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Linking environmental economics, game theory and fisheries: an estimation of the economic benefits to sharing the *Illex argentinus* fishery in the Patagonian large marine ecosystem

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Abstract

The Patagonian marine ecosystem supports one of the most productive straddling fisheries of the world, with important commercial shared fish stocks such as the Argentine shortfin squid *(Illex argentinus)*. This resource is exploited by different foreign fleets that operate both within the Argentine exclusive economic zone and within the adjacent area beyond the 200-limit, as well as in Falklands (Malvinas) waters. Hence, the countries face what is known as stock externality in which one nation catch impacts negatively on another's. However, little research has been done on the economic aspects of this fishery. In so doing, is this paper we use the predictive power of the game theory to explore the economic benefits of cooperative or non-cooperative fisheries management of *Illex argentinus* between Argentina and the United Kingdom. The model used here is a discrete-time of finite horizon with the fishery steady state static model of fishing. The preliminary empirical results suggest that there is a correspondence between what the fishery has experimented over the last few years with a situation of non-cooperative scenario. However, the paper demonstrate that in the cooperative scenario, both players would obtain better economic benefits, because both would reduce the fishing effort and the abundance of the stock would remains below the reference points recommended by scientists.

Keywords: *Illex argentinus* fishery, Patagonian large marine ecosystem, Game theory, Economic benefits

1. Introduction

The Patagonian large marine ecosystem (PLME) supports one of the most productive straddling fisheries of the world, with important commercial shared fish stocks such as the Argentine shortfin squid *(Illex argentinus*) (Bisbal 1995; Agnew *et al.* 2005). The *Illex argentinus* is exploited by different local and foreign fleets that operate both within the Argentinean Exclusive Economic Zone (EEZ) and within the adjacent area beyond the 200-limit, as well as in the Falklands (Malvinas) and the High Sea. Vessels from European (mainly Spain) and Asian countries (Taiwan, South Korea, China and Japan) participate in the large *Illex argentinus* fishery (Villasante and Sumaila 2008). Hence, the countries face what is known as stock externality in which one nation's catch impacts negatively on the other countries´.

Nevertheless, only biological and management aspects have been studied (Basson *et al*. 1996; Agnew *et al.* 2005), and little research has been carried out on economic aspects of this key worldwide squid fishery. Therefore, the main objectives of this paper are (i) to reconstruct the biomass and recruitment series of the *Illex argentinus* fishery and (ii) to develop empirical game theoretical analysis by estimating the economic benefits of the *Illex argentinus* fishery under both cooperative and non-cooperative scenarios.

The paper is organized as follows. Section 2 describes the fisheries management and the application of game theory to shared stocks. Section 3 turns to define and explain the model employed to estimate the economic benefits under cooperative and non-cooperative scenarios, and the estimations of the biomass and data required to solve the model. Section 4 shows the main numerical results from the sensitive analysis, and Section 5 discusses the policy implications of the results obtained.

2. Management of shared stocks: an overview

2.1. The United Nations Convention on Law of the Sea (UNCLOS)

One main concern resulting from the extension of territorial waters has been the management of transboundary resources (Munro, 1987), because economists usually look upon fishery resources as a form of natural capita (Clark and Munro, 1994).

UNCLOS addresses the fisheries management of these stocks through articles 63-64 (Economic Exclusive Zone), article 87 (Freedom on the High Seas) in conjunction with articles 116 to 120 (Conservation and Management of the living resources of the High Seas). UNCLOS does not define the term straddling stocks but it refers to them in article 63(2) "*the same stock or stocks of associated species (which) occur both within the economic exclusive zone and in an area beyond to the zone*" (UN, 1982). Hence, straddling fish stocks is a catchall term for all other fishery resources, such as demersal or pelagic ones, crossing the EEZ boundary into the adjacent High Seas (Kaitala and Munro, 1997).

Only one article refers directly to the management of straddling stocks, namely Article 63(1) that provides as follows: "*Where the same stock or stocks of associated species occur within the exclusive economic zones of two or more coastal States, these States shall seek, either directly or through appropriate sub regional or regional organizations, to agree upon the measures necessary to coordinate and ensure the conservation and development of such stocks without prejudice to the other provisions of this Part [V]"* (UN, 1982). Therefore, UNCLOS imposes a duty upon the relevant coastal States to negotiate arrangements for transboundary stock management but it does not impose upon the States the duty to reach an agreement (Burke, 1989). If the involved States are unable to reach an agreement, then each State shall manage the segment of the transboundary stock occurring within its EEZ (Munro *et al*. 2005).

Moreover, it is important to highlight that, if neighboring coastal States harvesting a shared stock attempt to manage the resource non-cooperatively, they are not necessarily in violation of the UNCLOS provision (Munro *et al*. 2005).

On the other hand, the High Seas fishing regime established in UNCLOS rests in Section 1 of Article 87, in which freedom of fishing on the High Seas is granted to coastal States as well as to non-coastal States, and all States have the freedom to fish in the area *"...subject to the conditions laid down in section 2 [of Part VII]*" (Article 87 (1) (e)) (UN, 1982). The High Seas regime in UNCLOS also states on the basis of Article 116 that all States have the right for their nationals to dedicate themselves to fishing on the High Seas subject to: "*i) their treaty obligations, ii) the rights and duties as well as the interests of coastal States provided for in Article 63, paragraph 2, and Articles 64 to 67, and iii) the dispositions of this section"* (UN, 1982). Article 116, of Part VII, requires that States harvesting highly migratory [as well as straddling stocks] on the High Seas adjacent to the EEZ take into account the rights, duties and interests of relevant coastal States. Nevertheless, because of the vagueness and imprecision of the articles 116-120 related to rights and responsibilities of coastal States and DWFNs with regards to the portions of the straddling and highly migratory stocks in the High Seas, a strong debate has been originated between them (Munro *et al.* 2005).

Trying to solve part of these problems the 1995 UN Fish Stocks Agreement achieved the status of international law in 2001. Straddling stocks are to be managed on a region by region basis through Regional Fisheries Management Organizations (RFMOs). This is because an effective management of shared stocks requires negotiations and agreement between the States concerned in order to settle some key issues such a resources access allocation and application of compatible management measures, among others. Under the framework provided by the 1995 UN Fish Stocks

Agreement, coastal States and interested States fishing on the High Seas should pursue cooperation in relation to these stocks either directly or through RFMOs or arrangements (UN, 1995). The fact is that he principle of cooperation in fisheries economics shall largely depend on the existing cooperation levels (primary or secondary level) between the involved States (Gulland, 1980), and on the condition that the number of interested parties is limited, at least in principle, to only a few (Hannesson, 1995).

