“Nash versus Stackelberg equilibria in a revisited fish war”

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Nash versus Stackelberg equilibria in a revisited fish war game

Abstract

Since January 2008, the fishing agreements between the European Union and ACP (African, Caribbean, Pacific) countries have changed to comply with World Trade Organisation (WTO) rules and improve the management of the fisheries. However, the poor countries depend perhaps too heavily on foreign aids to impose any management system to the distant water fishing nations. A classical game theory approach (fish war model) is revisited to take into consideration the macroeconomic dependence of developing countries and identify the theoretical conditions (time preferences, compensatory payment level, negotiation leadership) under which the stock can increase and the countries share the resources. In this game, each ACP country has its own exclusive economic zone (EEZ) of a natural stock and can fish on its own or partly sell the access to the EU fleet (quota) against a compensatory amount. The Nash equilibrium context is compared to two Stackelberg settings.

Keywords: fish war game, EU-ACP fishing agreements, dependence.
JEL Classification: C72, C78, Q22.

Introduction

Since the extension of the exclusive economic zones (EEZ) under the UN Convention on the Law of the Sea in the late 1970s and the implementation of the Common Fisheries Policy at the beginning of the 1980s, the European Union (EU) negotiates bilaterally (the fishing agreements) and multilaterally (under the various Lomé Conventions since 1975 and the Cotonou agreement in 2000) the access right for the European fleets to fish in the waters of the African-Caribbean-Pacific (or ACP) countries. As early back as June 15, 1979, the first fishing agreement was signed up with Senegal, soon followed by other agreements such as Guinea Bissau in 1980 and the Seychelles Islands in 1984.

In June 2008, some 17 bilateral agreements are in force for an annual lump sum of 161 million euros paid by the EU (not including the access fees paid by the vessel owners which represent approximately some additional 20% to this amount). A large majority of these agreements concern the migratory tuna species which pass by in most of the inter-tropical African (Indian and Atlantic oceans) or Pacific countries' EEZ and can even be found in the high and open sea. In 2003, the USA, Japan, Taiwan, Korea and others paid 48 million euros (68 million USD) for the access to the tuna fisheries of the south west Pacific island countries (Campling et al., 2007).

Although important, these figures appear fairly limited when reported to the gross revenue earned by the northern fleets from the fisheries: between 5% and 10% of gross revenue (Petersen, 2003). The ratio of total access fees (public aid + shipowners license fees) to the catch value restricted to the sole EEZ of a country is probably higher and was estimated in the early 1990s to 18% for the Seychelles, 26% for Madagascar and 45% for Senegal (Iheduru, 1995). However, the average proportion is usually much lower, around 8-10% (Kaczinski and Fluharty, 2002). The case was reported that Papua New Guinea tried in the late 1980s to increase the rate to 6% (instead of the usual 5%) for Japan which in return decided to leave this EEZ for other fishing grounds (Petersen, 2006, p. 132). The threat of losing the access to the rich countries' markets also matters a lot for the developing countries. Most of the seafood products produced or processed by ACP countries enjoy a duty-free entry to the EU markets, as long as the exported goods respect the rule of origin (either EU or ACP/GSP – general system of preferences – origin). However, this privilege is challenged by the new economic partnership agreements (EPA) set under the pressure of the World Trade Organisation (WTO), since the trade advantages may become reciprocal in the future (Sumaila et al., 2007).

The bargaining power is not necessarily in the hands of the resource owners who depend heavily on the EU subsidies for their own economy (Sumaila et al., 2007). For example, the access fees represent 25% of the government revenue for the Marshall Islands, 29% for the Federal States of Micronesia (FSM), 35% for Tuvalu and 61% for Kiribati (Petersen, 2006, p. 30). In Africa, the EU compensation aid amounted up to 45% of the government revenue in Guinea Bissau (Kaczinski and Fluharty, 2002, p. 89) and 75% to 100% of the Ministry of fisheries revenue for a lot of countries (UICN et al., 2005). The seafood industry is not far from valuing 100% of the export revenues sometimes (Marshall Islands, Federal States of Micronesia, Seychelles) and several points of the gross domestic product (Fiji, Seychelles, Samoa, Solomon Islands, Tuvalu, Kiribati, etc.).

