The Role of Game Theory in Fisheries Economics: From Non-existent to Indispensible

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Abstract: This paper is designed to "set the stage" for the Special Session on Game Theory and Fisheries. It traces the origins of the application of game theory to fisheries economics, noting that, for the first quarter of a century after the publication of H. Scott Gordon's 1954 seminal article, the role of game theory in fisheries economics was all but non-existent. The coming of the EEZ regime, and the emergence of the internationally shared fish stock problem, forced the hands of fisheries economists compelling them to bring game theory to bear, since strategic interaction between and among fishing states sharing the aforementioned stocks lay at the heart of the problem. That problem became increasingly complex over the ensuing decades requiring, in turn, the application of increasingly sophisticated game theoretic models. The question now concerns the relevance of game theory to the management of intra-EEZ fishery resources. The paper argues that game theory is in fact highly relevant, but that the application of game theory to the management of intra-EEZ fishery resources lags far, far behind the application of game theory to international fisheries. The paper goes on to explore this "new frontier", introducing such concepts as multi-level cooperation.

I Introduction

This paper is designed to "set the stage" for the IIFET 19 Special Session on Game Theory and Fisheries. It traces the origins of the application of game theory to modern fisheries economics from the mid-1950s up to the present, arguing that, with respect to fisheries economics, game theory has gone from irrelevancy to indispensability. The paper draws heavily upon the introductory chapter of the forthcoming book: *Game Theory and Fisheries Management: Theory and Applications* (Grønbæk et al. forthcoming), under preparation by the four authors of this paper[1].

II The Era of Irrelevance

A game theoretic situation is deemed to arise when the actions of one decision maker, which can be a person, a firm, a region, a state, have a perceptible impact upon one or more other decision makers, leading to a strategic interaction between or among them. The evo-

[1] The paper draws as well upon: Grønbæk et al. 2018.

lution of the application and relevance of game theory, or the theory of strategic interaction, to fisheries economics, follows, albeit only approximately, the stages of the economic management of capture fishery resources.

Stage 1, up to the late 1930s, can be seen as that of no economic management, except in a few isolated cases. Stage 2, when the need for management for the resources worldwide came to be clearly recognized, can be thought of as extending from the late 1930s to the late 1960s. It was within that period that modern fisheries economics came into its own with the publication of H. Scott Gordon's seminal article in 1954 (Gordon 1954)[2]. For the quarter of a century following the publication of the Gordon article, the impact of game theory upon fisheries economics was negligible.

In Stage 2, the response to perceived resource overexploitation was to attempt to limit global harvests through gear restrictions and/or global quotas, but without effective controls over fleet size, what has become popularly known as Regulated Open Access (Wilen 1985). Given that, under existing international law, coastal state jurisdiction over marine capture fishery resources did not extend beyond twelve nautical miles, most of the limited attempts had to be undertaken internationally.

The Gordon article, it will be recalled, is primarily about the severe economic consequences of an untrammeled common pool fishery, characterized by Pure Open Access. This is contrasted with the fishery being under the control of a "sole owner". It is assumed in the Pure Open Access case that the fishing industry is perfectly competitive (Gordon 1954). In either case, there is no strategic interaction, and thus no need for game theory.

Gordon did describe the Regulated Open Access case, where resource rent dissipation is seen as coming about through the build up of excess capacity, rather than resource over-exploitation. The assumption that the fishing industry is perfectly competitive is retained. Once again, there is no strategic interaction.

It is certainly true that attempts to impose harvesting controls at the international level involved strategic interaction among the states involved. This fact was largely ignored. In part, this may be due to the fact that the international aspects of fisheries management were treated but lightly by economists at that time[3]. Furthermore, the argument has been made that, while the application of game theory to economics can be traced back to the mid-1940s, the widespread use of game theory by economists did not occur until the early 1970s (see, for example, Bierman and Fernandez 1993, 4). If the argument is valid, it would help to explain the lack of interest of fisheries economists in game theory. Be that as it may, it is

[2] The authors acknowledge that, in fact, what we term modern fisheries economics can be traced back to J. Warming's 1911 article (Warming 1911). They would say that Gordon's 1954 article gave the fullest and most widely recognized expression of modern fisheries economics.
[3] A prominent book of the time, which does, in fact, discuss in detail international attempts to control fishery exploitation, is *The Common Wealth in Ocean Fisheries*, by economists F. T. Christy and A.D. Scott. There is not even a hint in this discussion of the significance of strategic interaction among the states involved (Christy and Scott 1965, Ch. 11).

to be noted that the first edition of Colin Clark's highly influential book, *Mathematical Bio-economics: The Optimal Management of Renewable Resources,* appearing in 1976, contains not a single reference to game theory (Clark 1976). This stands in contrast to the second edition of the book, appearing fourteen years later (Clark 1990).