2.2. Economics, game theory and fisheries

Two types of analytical tools are available for the analysis of shared fish stocks. The first of them is the standard application of bioeconomic models used in the study of stocks managed by a single State, namely the Schaefer model in discrete time, the Ricker model in continuous time and the cohort models developed by Beverton and Holt. The second one is the game theory.

Game theory is a mathematical tool to examine interaction between and among individuals, firms or States, introducing methods for analysing strategic choices among agents who share a common fish stock (Sumaila, 1999). Munro's work was the most stimulating contribution to the game theory applications to shared fishery resources before and after UNCLOS era (Munro, 1979, 1987). Since that, the application of the game theory to the international management of fisheries was rapidly increased in the 1990's after, creating a valuable work area for the analysis of shared stocks (Flaaten and C. Armstrong, 1988; Kaitala and Munro, 1993; Sumaila, 1997; 1999; Arnason *et al*. 2000; Kronbak and Lindroos, 2007; Bailey *et al*. 2010).

2.3. Cooperative and non-cooperative games

Games can be divided into two broad categories: cooperative and non-cooperative or competitive games (Nash, 1951). In a non-cooperative or competitive game, players are assumed to be motivated entirely by self-interest. Of critical importance is the fact that players are able to communicate with one another effectively. In non-cooperative or competitive games, the lines of communication between and among the players are faulty, or are simply non-existent (Sumaila, 1999).

Disputes between users of a given resource may arise when a State catches a stock in its EEZ, while another (coastal or non-coastal) State or firm catches this same stock on the High Seas due to the mobility of the resource that, for biological reasons, migrates from one zone to another. So, the theory focuses on the characteristics of each player's strategy, and allows researchers to predict the possible solutions to the game in the form of more or less lasting coalitions (Bailey *et al*. 2010).

The classical literature have conclude that the solution of non-cooperative management suppose, in the major cases, a significant overexploitation of the resources (Munro, 1979). Clark (1980) argues that, if the players are symmetric, i.e., identical in all respects, the outcome will be similar to that encountered in an unrestricted open access domestic fishery, referred to in the economics literature as "*Bionomic equilibrium"* (Gordon, 1954). Therefore, according to the game theory the non-cooperation management between players has undesirable consequences on the resources, when the harvesting activities of one country or entity are almost entirely motivated by self interest. This mean that whatever player exploits the stock by its self-interest the solution will produce undesirable if not destructive outcome. This is because the outcome is Paretto–inefficiency, implying that the payoffs of some of the players can be increased without decreasing those of others (Sumaila, 1999). As a result, the overall outcome to the fisheries game is an example of what is probably the most famous of all non-cooperative games, called as the "*Prisoner's Dilemma*" (Munro *et al*. 2005).

On the other hand, a stable solution to a non-cooperative game was defined by John Nash (Nash, 1951, 1953) as the situation in which each player has no incentive to change, given the strategies being followed by the other player. There are two conditions if there is to be a stable solution to the cooperative game: the Pareto Optimality, that is, any change which makes at least one individual better off, without making the other individual(s) worse off, is deemed to be Pareto improving. Hence, Pareto Optimality implies a situation, in which the opportunities for Pareto improvement have been exhausted, and in which it is not possible to make one individual better off, except at the expense of the other individual(s). The second requirement is often called the satisfaction of the individual rationality condition. It states that a solution to the cooperative game will not be stable, unless the payoffs arising from the solution make each and every player at least as well off as it would be under conditions of non-cooperation (Kaitala and Munro, 1993; Munro *et al*. 2005).

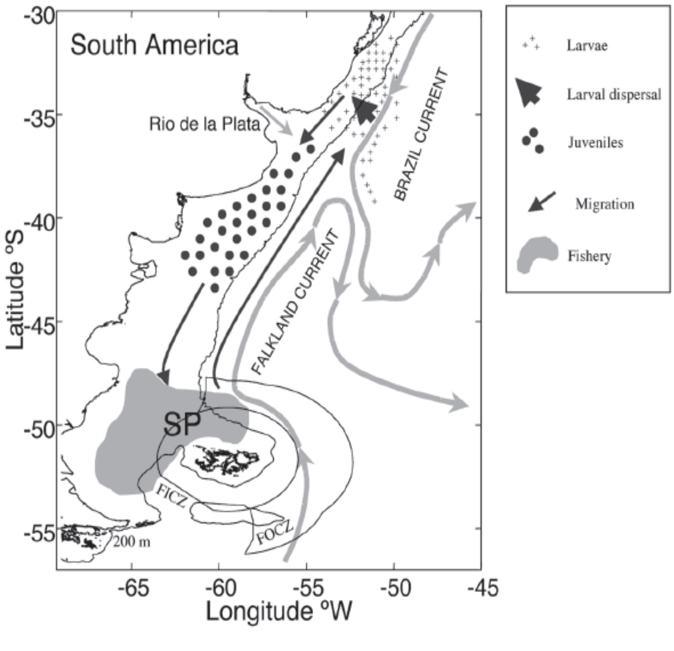
3. The bioeconomic model

3.1. The *Illex argentinus* fishery

One of the highest migratory shared resources in the world is the *Illex argentinus,* a neritic-oceanic species that has been found from the 54ºS to the 23ºS (Brunetti *et al*. 2000). The population has a life cycle of around one year (Hartfield 1991) in which the biomass can vary greatly from year to year (Agnew *et al*. 2005). The Argentinean shortfin squid is found off Argentina at bottom temperatures of 2.1-13.5°C, but mainly at 4-12°C (Brunetti 1990). Off southern Brazil, juveniles occur from 12ºC to 17°C and maturing and spawning specimens from 4ºC to 12°C (Figure 1). Brunetti (1990) distinguished three main spawning stocks in the southern range of the distribution of *Illex argentinus*: the Summer-Spawning Stock (SSS), the South Patagonic Stock (SPS) and the Bonaerensis-Northpatagonic Stock (BNS).

The most commercially important population, the South Patagonic (SPS) or winter-spawning stock, spawns and hatches between 28°S and 38°S (Laptikhovsky *et al*. 2001). In 1987 the United Kingdom government enforced a system of fisheries jurisdiction referred to as Falklands Interim Fisheries Conservation Zone (FICZ) to ensure the conservation of marine resources. This was done through the Declaration on the Conservation of Fish Stocks and the Proclamation No. 4 of 1986, covering a 150-mile zone, as well as through the declaration of the Falklands Outer Conservation Zone (FOCZ) which was introduced on December 1990, extending beyond the FICZ to the north, east and south of the Fakland (Malvinas) Islands to 200 miles, measured from coastal baselines and including a total area of about 527,000 Km^2.