Since the Cotonou agreement (June 2000) and the reform of the Common Fisheries Policy (December 2002), a new era is supposedly beginning for the EU-ACP relationships under the so-called fishing partnership agreements (Failler et al., 2005). The FAO objectives of responsible fishing are meant to replace the former "payment for access" agreements. This new orientation takes place in a context of increasing competition with other distant water fishing nations (DWFN: China, Taiwan, Japan, Russia) for the access to fish stocks. The main issue remains: how far a poor country can fish and manage its own EEZ resources without any technical support (monitoring equipment, effective research)? The negative counterpart of this statement explains the high level of dependence of ACP states with regard to foreign aid (Failler and Lécrivain, 2003), meanwhile the consequences of this economic dependence is increasingly difficult to bear for the poor countries. The most severe criticisms are encountered to depict the detrimental impact of fishing agreements on natural resources and local population: overfishing, undernourishment, undercompensation (Posner and Sutinen, 1984), depletion of ecosystems and degradation of local supply chains (Munro and Sumaila, 2002; Alder and Sumaila, 2004). Is the new EU-ACP framework credible to promote sustainable fishing? How deeply the dependence towards northern subsidies affect the domestic fishing strategy of the southern countries?

The famous fish war model (Levhari and Mirman, 1980) is revisited to take into consideration the macroeconomic dependence of developing states. It has been done recently to analyse the outcome of coalitions in such a case (Vallée et al., 2009). The present work identifies the theoretical conditions of the negotiation process with respect to the time preferences of countries and the claim on access fees. The hypothesis could be a higher preference for the future of the less developed country (LDC) since its interest for the resource is expectedly of longer interest than those of foreign countries, but the opposite case has also been considered because several poor countries showed a rather short-term interest for their resources sometimes. First, the Nash equilibria between the EU and an individual ACP state is compared to the cooperative case. In a second step, the negotiation balance is re-examined through the Stackelberg equilibria conditions after considering that one of the partners (either the EU or the LDC) has the leadership.

1. The 2-country model: Nash equilibria

The well-known "fish war game" (Levhari and Mirman, 1980) is used as a basis for the 2-country case. The two states are the E U and LDC exploiting a common and renewable fish stock. Their utility functions are respectively:

$$U_{EU} = \log((1-\alpha_{LDC})x_{EU}) + \beta_{EU}\log(Q - x_{EU} - x_{LDC})^{\tau}, \quad (1)$$

$$U_{LDC} = \log(x_{LDC} + \alpha_{LDC}x_{EU}) + \beta_{LDC}\log(Q - x_{EU} - x_{LDC})^{\tau} \quad (2)$$

with $0 \le \alpha_{LDC} < 1$; $0 < \beta_{EU}$, $\beta_{LDC} \le 1$;

$0 < \tau < 1$; $0 < Q \le +\infty$, and

$$(x_{EU}, x_{LDC}) \in$$

$$D = \{(x_{EU}, x_{LDC}) : x_{EU} \ge 0, x_{LDC} \ge 0,\ x_{EU} + x_{LDC} \le Q\} \quad (3)$$

The β_i parameters reveal the respective preferences of the two partners for the future, τ is the instantaneous growth rate of the fish stock and Q is the total allowable catch. The α_{LDC} parameter is a monetary transfer rate, proportional to the resources extracted by country 1 (EU) and granted to country 2 (LDC) in compensation of the access to its EEZ. This transfer reduces the utility value of country 1, other things being equal, but increases the welfare of country 2 which in turn can self-limit its own catch level.