III The UN Third Conference on the Law of the Sea: Relevance Achieved

Stage 3 can be thought of as extending from the early 1970s until the early 1990s. The most important event occurring during that period was the UN Third Conference on the Law of the Sea, 1973-1982. The Conference, and the resultant 1982 UN Convention on the Law of the Sea (UN 1982), did, as all are aware, revolutionized world capture fisheries management through the implementation of the EEZ regime. While the Conference did not end until 1982, the fisheries issues within the Conference were effectively concluded by 1975, with the result that many coastal states, commencing in 1977, introduced EEZs unilaterally[4]. The advent of the EEZ regime had a two-fold impact. The first was to increase dramatically the importance of fisheries management at the national/regional level. The second was to bring the management of internationally shared fish stocks to the fore. It was the second that was to transform the role of game theory in fisheries economics from being irrelevant to decidedly relevant.

Coastal states implementing EEZs were forced to recognize that, because of the mobility of most fishery resources, some of their fishery resources would cross the EEZ boundary into neigbouring EEZs (transboundary stocks) or into the adjacent high seas (straddling stocks)[5]. If coastal states were forced to recognize the importance of internationally shared fish stocks, then so were fisheries economists. Since strategic interaction between and among the states sharing the resources is central to the economic management of the resources, fisheries economists were compelled to bring to bear the theory of strategic interaction – game theory. The first game theoretic analysis of the economic management of internationally shared fish stocks appeared in 1979-1980.[6]

There is no question that Extended Fisheries Jurisdiction (EFJ) greatly increased the tractability of managing internationally shared fishery resources, which meant in turn that the economic analysis required to study their economic management was much simplified. An example is provided by the ancient and important fishery, North Sea herring. By the late 1960s, early 1970s, there were up to 14 states exploiting the resource, as a consequence of most the North Sea being high seas. There was an attempt at international management through the Northeast Atlantic Fisheries Commission (NEAFC), an attempt, which proved to be hopelessly inadequate. All of this changed abruptly on January 1, 1977, when the coastal states surrounding the North Sea jointly implemented EEZs. The segment of the North Sea constituting high seas shrank to zero, with the result that those sharing North Sea herring were reduced to two in number: the EU and Norway (Dickey-Collas et al. 2010).

[4] e.g., USA, Canada and the coastal states of Western Europe.
[5] or both.
[6] Munro (1979); Clark (1980); Levhari and Mirman (1980).

A further simplification for economists, in the early days of EFJ, was the fact that it was thought (wrongly) that, among internationally shared fish stocks, only transboundary stocks were significant. It was estimated that, if the EEZ regime became universal, the remaining high seas would encompass no more that 10 per cent of the commercially exploitable marine capture fishery resources. Thus, straddling stocks were deemed to be of minor importance (Munro et al. 2004).

The theory of games is thought of as being divided into two broad categories, non-cooperative and cooperative[7]. The application of non-cooperative game theory to the management of transboundary stocks led to the conclusion that non-cooperative management of the stocks brought with it the serious risk of mismanagement – a fisheries version of the Prisoner's Dilemma[8] - a conclusion that was to be validated many times over. Thus, in other than exceptional circumstances, cooperation does matter.

A cooperative game is one in which there is communication between/among the players, and in which the negotiation between or among the players leads to a binding agreement[9]. If the agreement is in fact not binding, it will disintegrate, and the players will revert to non-cooperation.

Whereas in non-cooperatives games it does not matter all that much if the number of players, n, is $n = 2$ or $n >> 2$, it does matter, and matter a great deal, in cooperative games. Cooperative games with $n = 2$ are much, much simpler than such games with $n > 2$. In analyzing the cooperative management of transboundary stocks, economists could, at least initially, get away with employing relatively simple $n = 2$ cooperative games.

The earliest cooperative game theory models applied to the economic management of transboundary stocks were deterministic two player models, which set forth the basic conditions to be met in achieving a stable cooperative game, and then assumed that once an agreement was achieved it would somehow, some way, prove to be binding through time. Optimal cooperative fisheries management programs were then investigated, allowing for the possibility that the players are not symmetric and that, as a consequence, they differ in terms of their perception of optimal resource management. It was demonstrated that compromise optimal cooperative programs could be developed. The beneficial effects of side payments were stressed[10].