Figure 1 Life history and migration pattern of the South Patagonic Stock (SPS) of *Illex argentinus* in the Southwest Atlantic Ocean.



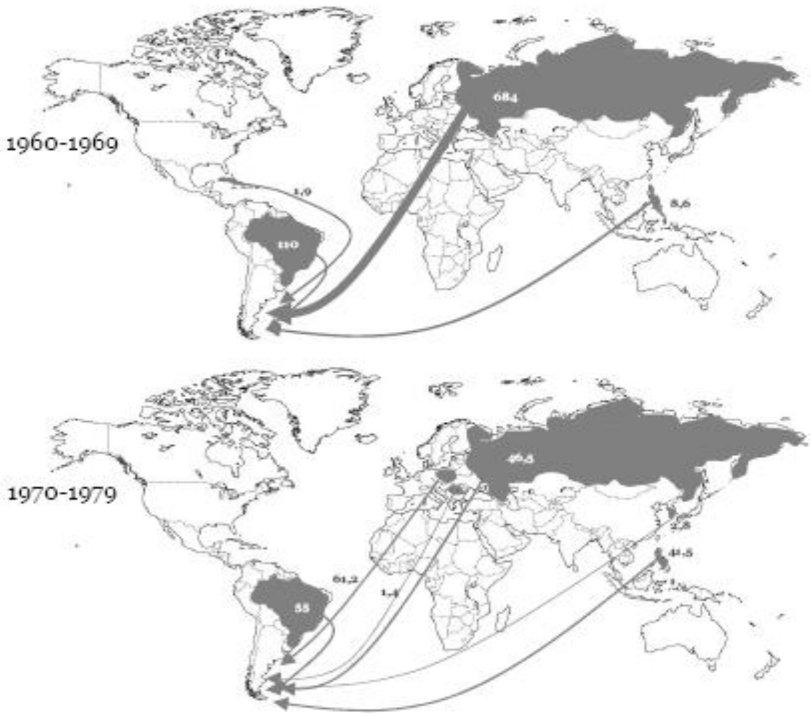
Source: Agnew *et al*. (2005).

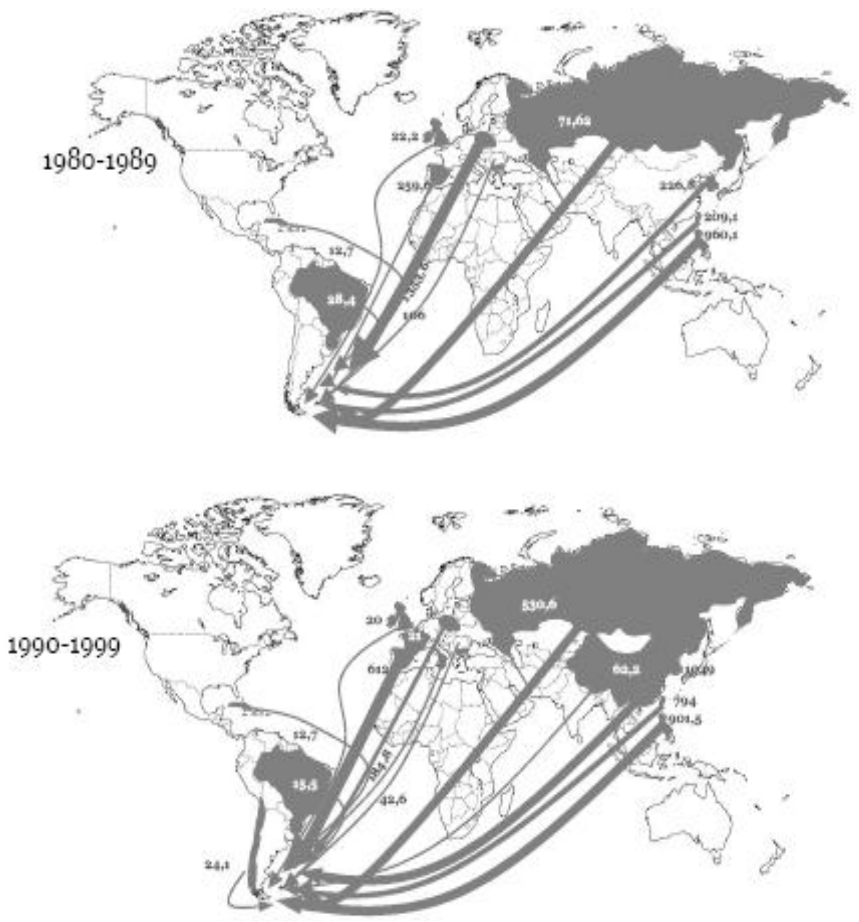
In the FICZ and FOCZ fishing effort is controlled by issuing a limited number of licenses that allow fishing for a period of time. The main goal of management is to minimize the risk of recruitment overfishing by defining a threshold minimum spawning stock biomass (Basson *et al*. 1996), and the level of fishing mortality is adjusted to ensure 40% of proportional escapement remains above the threshold minimum. The fishery currently operates a minimum target escapement (Spawning stock biomass, SSB) of 40,000 t (Agnew *et al*. 2005).

3.2. Economics of the *Illex argentinus* fishery

According to the Sea Around Us Database, total catches in the PLME raised from 45.700 t in 1950 to 1.19 million t in 2002. The peak catches were made in 1997 with 1.792 million t. The catch of DWFNs has increased from 1.5 thousand t in 1965 to 610.1 thousand t in 1999. It is noteworthy that DWFN experienced a growth ratio of 241% in the 1980s (harvesting 3.8 million during that decade) and in the ‘90s (4.2 million), with a peak catch point of 751.5 million t in 1988.

Figure 2 Catches of DWFNs and other coastal States from the PLME in decades (in thousand t). The lines indicate the intensity of foreign fishing fleet activity in terms of catches.