1.1. The Nash equilibria. Each country will maximise its utility (1) or (2) given the constraints (3) and the other country's output. The non-linear programming problem becomes:

$$\underset{x_{i},\lambda_{i,1},\lambda_{i,2}}{\text{Max}}\ L_i \text{ with } L_i = U_i + \lambda_{i,1}(Q - x_{EU} - x_{LDC}) + \lambda_{i,2}x_i, \quad (4)$$

where λ_{ij} are the Lagrangian multipliers under the constraints (3). The solutions are given by the Kuhn Tucker conditions:

$$\partial L_i / \partial x_i = 0,\ \lambda_{i,1}(Q - x_{EU} - x_{LDC}) = 0,\ \lambda_{i,2}x_i = 0\,. \quad (5)$$

The reaction functions are the following ones, with $T^i : R \to R$, for the country i:

$$\text{EU: } x_{EU=}\frac{(Q - x_{LDC})}{1 + \beta_{EU}\tau} \equiv T_{EU}(x_{LDC}),\ \lambda_{EU,1} = 0,\ \lambda_{EU,2} = 0, \quad (6)$$

$$\text{LDC}: \begin{cases} x_{LDC} \ge 0 \text{ et } x_{LDC} = \dfrac{Q - x_{EU} - \alpha_{LDC}x_{EU}\beta_{LDC}\tau}{1 + \beta_{LDC}\tau} \equiv T_{LDC}(x_{EU}),\ \lambda_{LDC,1} = 0,\ \lambda_{LDC,2} = 0, \\ x_{LDC} = 0 \text{ et } \lambda_{LDC,1} = 0,\ \lambda_{LDC,2} = \dfrac{\beta_{LDC}\tau}{Q - x_{EU}} - \dfrac{1}{\alpha_{LDC}x_{EU}}. \end{cases} \quad (7)$$

Note that some of the figures for the EU catch are such that the non-negativity condition for the LDC catch does not hold. In such a case, the shadow price of the LDC catch becomes different from zero and the quantity harvested is null.

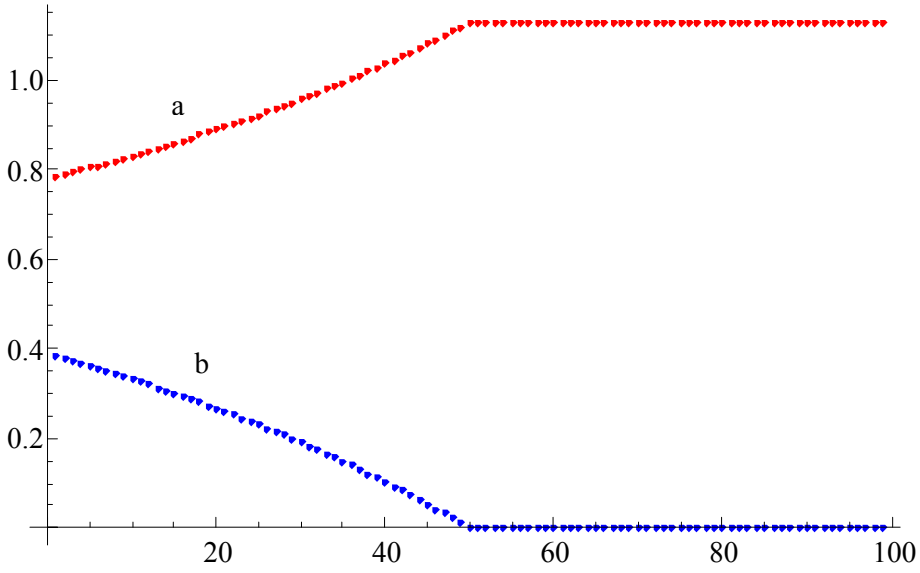
If the EU reaction curve is not different from the original Levhari-Mirman model, the LDC curve is all the more distinct as the proportion of its revenue coming from the access fees paid by the EU increases, meaning that $\frac{\partial T_{LDC}(x_{EU})}{\partial \alpha_{LDC}} < 0$. In other words, the more EU transfers part of its catch earnings to the LDC, the less the latter will go fishing, other things being equal. The LDC can even stop fishing when $x_{EU} \geq \frac{Q}{1+\alpha_{LDC}\beta_{EU}\tau}$. This limit diminishes when the transfer increases.