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[7] The categories cannot, however, be thought of as being mutually exclusive. While it certainly possible to think of non-cooperative games that are strictly non-cooperative, one has difficulty of thinking of cooperative games that are strictly cooperative. The players in such a game are assumed always to have the non-cooperative alternative at the backs of their minds.
[8] See either Clark (1980) or Levhari and Mirman (1980).
[9] The agreement is binding in that the players willingly adhere to the terms of the agreement and have no incentive to defect.
[10] e.g. Munro (1979); Armstrong (1994).

The assumption that the agreement would be binding through time was, of course, subject to criticism. The assumption is not too outrageous in the case of two player games. There have been, in point of fact, cooperative transboundary stock management regimes that have proven to be remarkably stable over time. Return to the case of North Sea herring, as an example. With the advent of EFJ in 1977, the destructive 14 player non-cooperative game was transformed into a two-player cooperative game. The cooperative resource management agreement has, over the past four decades, proven to be stable, to be binding.

Nonetheless, the question of what steps could be taken to enforce the binding nature of the agreement, if players are tempted to cheat, had to be addressed. That was done before the close of the 1980s (e.g. Kaitala and Pohjola 1988). Basically, what then becomes necessary are punishment schemes sufficiently effective to deter would be defectors. One issue that remains to be addressed fully is the consequence of relaxing the assumption of determinism, and then dealing with the threat of unpredictable shocks to the agreement.

While progress could be made with two player games, it had to be recognized that, even in the management of transboundary stocks, there are cases in which the number of players exceeds two by a wide margin. Once the number of players exceeds two, then one must allow for the possibility of sub-coalitions being formed, which means that one must enter the realm of coalition games. An important issue that arises is the optimal sharing, in terms of "fairness", of the net economic benefits from the cooperative management of the resources – optimal sharing of the net economic benefits cake. Sharing that is deemed to be unfair threatens the stability of the cooperative agreement and does so for obvious reasons. Optimal sharing, which is straightforward when the number of players is two, becomes complex when the number exceeds two, and is to be analysed through the application of characteristic function games. This question was addressed and analysed in the 1990s (e.g. Kaitala and Lindroos 1998).

IV The RFMO Regime

Stage 4 extends from the early 1990s until the present, with the commencement of Stage 4 being marked by the coming of the RFMO regime. In international fisheries, the comfortable assumption that straddling stocks could be safely ignored was undermined over the course of the 1980s. Case after case of straddling stocks being the basis of serious resource mismanagement arose. By the early 1990s, the UN felt compelled to deal with the issue, and did so by convening a conference, popularly known as the UN Fish Stocks Conference, 1993-1995. The Conference gave rise to an agreement, designed to supplement the 1982 UN Convention on the Law of the Sea, popularly known as the 1995 UN Fish Stocks Agreement (UN 1995).

The mechanism preferred by the Agreement for the management of straddling stocks consists of Regional Fisheries Management Organizations (RFMOs)[11]. Within a given RFMO

[11] Examples of which are the Northwest Atlantic Fisheries Organization (NAFO) and the Western and Central Pacific Fisheries Commission (WCPFC).

all relevant coastal states and distant water fishing states (DWFSs) are to come together to manage cooperatively the straddling stocks in question.

Managing straddling stocks through RFMOs is a far, far more difficult problem than managing strictly transboundary stocks[12]. First, the typical RFMO has a large number of members (players)[13]. Secondly, in contrast to fishery resources within EEZs, the property rights to fishery resources within the high seas portions of RFMOs are ambiguous.
An important consequence of the large numbers of players and the property rights ambiguity is that free riding is much more pervasive in RFMOs than is to be found in transboundary cooperative fishery management arrangements. The achievement of stability of RFMOs through time is the overarching question.

This difficult fisheries management problem has required the application of game theoretic analysis considerably more complex than that required for the analysis of transboundary fish stock management. To date, the game theoretic models that have proven to be most effective in addressing this problem are partition function games, introduced into the fisheries economics literature in the 2000s (e.g., Pintassilgo 2003; Pintassilgo et al. 2010). Here the goal is seen as the achievement by the RFMO Grand Coalition of "internal stability" – a binding RFMO cooperative agreement.

Game theoretic work on these issues is ongoing at the time of writing, as evidenced by several papers in this Session. It can be predicted with confidence that this work will continue unabated for many years to come.