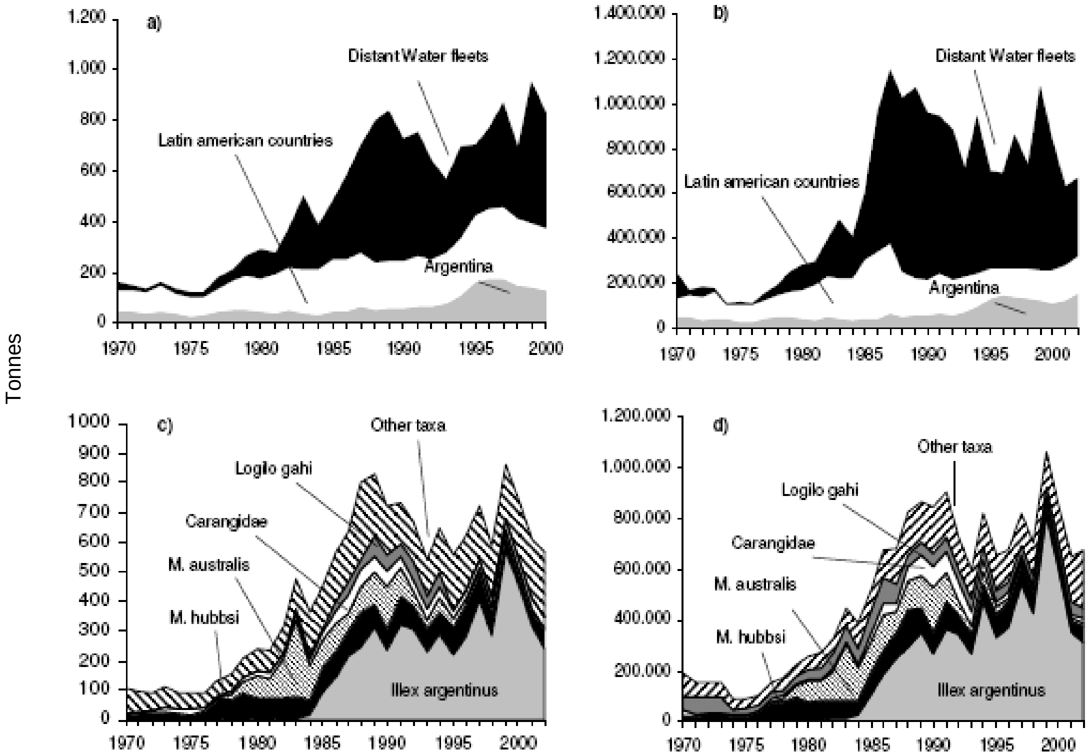
Source: Sea Around Us Database.

The Spanish fleet, mainly High Seas freezers, is one of the most important fleets operating in the area. It operated on an irregular basis between 1960 and 1983, and increased its fishing effort gradually until it reached its highest level in 1990 when the Namibian ground was closed (Portela *et al*. 2005). This change leads to an increase of 50% in the number of vessels operating in the PLME (Figure 2).

Moreover, in the last three decades, catches of Argentinean vessels in the High Seas experienced a significant decrease, going down from 43.8% to 17.4% of the 15.1 million t harvested by all countries in the period 1970-2000, despite the increase in the overall caught volume (from 29.8 to 131.1 thousand t). There is extensive bottom fishing by DWFNs, most of which appears to be taking place within the EEZs of Argentina and the Falklands (Malvinas) (Villasante and Sumaila 2008).

The most important resources harvested in the PLME over time are shared-straddling ones, which represent the 77% of 28.3 million catches (*Merluccius hubbsi* 36.6%, *Illex argentinus* 30.3%, *Micromesistius australis* 6.3% and *Macruronus magellanicus* 3.7%, respectively) in the 1950-2002 period (Figure 3C-D). The significance of these types of stocks increased enormously on the total catches over time, from 9,400 t in 1950 to 946,000 t in 2002 in volume, and from US$ 18.7 million to US$ 1,108.4 thousand million in value (Villasante and Sumaila 2008) (Figure 3A-B).

Figure 3 Catch trends in the High Sea area of FAO (41) Southwest Atlantic Ocean between 1950-2002 **a)** Argentina, Latin American (including Brazil and Uruguay) countries and Distant Water Fishing fleets (South Korea, Taiwan, Poland, Japan, USSR/Russian Federation, Spain, Ukraine, China, Bulgaria, Lithuania, Latvia, Estonia, Germany, Portugal and Italy) (volume in thousand t) **b)** Argentina, Latin American countries and Distant Water Fishing fleets (value, millions U$D) **c)** Main commercial species (volume, thousand t) **d)** Main commercial species (value, millions U$D).

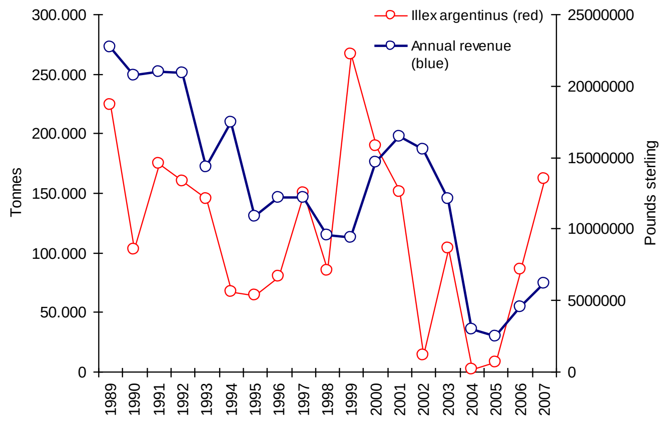


Source: Sea Around Us Database.

Nowadays, the Falklands (Malvinas) fisheries fleet is made up of trawler-jiggers, jiggers, long liners and trawler vessels, most of them foreign flagged vessels (especially European vessels and Spanish vessels flagged to the Falklands (Malvinas)), and vessels owned by joint ventures with Falklands (Malvinas) companies (Antonio Cordeiro, pers. comm.).

In 2007, 58 jiggers received their licenses to fish, generating more than £6.2 million for the local economy, a value significantly lower than those of previous years (£16.4 million in 2001) (FIFD, 2008). Catches in Argentine waters have dropped over the last years: from 338,117 in 1999 to a low of 233,068 t in 2007. As regards the current exploitation status, *Illex argentinus* is fully exploited; the state of Argentine hake *Merluccius hubbsi* (found and caught mostly within the EEZs) is reported as overexploited or depleted, whilst biomass of Southern blue whiting (*Micromesistius australis*) (Wölher *et al*. 2007) and pink cusk-eel (*Genypterus blacodes*) is diminishing (Cordo, 2006); whereas the biomass of Patagonian grenadier (*Macruronus magellanicus*) is increasing as a result of four good years of recruitment (1993, 1995, 1996 and 1998) (Wölher *et al*. 2007a).

Figure 4 Catches (•) and revenues (•) of *Illex argentinus* in Falklands conservation zones.



Source: Falkland Islands Fisheries Department (FIFD).