The Nash equilibria are $(x_{EU}^N, x_{LDC}^N) \in T_{EU} \cap T_{LDC}$ and:

$$\begin{cases} x_{EU}^N = \dfrac{Q\beta_{LDC}}{\beta_{EU}(1+\beta_{LDC}\tau)+\beta_{LDC}(1-\alpha_{LDC})}, \; x_{LDC}^N = \dfrac{Q(\beta_{EU}-\alpha_{LDC}\beta_{LDC})}{\beta_{EU}(1+\beta_{LDC}\tau)+(1-\alpha_{LDC})\beta_{LDC}}, \text{ if } \alpha_{LDC} < \dfrac{\beta_{EU}}{\beta_{LDC}} \\ x_{EU}^N = \dfrac{Q}{1+\tau\beta_{EU}} \text{ and } x_{LDC}^N = 0, \text{ if } \alpha_{LDC} \geq \dfrac{\beta_{EU}}{\beta_{LDC}}. \end{cases} \quad (8)$$

At the Nash equilibrium, the condition for a non-zero LDC catch meets the inequality $\alpha_{LDC} < \frac{\beta_{EU}}{\beta_{LDC}}$. In the case where the LDC country ceases to fish, the optimal strategy for EU does not rely any longer on the LDC parameters.

1.2. Properties of the Nash equilibria. If $\alpha_{LDC} < \frac{\beta_{EU}}{\beta_{LDC}}$, then one can verify that $\frac{\partial x_{EU}^N}{\partial \alpha_{LDC}} > 0$ and $\frac{\partial x_{LDC}^N}{\partial \alpha_{LDC}} < 0$ (see Figure 1).

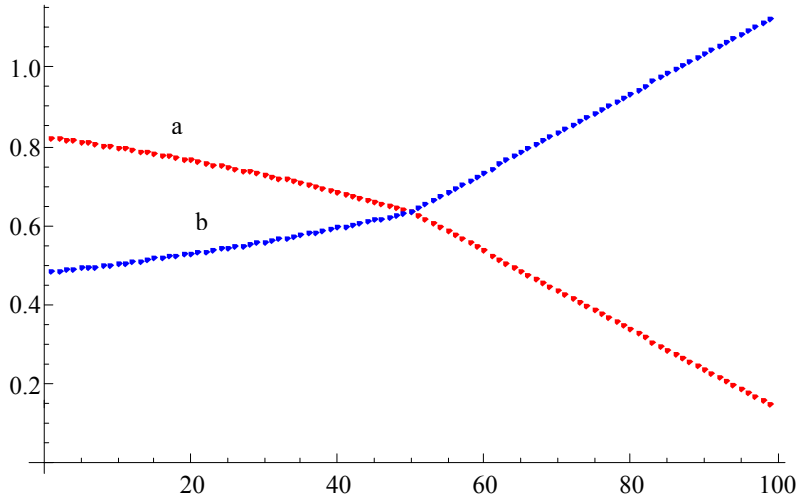


Note: a – EU, b – LDC.

Fig. 1. Evolution of catches under different values of monetary transfer with $Q = 1.259$, $\tau = 0.2852$, $\beta_{EU} = 0.4$ and $\beta_{LDC} = 0.8$

The catch level of the EU will increase if it accepts to pay the LDC state with a higher access fee. Symmetrically, the same rate gives the LDC trade-off strategy between its own catch levels (low values of alpha) or to sell access rights to the EU fleets, hence the negative derivative of the LDC catch to the α-parameter. When alpha increases, the LDC state is getting closer to the limit-value where it stops harvesting.

