{cases}$$

This result means that the country with higher production costs will be pursued outside of the fisheries:

If $x_1^* < x_2\infty$ an optimal, lucky solution would be found. The result is not particularly good for the country 2 but the cooperation is punctual.

If, on the other hand, $x_1^* > x_2\infty$, then the resource will be driven to $x_2\infty$, a result clearly undesirable for both countries. We are confronted with the Prisoner's Dilemma - both players' rational decision leads to results that both consider undesirable, but that are inevitable without cooperation. Therefore, the incentive to the cooperation exists. The consequences of the non-cooperation approach the result that would be reached by a non-regulated fishery in the equivalent waters of only one country. Overexploitation and overcapacity will occur ((MUNRO, 1987, 1990); CLARK (1990)).

2.2 Cooperative Management: The Straddling Stocks Case

Recognising the advantage of the cooperation for some fisheries, we should continue an analysis of cooperative management. The process is the same, i.e., combination of the basic model of the fisheries with the Theory of Games, in this case, of the cooperative games among two people (NASH, 1953).

In the cooperative games it is assumed that the two players can communicate and are capable of establishing firm agreements.

The first subject is the one of knowing if the co-managers are willing to establish a formalised agreement, susceptible to enforcement, a coercive (binding) agreement, or simply more informal agreements, no-coercive (non-binding), without the establishment of a structure and rigorous enforcement rules.

The analysis of the cooperative fisheries is simpler in the cases of formalised, coercive agreements. There are several alternatives. The seminal analysis is the one of MUNRO (1979).

The functional objective of the two co-managers can be described in the following way:

$$\text{Max } PV_1 = \int_0^{\infty} e^{-\delta_1 t} \left(p - c1(x)\right)\alpha(t)\, h(t)\, dt$$

$$\text{Max } PV_2 = \int_0^{\infty} e^{-\delta_2 t} \left(p - c2(x)\right)\left(1-\alpha(t)\right)h(t)\, dt$$

$\alpha(t)$ it is the quota/share in total capture, for the country 1.

The co-managers have to consider two subjects:

- The division of the liquid benefits
- The possibility of different management objectives.

A potential agreement can be characterized in the following way:

$$\text{Max } PV = \beta PV1 + (1 - \beta)\, PV2$$

with $0 \le \beta \le 1$.

The objective is to maximize the global common profit. The coefficient β can be seen as the negotiation coefficient. If $\beta=1$ the preferences in terms of conservation policy of the country 1 are totally dominant, if $\beta=0$ the dominant preference is the one of the country 2. The value of this coefficient will be determined by the solution, if it exists, of the cooperative game of Nash.

Using the common procedures in treating these problems, we'll find another modified Golden Rule. The equation is:

$$F'(x^*) - \frac{c'(x^*)F(x^*)}{p - c(x^*)} = \frac{\delta_1 \beta\alpha e^{-\delta_1 t} + \delta_2\left(1-\beta\right)(1-\alpha)e^{-\delta_2 t}}{\beta\alpha e^{-\delta_1 t} + \left(1-\beta\right)(1-\alpha)e^{-\delta_2 t}}$$

The fundamental result of the analysis is the following:

The differences in the social rates of discount produce different arrangements in the favourite strategies. Ceteris-paribus, the co-manager that uses a relatively lower discount rate prefers a

conservationist policy and it is willing to invest in the resource. Therefore, the commitment favours in the immediate future the co-manager more short-sighted. Using a higher discount rate, he values more the close/near benefits. In the long term, the preferences of the more conservationist will be the more considered. According to MUNRO (1990): an "optimum-optimorum" will be found if the preferences of that, which attributed a higher value to the fishery, are predominant; he should establish the management program, and obviously, should compensate the other members, in any way. It is the "***The Compensation Principle"*** [KAITALA and MUNRO, (1993)].

Also, the economic analysis indicates that the commitments in the fisheries policy through cooperative games with transfers are more efficient. The economic consequence of transfers (side payments) is that the partners are encouraged to focus on the allocation of the benefits instead of the division of capture shares.

STRADDLING STOCKS MANAGEMENT

When the resource is a straddling, the management analysis is similar to the applied to the shared resources. It is assumed that the relevant coastal state is confronted with one or more nations of distant fishing in the waters of High Seas, adjacent to EEZ.