As regards the *Illex argentinus* fishery, the best catch record registered in Falkland (Malvinas) waters was in a previous period (1997-1999), when daily catches per vessel increased due to the reduction the number of licensed vessels. However, from 2001 to 2002, catches in Falkland (Malvinas) waters plummeted from 150,631 t to 13,411 t. Catches recovered, going up to 103,375 t in 2003 but then dropped to the lowest level in more than 15 years, 1,720 t in 2004, to finally reach 7,936 t in 2005 (Figure 4). In 2004, recruitment, total catches in the Falkland (Malvinas) and Argentine waters, and observed spawning biomass were the lowest on record (Villasante and Sumaila 2008).

This poor performance for 2005 represents the third lowest catch record since the creation of the Fisheries Interim Conservation Zone and Fisheries Outer Conservation Zone. Stock collapses, due to overfishing or/and environmental factors, are likely to negatively impact both Argentinean and Falklands (Malvinas) economies (Barton *et al*. 2004; Agnew *et. al.* 2005). This can be seen by the reduction of the volume (r^2=0.68) and in economic benefits (r^2=0.58) derived from granting Type B licenses for catching *Illex argentinus* from 1989 to 2007.

3.3. Assumptions of the model

The model comes from the pioneer work of Munro (1979, 1990) for transboundary fishery stocks, and later works (Sumaila 1999; Domínguez-Torreiro and Surís-Regueiro, 2007). The countries participating in the fishery are Argentina, the Falkland (Malvinas) Islands and other distant-water fishing fleets (DWFFs) such as those from Spain, as well as Japan, South Korea, Taiwan and China (Villasante and Sumaila 2008).

However, the most important players, Argentina and the Falkland (Malvinas) Islands, provide favorable conditions to apply the traditional bioeconomic model by Munro (1979, 1990) and Sumaila (1997). Using these models, the effects of cooperation and non-cooperation on the biology and on the economic results of the players are analyzed. Considering this analytical framework, we apply the model used by Munro following a series of assumptions with the aim of extending the model, so it adapts to the reality of the *Illex argentinus* fishery. In most of world fisheries, and particularly, in those in the South Atlantic Ocean, the traditional theoretical framework does not reflect the diversity of existing situations. Therefore, starting from the Munro model (1979,

1990) and its extended version of Domínguez-Torreiro and Surís-Regueiro (2007), which is based on two players, in this case Argentina and the Falklands (Malvinas), the following extensions are made:

- The players targeting the stock in the ecosystem are not just Argentina and the Falklands. However, at present no data is readily available for the foreign fleets, then the modeling becomes the only way presented in this work;
- The production functions for each country are different and they reflect the technological differences that exist in their fleets;
- The discount rate for both countries is assumed to be equal, at an annual discount factor φ =1/(1+r) of 0.96, for a long-term rate of 4% (r=0.04);
- The production functions are not linear. Unlike the linear specification proposed in Domínguez-Torreiro and Surís-Regueiro (2007), in this paper a *Gamma* production function is used, because it better represents the trend of the biomass, and because it is necessary to incorporate the high variability of the recruitment;
- The fishing effort is introduced as a variable in the form of catch per unit effort. This is mainly because in the Patagonian shelf effort limitations are employed as the enforced restrictive management mechanism;
- The competitive behavior of the players may be due purely to short term incentives or may take the effect of fishing activity on the resource evolution over time into account. This consideration will also have an effect on the possibilities to reach potential cooperative agreements;
- Other parameters could also be introduced in the model. Nevertheless, data required are difficult to obtain, and this model incorporate the key parameters of the fishery;

- The model introduced is a discrete time model with a finite time horizon, because establishing a fixed time horizon is very common in international fishing agreements. Additionally, the Falkland Islands Fisheries Department (FIFD) established a new legal system in 2005, and model tries to incorporate aspects of this new system.

We also adopted several assumptions about stock migrations and the relationship between stock abundance and catch per unit effort. Following Basson *et al*. (1996), these assumptions are:

- In spite of existing two grounds in the stock at 45º South, we assume a single stock as a reasonable and practical working hypothesis for assessment and management purposes;
- Stocks move between Falkland (Malvinas) Islands EEZs and outside them, and the catchability coefficients of fleets are the same inside and outside the zone;
- Stocks move but the proportion of the total population in each area remains constant.

3.4. The data

Data available for this fishery exists for different periods of time, in various formats and in different levels of detail depending on the reporting fishing country. While fisheries data from some reporting countries may include yearly and monthly catch data, length frequency data, fishing effort, fishing area, etc., and might even be complemented with information on mean weight, sexual maturity and other biological observations, other countries may only report total annual squid catches for the whole FAO Area 41 (Southwest Atlantic Ocean), without further details regarding specific fishing grounds or differentiation by species.

For these reasons, the data for running the model was gathered by the research campaigns conducted annually by the National Institute of Fisheries Research and Development (INIDEP) in Argentina, and by the Imperial College (United Kingdom) in the Falkland (Malvinas) Islands. The initial information used in the model comes from the data of biomass in the area of the Falklands from Agnew *et al*. (2005), for the period of 1987-2001, and from the FIFD for 2002, 2005 and 2007. Catches between 1989-2007 from the FIFD (2005, 2006, 2007, 2008), and recruitment between 1987-2001 from Agnew *et al*. (2005). In the area of Argentina, the biomass data for 1993-1998 comes from Brunetti *et al*. (2000) and from Bertolotti *et al*. (2001) for 1999-2000. Data of catches between 1990-2000 was gathered with information from SAGPYA (2007, 2008) during 1990-2006; and information on recruitment for 1993-2000 from Brunetti *et al*. (2000).

As these official sources do not provide final series data that is sufficiently homogenous and complete, we reconstructed the historic series of the biomass from indirect estimations. Despite the high variability, and taking into account the uncertain estimation of stock biomass, we model the dynamics of the biomass from initial values, combining it with catch data of both countries and the spawning biomass of SSP stock, thus obtaining a total value of the existing biomass in each year of the period of study (Laptikhovsky, pers. comm.). For this reason, we consider the data of the initial number of individuals, catches (in number of individuals), biomass, recruitment and average weight in every week of the squid fishing season in the Argentinean Economic Exclusive Zone and the conservation areas of the Falklands, collected by Brunetti *et al*. (2002, 2006, 2007); complemented with the biomass data by Basson *et al*. (1996) and Agnew *et al*. (2005). Also, all the information published in the Fisheries Bulletins of the FIFD (1989-2007) and the INIDEP scientific reports on the stock (1990-2005) were gathered. Moreover, the FIFD provided us with detailed information about daily catches per vessel for the period to 1990-2000.