One can also check that, although the fishing effort of the EU increases with the α-parameter, the "net'' catch of the EU, $x_{EU}(1-\alpha_{LDC})$, reduces with this parameter. Conversely, the net revenue of the LDC increases.

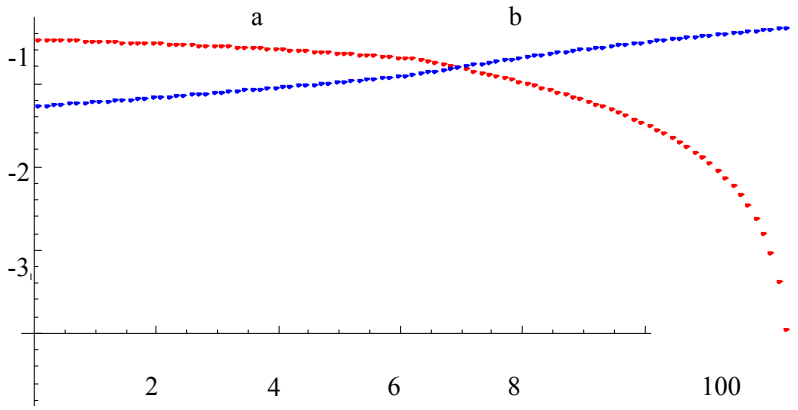


Note: a – EU, b – LDC.

Fig. 2. Evolution of the "net" catch with $Q = 1.259$, $\tau = 0.2852$, $\beta_{EU} = 0.4$ and $\beta_{LDC} = 0.8$

One could also show the sign of the derivatives for UE (see also Figure 3):

$$\frac{\partial x_{EU}^N}{\partial \beta_{EU}} < 0,\ \frac{\partial x_{EU}^N}{\partial \tau} < 0,\ \frac{\partial U_{EU}^N}{\partial \alpha_{LDC}} < 0,\ \frac{\partial x_{EU}^N}{\partial \beta_{LDC}} > 0,\ \frac{\partial U_{EU}^N}{\partial \beta_{LDC}} > 0,\ \frac{\partial (x_{LDC}^N + x_{EU}^N)}{\partial \beta_{LDC}} < 0 \text{ and } \frac{\partial (x_{LDC}^N + x_{EU}^N)}{\partial \beta_{EU}} < 0.$$



Note: a – EU, b – LDC.

Fig. 3. Evolution of the utilities with $Q = 1.259$, $\tau = 0.2852$, $\beta_{EU} = 0.4$ and $\beta_{LDC} = 0.8$

It means respectively that:

- If the EU preference for the future increases, then its catch decreases.
- If the growth rate of the renewable resource increases, the UE catch decreases (because a stock recovery policy would then be preferred).
- If the monetary transfer rate demanded by the LDC is higher, then the utility of the EU diminishes.
- If the time preference of the LDC PVD increases, then the utility of the EU is greater. Indeed, such an increase would result in bigger catches for the EU, both in gross terms than with the transfers off. Along with the diminishing level of total catch, the utility of the EU will improve a lot through the long-term component of the utility function.

For the LDC, with $\alpha_{LDC} < \frac{\beta_{EU}}{\beta_{LDC}}$, we have:

$$\frac{\partial x_{LDC}^N}{\partial \beta_{LDC}} < 0,\ \frac{\partial x_{LDC}^N}{\partial \tau} < 0,\ \frac{\partial U_{LDC}^N}{\partial \beta_{LDC}} < 0,\ \frac{\partial U_{LDC}^N}{\partial \alpha_{LDC}} > 0 \text{ and}$$

$$\frac{\partial (x_{LDC}^N + \alpha_{LDC} x_{EU}^N)}{\partial \beta_{LDC}} < 0.$$

It means that:

- If the preference of the LDC for the future increases, then its catch level decreases and so

does its utility. The utility gain due the additional transfer from the EU which fishes more does not compensate the LDC loss issued by the catch reduction.