V The Management of Fish Stocks at the National Regional Level

We come now to the relevance of game theory to economic management of fisheries at the national/regional level. It can be said straight off that, while game theory is becoming increasingly relevant at this level, the application of game theoretic analysis lags far behind the application of the analysis to economic management of international fisheries.[14]

Upon looking back upon the stages of the economic management of fisheries, it will be recalled that in Stage 2 the management was dominated by what has been termed Regulated Open Access. Attempts were made to control global harvests, thereby conserving the resources, but no attempts were made to control the fleet sizes. The result was the build up of excess capacity and the dissipation of resource rent. It is a straightforward matter to construct an economic model of the fishery predicting this outcome, and to do so without the use of game theory (see, for example, Munro and Scott 1985, 613 ff.).

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[12] The term *strictly* transboundary stocks is used in recognition of the fact that there are numerous stocks, which are both transboundary and straddling.
[13] One of the first articles to examine the consequences of a large number of players was Hannesson (1997).
[14] This is not to imply that the application has been zero. One of the few economists who has done significant work in applying game theory to national/regional fisheries is U. Rashid Sumaila. See: Sumaila (2013).

Towards the latter part of Stage 2 and into Stage 3 and then on to Stage 4, there was a gradual shift away from Regulated Open Access. In addition, and of great significance, the importance of fisheries management at the national/regional level was, as noted, greatly enhanced by the coming of the EEZ regime.

The gradual shift has been primarily towards the implementation of harvesting rights-based management schemes[15]. Using North America as an example, one can see two paths. In the United States and Canada, there was an intermediate phase consisting of limited entry programs, without harvesting rights, followed by limited entry with harvesting rights in the form of ITQs, and to a lesser extent fisher cooperatives. In Mexico, on the other hand, the shift, to the extent that it has taken place, has been directly towards fisher cooperatives[16], with little or no use of ITQs.

In either case of the paths followed, there were limitations placed on the number of vessels, of fishers, in the fishery. Given these limitations, the assumption that the fishing industry is perfectly competitive ceases to be valid. Strategic interaction among vessel owners, among fishers, becomes a distinct possibility.

If a strategic interaction among vessel owners, fishers, does occur, then one has to think, not only in terms of a fisher (vessel owner) game, but also in terms of a game between the industry and the resource manager. Stage games are required. The appropriate framework was first formally set out by Kronbak and Lindroos (2006). In their model, the resource manager is seen as playing a leader-follower game with the industry. There is in turn an intra-industry game. At the first stage, the resource manager makes its move by setting out fishery management regulations. In the following stages, the industry reacts. The industry game may be non-cooperative, partially cooperative or fully cooperative. Analysis reveals, to no surprise, that the resource manager is better off, the greater is the degree of cooperation among the industry members (Kronbak and Lindroos 2006).

Now consider the first path, as exemplified by the US and Canada, in which there was a limited entry intermediate phase. In this intermediate phase, the fisher game was strictly non-cooperative. Indeed, the regulations were such that the fishers were encouraged to compete for shares of the limited season by season global harvest (Bjørndal and Munro 2012). Wilen explored the consequences, employing, appropriately, the theory of non-cooperative games (Wilen 1985).

The objective of the resource managers in the intermediate phase is to control and limit fleet capacity (the ability to catch fish) in the face of vessel owners having the incentive to expand that capacity. Controlling the number of vessels is inadequate, because capacity is

[15] Taxes are another alternative, but the use of taxes for this purpose has been very limited.
[16] The definition of a fisher cooperatives, being used is a broad one. No distinction is being made between fisher cooperatives and TURFs. A TURF is seen as a fisher cooperative with a specific geographical base. Let us immediately concede that fisher cooperatives in Mexico and other parts of the world, have, of course, existed long before the latter part of Stage 2.

commonly made up of a set of substitutable inputs. Resource managers have in practice found it virtually impossible to control all inputs.

Wilen demonstrates that, even if all vessel owners realize that their attempts to expand fishing capacity will dissipate resource rents, each vessel owner has no choice but to attempt to expand its capacity. In other words, we are presented with a text book example of the Prisoner's Dilemma (Wilen 1985). The Wilen predictions have been validated over and over. In fact, in many instances, not only has resource rent been dissipated, but the resource manager's ability to regulate effectively the season by season global harvest has been undermined (Clark and Munro 2017).

With the increasing move to ITQs, the assumption commonly adopted by economists is that the ITQ holders are playing as singletons. The possibility of cooperation among ITQ holders has been considered, but the general conclusion is that the scope for such cooperation is very limited. Only if the ITQ players are few in number will cooperation prove to be stable, or so it has been argued (e.g. Arnason 2012).