The data of ex-vessel prices of *Illex argentinus* for the Argentinean fleet for 1993-2007 was collected from SAGPYA. For the fleet which operates in the Falklands, this information was taken from FIFD (2008) for the same period. In both cases, the information has been contrasted and, in any case, combined and validated with the prices reported by Sumaila *et al*. (2007) and available at the Sea Around Us website. Costs of exploitation were collected from Bertolotti *et al*. (2001) and SAGPYA (2008) for the Argentinean case and from García-Negro (2003) and MRAG (2008) for the Falklands (Malvinas) fleet. There is a reasonable similarity between the Spanish and Faklands (Malvinas) fleet; hence we assume they are similar. Discounts rates, prices and cost parameters, both official and information collected from direct survey were used.

3.5. Estimation of the biomass and limitations

Biomass constitutes a key element which indicates the relative abundance of a given stock (Hilborn and Walters, 1992). The life-cycle characteristic of cephalopods is one of the main reasons for the large inter-annual fluctuations of population densities (Agnew *et al*. 2005). Abundance of *Illex argentinus* is difficult to estimate due to its short lifespan, complicated population structure, and the high inter-annual variability in its population size (Brunetti *et al*. 2000; Basson *et al*. 1996).

There is a high variability of abundance and recruitment of the *Illex argentinus* stock, due to unsatisfactory results, which are generally subject to environmental and biological factors (Agnew *et al*. 2005; Portela *et al.* 2005). This is because in short-lived marine species, such as cephalopods, it is important to take environmental effects on population dynamics into account (De Oliveira 2005). This has meant that the *Illex argentinus* fishery has had to be closed early on a number of occasions, suggesting a relationship between the recruitment and the variations in environmental conditions (Basson *et al*. 1996; Waluda *et al*. 2001; Agnew *et al.* 2005; Portela *et al*. 2005). Also, there are other factors that influence biomass estimations such as depth, temperature, day time and presence and/or absence of clouds. As a result of the influence of all of these, the biomass estimations of *Illex argentinus* are inherently variable (Laptikhovsky, pers. comm.).

Inter-annual variations in the area of confluence of Brazil and the Falklands (Malvinas) currents act as important factors, which influence recruitment and consequently the modification of population size of the winter spawning stock. Authors such as Waluda *et al.* (2001) and Chen *et al.* (2007) have used remote sensing and seasonal series of temperature anomalies of the sea surface temperature (SST) as techniques to relate the influence of environmental conditions to the abundance of the *Illex argentinus* squid. Brunetti *et al*. (2000) assert that the availability of fishery resources with annual or almost annual life cycles, as is the case of *Illex argentinus*, depend to a large extent on the success of reproduction and on the following events, which will lead to recruitment. Brunetti *et al*. (2000) also show that the availability of recruitment effort is the determining factor of the abundance of resources for each fishing season.

According to Basson *et al*. (1996) current evidence from age, growth and genetic studies indicate that a single stock occurs south of 45ºS. So, they assume a single stock 45º South as a reasonable and practical working hypothesis for assessment and management purposes. Thus, there is a need to extend the assessment-methodology to estimate the total stock size rather than only the portion in the EEZ or fisheries conversation zones. There is also a need to relate the management goals to the stock as a whole (Basson *et al*. 1996). In addition, the pre-season scientific assessment of *Illex* *argentinus* is based on the Leslie-DeLury depletion method, which remains the only example that has been used consistently for a number of years (Basson *et al*. 1996). Other post-assessment methods include understanding the relationship between environmental conditions (sea surface temperature) and stock size (Waluda *et al*. 2001; Agnew *et al*. 2005).

In this work, we take the first part of Basson *et al*.'s assumption (1996)[1], although we present an alternative model of estimation of the biomass, which was carried out from data published by Brunetti *et al.* (2000), Bertolotti *et al*. (2001) and Agnew *et al.* (2005). These collect values for the fishing season 1994, 2002 and 2007, i.e., we count on a limited number of observation points. However, to run the model and to carry out the sensitive analysis under different cooperative and non-cooperative scenarios, a seasonal series, which spans the entire period to provide a robust model is needed. Thus, the biomass, which represents the population of *Illex argentinus* increases as time goes by due to the higher weight of each individual over the course of the year. Nevertheless, it is reduced due to the fishing effort it supports. Thus, to express the biomass of the species in each year, a decision was taken to add catches of the Falklands and Argentinean fleets, spawning biomasses, which remained at the end of the fishing season and an estimation of the biomass, which was lost every week due to natural mortality.

The time period chosen for the assessment is a week, being a sensible and convenient time period (Basson *et al*. 1996). The latter was estimated from data from the INIDEP reports on the estimated number of pre-recruitment at the start of the fishing season and the residual biomass estimated for the INIDEP for each year (Brunetti *et al*. 2002, 2006, 2007). For this, unlike the model developed by Basson *et al*.

[1] In the sense that we assume a single stock as a reasonable and practical working hypothesis.

(1996) and Domínguez-Torreiro and Surís-Regueiro (2007), a *Gamma* function was used with specific parameters for the period of weeks when fishing is developed each year, incorporating another relevant parameter as the recruitment. The resulting formula is the following:

$$
\begin{gathered}
Biomass_{t+1} - Biomass_t = (1.166)Biomass_t - (6.5994\mathrm{E}\text{-}07)Biomass_t^2 - Catches \\
t - stat : [5.7001][2.4240] \\
R^2 = 0.6482 \\
R^2 adjusted = 0.6130 \\
MultipleCorrelationR = 0.8051
\end{gathered}
\tag{1}
$$

The results of the estimation of the biomass of stock at 45º South in Argentina and the Falklands (Malvinas) are seen in Table 1. Thus, a high variability in the entire period is observed, with minimum values in 2004 (~130,000 t) and maximum in 1999 (~1,820,000 t).

Table 1 Estimation of the total biomass of the South Patagonic Stock (SPS) at 45º South in Argentina and the Falkland (Malvinas) Islands

Year	Total Biomass (t)	Total Catches (t)
1993	1,080,384	282,665
1994	349,719	189,750
1995	290,234	129,465
1996	494,076	246,077
1997	839,412	523,407
1998	1,164,786	272,748
1999	1,821,676	548,899
2000	1,240,036	452,576
2001	748,445	316,140
2002	358,387	116,692
2003	251,175	222,587
2004	130,715	47,025
2005	395,872	87,262
2006	1,237,515	339,216
2007	1,822,338	377,476

Source: Own elaboration.

We can differentiate three different phases: a first period (1994-1997) with important oscillations of the biomass below 1 million t; a second period follows with a growing tendency (1998-2000) and a third decreasing step (2001-2005), to finally experiment an increase in the last part of the period.