However, an important difference in terms of the Theory of Games - it concerns the symmetry. In the relationship between two countries of contiguous EEZs there is a relationship of perfect symmetry, in the sense that each one has a power perfectly defined in his EEZ and none can use the resources of the other's EEZ without previous authorization. In the case of the straddling stocks, the relationship is asymmetrical. Nothing impedes the fleet of the coastal country in acceding to the waters of High Sea where the free access is maintained, but the fleets of distant fishing nations only enter the coastal countries EEZs if they are allowed.

In spite of this difference, the common trunk can be used with small alterations. The results don't also stand back significantly. If the non-cooperation prevails in the management of the resources the result will be the depletion of the resources.

Be noticed that, in the case of the straddling stocks, the number of participants can vary. Plus, that number can vary in time. When these issues are considered, the problem becomes significantly more complex.

Two additional issues are to be considered: the possibility of alliances between partners and the capacity of the "new entrants" to enter a given fishery. The existent analysis still constitutes an introduction to the problem (see KAITALA and MUNRO (1993). The theoretical analysis suggests some interesting conclusions:

With the number of players exceeding two, the possibilities of alliances among competitors must be considered. The analysis can get complicated considerably and, in practical terms, increases the difficulty of finding a stable cooperative arrangement.

The search of a cooperative agreement requests that each partner receives, at least, the payoff equivalent to the threaten point (the payoff of the situation of non-cooperation). But, also, that the partners of any sub-alliance obtain a result at least as good as that they would have if they chose any partner and they refused the cooperation with the third part of the organisation. That is: it is necessary an agreement whose payment is superior to the payment of the no-cooperative game and that's the largest of all the possible ones, in the possible alliances. In practice, it is the fundamental

question of drawing the institutions (the International Organisations of Fisheries), and asking for their operational capacity: definition, constitution, game rules, powers, management purposes.

The problem suggested by the possibility of non-members of the Regional Organisations enter the fisheries in High Seas is very significant. Using the Game Theory we can conclude that the possibility of a member to transfer his property for the "**new entrant**" ends for increasing his bargain position, extracting a larger part from the liquid benefit resulting from the cooperation. The simple threat of transfer of his position increases his expected payoff immediately for the cooperative agreement.

This conclusion evidences the difficulty of reaching a stable agreement if in the Regional Organizations there aren't clear rules and restrictive regulation in relation with "new entrants". The blackmail strategies and bluff can happen. The negotiations become more difficult and the agreement, very unstable.

Anyway, the advantages of the cooperation are unquestionable. The process of establishing the agreements and his operational performance is a subject whose analysis stays unfinished. And it puts in relief the institutional subjects and the need of evaluating the transaction costs involved in the process of establishing the agreements.

3 The United Nations Agreement of 1995

In 1992, the United Nations accepted the accomplishment of a Conference on the Management of Transboundary Resources and Highly Migratory Species. The final Agreement came in 1995.

In the negotiations two thought schools emerged. For both it seems obvious that the management regime of the stocks in the adjacent areas of High Seas should be the same that guides the portions of that stock in EEZs.

The first school supports the "*consistency principle*". This simply states that the applied regime to the portion of the stock in the area of High Sea should be consistent with the established regime for the portion of the stock inside the EEZ. Innocuous (or maybe not), the principle seems to repeat the need of no divergence in the management regimes for the same stock. Be noticed, however, that the relationship, just as it is put, has not the two senses. By the article 56, the coastal country determines the management regime in his EEZ and, consequently, if it goes acceptance the consistence need, it owes the same regime to be in force for the remaining part of the stock. The preferences of the coastal State appear as dominant. MILES and BURKE (1989), defenders of this solution, maintain that the article 116 establishes that the coastal State has a superior right, responsibility and interest in the management of the straddling stocks, despite that the necessary distribution of competence is not prescribed.

For the maritime potencies that principle is just one more reflex of the "Creeping Jurisdiction" that shapes the recent evolution in the Maritime International Law. Some coastal countries, especially those with extensive Continental Platforms (for example, Canada), intend to maintain that principle to value his negotiation position. The distant waters fishing nations speak about co-management and justify their role in the determination of a management regime for those stocks. However, if such a rule was established, for consequence, the maritime potencies could influence the administration

regime out of EEZs, and inside of them. For the coastal countries, this position, designated "*School of Article 64*", limits the sovereignty in their EEZs.