Consider now an ITQ scheme, with ITQ holders playing as singletons, in the context of the Kronbak-Lindroos model. The management regime, introduced by the resource manager, leads to a non-cooperative game among the vessel owners, but a non-cooperative game in which the competition is mitigated. As Ragnar Arnason states in his review of such schemes, the schemes have many benefits and carry us far towards optimality. They do not, however, carry us far enough. Many inefficiencies persist (Arnason 2017).

The proposition that cooperation among ITQ holders is strictly limited, in terms of number of players, has now been countered. There exists a widely documented case of an ITQed fishery off Pacific Canada, in which the "players", while large in number, are, and have been, playing a stable cooperative game. (Wallace et al. 2015; Grønbæk et al. 2016; Clark and Munro 2017).

Furthermore, the Pacific Canada case reveals a development not considered by Kronbak and Lindroos (2006). In the Pacific Canada case, the industry - resource manager game was, in the past, a highly competitive one. That game, for reasons not entirely clear, has evolved into a cooperative one. This development, in turn, has given rise to de facto co-management. While the ultimate resource management decisions rest with the resource manager, the fishers have been able to influence resource management and have done so in a positive direction. There are recorded instances in this fishery in which the fishers have pressed the resource manager to slash TACs on certain stocks, with the fishers suspecting before the resource manager that the stocks were endangered. The followers have turned leaders, proving to be more conservationist than the resource manager (Grønbæk et al. 2016).

Perhaps the Pacific Canada ITQ experience is unique. If there exists a valid reason why this should be so, it is a reason of which the authors are wholly unaware.

If one turns to the second path, as exemplified by Mexico, fisher cooperatives, then it is to noted that fisher cooperatives are being increasingly seen as the basis for solutions to the problem of sustainable fisheries management. It is to be noted as well that fisher cooperatives have received less attention, certainly from economists, than have other alternative catch share schemes, ITQs in particular (Ovando et al. 2013).

The need for game theoretic analysis becomes even more obvious than it does in the case of ITQs. To begin, a successful fisher cooperative is, by definition, a stable cooperative game.

Furthermore, fisher cooperatives do not normally exist in isolation. They commonly have to negotiate with neighbouring cooperatives – domestic transboundary stocks. In addition, like ITQ holders, they have to deal with resource managers. The game between vessel owners and resource managers can, as in the case of ITQs, prove to be cooperative or non-cooperative[17].

Some game theoretic analysis has been applied to fishery management through fisher cooperatives, in particular by Elinor Ostrom and her colleagues (Ostrom et al. 1994).[18] Surprisingly little use, however, has been made of cooperative game theory, with the one significant exception discovered by these authors being Polasky et al. 2006.

It is to be seen that there is one common aspect of cooperative fisheries management under ITQ schemes and fisher cooperatives, an aspect that has been given insufficient recognition in the past. This is the distinct possibility that the cooperation required for effective resource management will be multi-level. The possibility is particularly evident in the case of fisher cooperatives

It can be argued, without fear of contradiction, that the game theoretic analysis required to determine when cooperation within a fisher cooperative or a group of ITQ holders will be stable over time has yet to be developed fully. As for the analysis of stable multi-level cooperation, this is indeed unexplored territory. The analysis is likely to call for game theoretic tools yet to be applied in fisheries economics.

VI Some Conclusions

During the first quarter century of the history of modern fishery economics, the role played by game theory was negligible. That game theory achieved relevance in fisheries economics is due to coming of the EEZ regime. The economic management of internationally shared fishery resources became an issue that could no longer be ignored. Since strategic interaction between and among states sharing these resources lies at the heart of the economic management of the resources, economists analyzing this economic management problem were forced to bring to bear the theory of strategic interaction – game theory.

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[17] Silvia Salas, CINVESTAV del IPN, Mérida, Mexico, personal communication.
[18] See as well: Deacon 2012; Wilen et al. 2012

As the economic management of internationally shared fishery resources became more complex, particularly with the coming of the RFMO regime, the required game theoretic analysis became increasingly complex and sophisticated. This analysis, as the Session will reveal, is very much ongoing.

The application of game theory to the analysis of the economic management of fishery resources at national/regional level lags far behind the application at the international level. With the increasing importance of harvesting rights-based management schemes such as ITQs and fisher cooperatives, the need for such application is becoming increasingly pressing. Game theoretical tools, yet to be applied in fisheries economics, will be called for.

This is the new frontier. It can be anticipated that exploring this frontier will engage fisheries economists for many years, if not decades, leading us to the inescapable conclusion that, in the analysis of fisheries management at both the international level and the national/regional level, game theory is a tool indispensible.

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