3.6. Estimation of the parameters

To estimate the production function of catches in Falkland Islands and Argentina, due to lack of other information, we used an indicator of the fishing effort, which took into account the number of licenses in a year, for each one of the two fisheries, combined with the number of weeks each fleet operated. The information needed to estimate the production function was gathered from Brunetti *et al*. (2002, 2006, 2007) for Argentina, and from FIFD (2005, 2006, 2007, and 2008) for the Falkland (Malvinas) Islands. The values of the resulting functions are the following:

Argentina:

$$\begin{gathered}\left(\frac{Catches}{Biomass}\right)_t = 3.1487 * \left(\frac{Effort}{Biomass}\right)_t^{0.4577} \\ t - stat : [2.1767][4.9536] \\ R^2 = 0.6537 \\ R^2 adjusted = 0.6270 \\ MultipleCo\ rrelationR = 0.8085\end{gathered} \tag{2}$$

Falklands (Malvinas):

$$\begin{gathered}\left(\frac{Catches}{Biomass}\right)_t = 0.2134 * \left(\frac{Effort}{Biomass}\right)_t^{0.1202} \\ t - stat : [0.8689][0.4196] \\ R^2 = 0.0134 \\ R^2 adjusted = -0.0625 \\ MultipleCo\ rrelationR = 0.1158\end{gathered} \tag{3}$$

The information for the estimation of economic parameters was gathered from Brunetti *et al*. (2002, 2006, 2007), Basson *et al*. (1996) and Agnew *et al*. (2005). The data used for the calculation of the sensitive analysis is shown in Table 2. In turn, one must establish the parameters of negotiation between the two countries, so that the different situations are established under the co-operative scenario. Thus, the players involved in the fishery could reach a potential joint agreement of exploitation and agree on how the total rent generated for the fishery could be distributed.

Table 2 Estimation of biomass, catches and fishing effort of the South Patagonic Stock (SPS) at 45º South in Argentina and Falkland (Malvinas) Islands

Year	**Biomass** (nº of individuals)	**Catches** (t)	**Fishing effort** (hours/year)	**Catches** (t)	**Fishing effort** (hours/year)
	Total	Argentina	Argentina	Falklands	Falklands
1993	1,080,384	137,480	2,150	145,185	2,340
1994	349,719	122,754	2,562	66,996	1,968
1995	290,234	65,343	2,484	64,122	1,320
1996	494,076	166,353	3,750	79,724	1,808
1997	839,412	373,644	3,750	149,763	1,564
1998	1,164,786	187,755	2,575	84,993	1,185
1999	1,821,676	282,698	2,600	266,201	1,462
2000	1,240.036	262,867	2,275	189,709	1,853
2001	748,445	165,509	2,162	150,631	1,972
2002	358,387	103,281	1,240	13,411	1,750
2003	251,175	119,212	2,162	103,375	1,830
2004	130,715	45,305	1,632	1,720	890
2005	395,872	79,325	1,162	7,937	490
2006	1,237,515	253,602	2,175	85,614	731
2007	1,822,338	215,983	1,955	161,493	798

Source: Own elaboration.

In the absence of side payments between parties, a possible agreement between participants is characterized by the following expression:

$$MaxPV = \beta PV_1(1-\beta)PV_2$$
$$\text{where } 0 \leq \beta \geq 1 \tag{4}$$

where *PV* refers to the weighted, discounted, and net flow which corresponds to each one of the participants. Value *β* refers to the value of the parameter of negotiation between countries. Thus, *β*=1 means that the preferences of the country or player 1 will be completely dominant (in our case Argentina), whilst a value *β*=0 signifies that the dominant preferences will be those of player 2 (Falklands (Malvinas)). To determine which value of *β* will come out of the process of negotiation, the Nash's model of co-operative games was followed; where π and *θ* are payments to players 1 and 2, meaning the flow of benefits which result from a determined strategy of exploitation. In this way, π^0 and θ^0 are the benefits which each player could potentially receive in a competitive or non cooperative scenario. Thus, by varying the values of *β*, the Pareto efficient frontier can be determined. β resulting from the process of negotiation will be that which maximizes the expression:

$$Max(\pi^{*}-\pi_{0})(\theta^{*}-\theta_{0}) \qquad (5)$$

The postulates of Nash's cooperative model indicate that no rational agent will accept a payment resulting from the game, which is lower to its threat point. For the case of the cooperative solution, we have calculated the results for values of β=0, 0.15, 0.30, 0.50, 0.70, 0.85 and 1 (Domínguez-Torreiro and Surís-Regueiro 2007). Moreover, information is also needed about the ex-vessel prices of *Illex argentinus*. For both cases, we choose the average ex-vessel prices over the period 2000-2004, to obtain a representative value a price per t of *Illex argentinus* in Argentina of U$D 994 and in the Falklands (Malvinas) a price in the range of U$D 1,862. Moreover, we also estimated the values of the parameters of cost per unit of effort of each fleet which operates in the fishery. Thus, the data of exploitation costs comes from Bertolotti *et al*. (2001) and SAGPYA (2008) for Argentina and from García-Negro (2003) and MRAG (2008) for the Falklands (Malvinas). For Argentina, the cost per unit effort was calculated on exploitation costs of a standard vessel, resulting in a value of cost per unit of effort of U$D 534. For the Falklands (Malvinas), the same procedure was followed but taking into account a standard Spanish vessel, resulting in a value of U$D 816.

4. Numerical results

4.1. Economic results

Once the parameters related to the biomass and catches have been estimated, it is possible to calculate the solutions of the model associated with the prevailing prices, exploitation costs and discount rates. Taking into account all the variables examined, the economic results for two seasonal horizons (5 and 10 years) are presented below. In general terms, by taking a seasonal horizon of 5 years, the results indicate that the greatest economic benefits are obtained with values of $0.3 \leq \beta \geq 0.7$.

Table 3 Summary results for a time period of 5-10 years (Discounted economic rent in million euros (€)

	Cooperative scenario							**Non-coop. scenario**
	β							
	0.0	**0.15**	**0.30**	**0.50**	**0.70**	**0.85**	**1.0**	
5 years								
Profits Argentina	0,0	21,4	29,7	32,4	33,6	34,8	39,0	36,6
Profits Falklands (Malvinas)	111,6	108,0	106,5	105,4	104,5	102,5	0	79,8
Total	111,6	129,4	136,2	137,8	138,1	137,3	39,0	116,4
10 years								
Profits Argentina	0,0	35,7	56,7	59,4	61,8	63,9	73,2	67,5
Profits Falklands (Malvinas)	202,8	199,5	197,5	192,4	185,4	164,1	0	155,5
Total	202,8	235,2	254,2	254,8	246,2	238,0	73,2	222,0

Source: Own elaboration.