In this context, a commitment emerged:

- It maintains the free access over the 200 miles and guarantees to the Regional Fisheries Organisations the regulation power in the areas adjacent to EEZs. The largest innovation is the capacity of those Organisations to extend their rules to the non-members. Previously, a simple objection was enough for non-application of the rules, even for the members.
- It was not solved the problem of the "new entrant". The Agreement just defined that any state with a "real interest" can be member and it should be encouraged to integrate the Organisation. However, it was not defined what means, in practice, "real interests".
- To the Organisations, the right is checked of establishing capture shares and controlling the number of boats for a given stock or area. But the Agreement doesn't say anything concerning as the decision it should be taken, if for consensus, if for majority. Once again, it will depend on the practice.
- The enforcement is another problem, because any state, by itself, can apply the law out of his territory. Each country member will have the inspection right on the ships of any other country. However, the legal action against eventual infraction only can be taken by the country of origin, of the ship found in fault. It seems that the potential effect of the enforcement is broadly bounded.

4 Routes for Further Research

The Agreement intended to promote a new cooperation formula among states interested in the resources management. Despite the cooperative atmosphere and some interesting results, this Agreement continues being the reason for discussion, especially in the context of NAFO. This situation stands for further research in, at least, three fundamental issues (Game Theory still developing a central role in every domain):

The "New Entrant" problem

Despite some interesting developments in this domain, many of them arising from the research of the so-called "Lisbon School", this issue still requires further investigation.

The charter members of an RFMO (Regional Fisheries Management Organisation) are facing a dilemma. They can attempt to prevent non-members from becoming explicit free riders, that is, turn poachers into "game-keepers" by encouraging them to apply as new members. If the offer is too generous the existing RFMO will be undermined. If the prospective new members feel that the proposed shares are not enough they will return to explicit free riding. The solution of the problem involves the application of a coalition bargaining analysis in the form of a partition function. New developments are expected in this area.

Also the possibility of creating a market of "chart member" has to be investigated. The possibility that each member has the right of selling his chart member, creating a market for the rights to

access the organization, is a matter of discussion and research because it involves a lot of problems in the division of the benefits from the cooperative use. Also, the problems of coalitions between partners.

The "Time Consistency" issue

As said before, the consideration of side payments in the models is a form of getting more stable commitments. The problem of time consistency refers to the question of knowing what are the conditions that make the commitments more stable for the future. Should the rules be more or less flexible? In a situation of uncertainty of stocks' recovery, what kind of agreement can be more trustable and less dependent of member states own motivations? What are the effects of introducing the climate change issues?

We return to the central question: coercive or non-coercive agreements? How can we design the organizations (their structures and rules) to make them more resistant to time passing and changes?

The "Interlopers" issue

This is a different form of looking at the "new entrant" issue. Suppose that a possible new entrant in the fisheries decides not to enter the RFMO and maintain a situation of free rider, exploiting the straddling stock (even with the better results that come from others' cooperative management in the RFMO). With the present rules of the game how can the "co-managers" enforce their rules to non-members?

Without a real capacity of intervention and enforcement (from detection to conviction), the efforts of cooperation will turn into disillusion and more incentives to get into free riding behavior, even for previous members of RFMO.

Most of the literature on fisheries management implicitly assumes law can be perfectly and cost-less enforced. Even when such costs and imperfections are recognised, they are not incorporated in the analysis to show how management and regulatory policies are affected by their presence. We could explore this issue with a formal model of fisheries law enforcement to show how fishing firms behave and fisheries policies are affected by costly, imperfect enforcement of fisheries law. This type of models should combine standard Economics of Fisheries analysis (Gordon/Schaefer model), Game Theory and the Theory of "Crime and Punishment" of Becker.

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Current addresses

Manuel Coelho, Professor Auxiliar
ISEG- UTL
SOCIUS
Rua do Quelhas, 6, 1200-781
LISBOA, Portugal
Phone: +(351) 213925800.
Fax: +(351) 213922808.
Email: coelho@iseg.utl.pt

José António Filipe, Professor Auxiliar
ISCTE – IUL
UNIDE – IUL
Av. Forças Armadas 1649-026 Lisboa, Portugal
Tel.+351 217 903 000
E-mail: jose.filipe@iscte.pt

Manuel Alberto M. Ferreira, Professor Catedrático
ISCTE – IUL
UNIDE – IUL
Av. Forças Armadas 1649-026 Lisboa, Portugal
Tel. +351 217 903 000
E-mail: manuel.ferreira@iscte.pt