For this β value higher benefits are derived under cooperation than under non cooperation. When it comes down to analyzing economic results, and in the absence of side payments, it can initially be seen that as β increases, the economic benefits of Argentina also increases. On the contrary, the economic benefits to the Falklands (Malvinas) decline. Therefore, the Falklands (Malvinas) are always interested in cooperating. However, this situation cannot be extrapolated for Argentina, as it would only cooperate in a situation where β=1, when Falklands (Malvinas) would not be willing to cooperate. Even modifying the time horizon to 10 years, the resulting qualitative values are maintained. As the temporal horizon increases, the possibilities of reaching a long term cooperative agreement are reduced.

4.2. Catches, biomass and fishing effort

As regards catches, a non-cooperative scenario shows greater levels of total catches, with a volume close to 335,000 t. Under the cooperative scenario, the largest catches are obtained for β=0.5, with 227,000 t. In relation to country analysis, the results indicate that if the value of β increases, Argentinean catches increase whilst those in the

Falklands (Malvinas) decreases. The best catches would be obtained in a situation of single owner β=1 or β=0, both for Argentina and Falklands (Malvinas).

With respect to the average yearly fishing effort for the fleet of the Falklands (Malvinas), they are always higher in both a competitive and non-competitive situation including under a single owner. For Argentina, the highest levels of effort are reached in the scenario whereby the Argentinean fleet adopts a dominant position in the fishery.

Table 4 Average estimated values for a time horizon of 10 years

	Cooperative scenario					**Non-coop. scenario**
	β					
	0.0	**0.30**	**0.50**	**0.70**	**0.1**	
Catches Argentina (thousand t)	0	66,5	97,5	104,5	139,5	135,5
Catches Falklands (Malvinas) (thousand t)	205,5	155,5	130,4	114,4	0	199,4
Total catches (thousand t)	205,5	221,0	227,9	214,9	139,5	334,9
F. effort Argentina (hours/year)	0	3,455	5,223	5,677	5,832	6,664
F. effort Falklands (Malvinas) (hours/year)	5,443	4,765	4,612	4,449	0	5,454
Stock biomass (t)	404,543	419,678	412,765	433,213	402,298	325,567

Sources: Own elaboration.

Finally, the best results in terms of the biomass are obtained in the cooperative scenario when value range between $0.3 \leq \beta \geq 0.7$, and in the competitive scenario the biomass is always lower. By comparing the results of the simulation showed with current trends of last years of the fishery. In terms of stock abundance, the closest solution corresponds to a non-cooperative situation. As far as fishing effort levels are concerned, the solution always approaches more the actual data of non-cooperation. Thus, there is a correspondence between what the fishery has experimented over the last few years with a situation of non-cooperation. Also, it should be highlighted that in the cooperative scenario, both players would obtain better economic benefits, because both would reduce the fishing effort and the stock would remain below the reference points recommended by scientists.

5. Policy implications

In terms of fishing policies, this paper is the first attempt to analyse the problem of how to manage the *Illex argentinus* fishery in the Southwest Atlantic Ocean in a sustainable manner by using the appropriate economic concepts and methodology of the game theory. Based on our analysis, the potential for obtaining net benefits from some type of cooperative management of the *Illex argentinus* are huge. In this sense, Gulland (1980) highlights two cooperation levels in international fisheries management: the first of them refers exclusively to research cooperation (primary level) without including coordinated zoning plans. The second level (secondary level) would involve active zone cooperation, i.e., the development and implementation of coordinated programs of shared stocks. If cooperation is not achieved at the primary level, it is obvious that it will not be achieved at the level of active fisheries management. Successful cooperative management approaches prove that cooperation at preliminary research levels has acted as a precursor for cooperation in active management (Sumaila *et al*. 2003).

The shared interest of Argentine and the United Kingdom on fisheries rights in the Patagonian marine ecosystem created the opportunity to re-establish the relationships between them after 1982, and the two governments agreed to open the way for cooperation in the conservation of fish stocks. This culminated in the Madrid declarations that finally created the South Atlantic Fisheries Commission (SAFC) in 1990. Besides, it fosters joint research between the involved parties, which actually has been almost the only scope where bilateral negotiations and agreements have been successful. Since 1994 the INIDEP (Argentina) and the Imperial College (United Kingdom) discuss annually the joint scientific assessment for managing the stock. After that they usually recommend the total annual catches for the whole area.

The experience of this first cooperative level is reasonably productive, agreeing an exchange of catch data and fishing effort data. The main achievements include (i) the exchange data of real-time assessment of the *Illex argentinus*, (ii) programs of joint scientific research, (iii) joint workshops to evaluate the status of some shared species, (iv) the implementation of an early warning system when scientists agree that spawning biomass is likely to fall below the conservation target; so the fishery can be closed (Barton *et al*. 2004). Nevertheless, the tension between the countries emerged again as a result of the Falklands (Malvinas) decision in 2005 to grant fishing licenses around the Falklands (Malvinas) over a 25-year period, rather by an annual renewal, being in force since July 2006. As response, Argentina impounded a British trawler, arguing that it was fishing illegally in the Argentine economic exclusive zone. After paying the penalty the vessel was released. In terms of conservation of the stock, this demonstrates that fishing is, unfortunately, a continued source of disputes between Argentina and the United Kingdom, especially when the stock is still under strong pressure and particularly in years of low abundance. Experience from around the world demonstrates that strong political commitments, at the highest level of government, are required to make joint management work. Therefore, if both countries decide to develop a more cooperative framework, it would have to fully back it up politically.

6. Concluding remarks

The Patagonian large marine ecosystem is one of the most productive ecosystems in the world, with important commercial shared stocks such as *Illex argentinus*. The models developed by using game theory to fisheries management demonstrated the negative consequences of non-cooperation between States or countries. They also showed, by estimating the economic benefits of the cooperative management of shared stocks, the high utility of them to determine viable cooperative solution outcomes.

Game theoretic models provides the necessary tools and conditions to estimate the net present value of the current regime and the potential benefits for Argentina and Falklands (Malvinas) Islands to exploit the *Illex argentinus* fishery in a sustainable way. The preliminary results presented here demonstrated the high predictive power of the theory. The empirical results obtained also suggest that in the cooperative scenario both players would obtain better economic benefits, because both would reduce the fishing effort and the stock would remains below the reference points recommended by scientists. Furthermore, the simulations obtained from the model indicate that there is a correspondence between what the fishery has experimented over the last years with a situation of non-cooperative or competitive scenario.

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