- If the growth rate of the natural stock rises, the catch level of the LDC will also decline.
- If the monetary transfer rate increases, the utility of the LDC will rise.

Numerical application: with Q =1.259, $\tau = 0.2852$, $\beta_{EU} = 0.4$ and $\beta_{LDC} = 0.9$. With such values, the LDC stops harvesting if $\alpha_{LDC} > 0.444$.

- If $\alpha_{LDC} = 0$, we have $x_{EU}^N = 0.807$, $x_{LDC}^N = 0.359$, $U_{EU}^N = -0.485$, $U_{LDC}^N = -1.636$, i.e., a total harvested quantity of 1.116.
- If $\alpha_{LDC} = 0.2$, $x_{EU}^N = 0.926$, $x_{LDC}^N = 0.226$, $U_{EU}^N = -0.555$, $U_{LDC}^N = -1.463$, total catches = 1.153.
- If $\alpha_{LDC} = 0.5$, $x_{EU}^N = 1.13$, $x_{LDC}^N = 0$, $U_{EU}^N = -0.805$, $U_{LDC}^N = -1.096$, total catches = 1.13.

Expectedly, the introduction of a positive transfer rate ($\alpha_{LDC} > 0$) will tend to reduce the LDC catch level and increase the EU one. The LDC is better off when the transfer rate increases. Note that total catches are lower with a bigger rate. In other words, improving the bargaining power of the LDC is good for the fishery as it reduces the pressure on stocks (through a declining utility of the EU), even though both players do not co-operate.

2. The 2-country model: Stackelberg equilibrium with the EU leader

Let's assume that EU can anticipate the way LDC will choose its optimal fishing strategy when choosing its own strategy and subsidies rate. The EU can therefore operate as a Stackelberg leader while the LDC would be the follower. This case is the most realistic one since we saw in the introduction that the access right paid by the EU may represent in some cases a high income for the local economy, the latter being furthermore unable to afford a capital-intensive fleet for its high-seas resources like tuna species.

We know that such a Stackelberg equilibrium will lie on the following two-stage process:

1. For any possible catch $x_{EU} \leq Q$ the follower will choose a quantity $x_{LDC} \leq Q$ that solves the following maximisation problem:

$$\underset{0 \leq x_{LDC} \leq Q,\, \lambda_{LDC,1} \geq 0,\, \lambda_{LDC,2} \geq 0}{\text{Max}} \; L_{LDC}$$

with $L_{LDC} = U_{LDC} + \lambda_{LDC,1}(Q - x_{EU} - x_{LDC}) + \lambda_{LDC,2} x_{LDC}$

From previous Section we know that the reaction function of the LDC follower is thus defined by:

$$\text{LDC}: \begin{cases} x_{LDC} \geq 0 \text{ et } x_{LDC} = \dfrac{Q - x_{EU} - \alpha_{LDC} x_{EU} \beta_{LDC} \tau}{1 + \beta_{LDC} \tau} \equiv T_{LDC}(x_{EU}), \;\; \lambda_{LDC,1} = 0, \;\; \lambda_{LDC,2} = 0, \\ x_{LDC} = 0 \text{ et } \lambda_{LDC,1} = 0, \;\; \lambda_{LDC,2} = \dfrac{\beta_{LDC} \tau}{Q - x_{EU}} - \dfrac{1}{\alpha_{LDC} x_{EU}}. \end{cases} \tag{9}$$

Given equation (11), the EU-leader will choose a catch $x_{EU} \leq Q$ solution of:

$$\underset{0 \leq x_{EU} \leq Q,\, \lambda_{EU,1} \geq 0,\, \lambda_{EU,2} \geq 0}{\text{Max}} \; L_{EU} \text{ with } L_{EU} = U_{EU} + \lambda_{EU,1}(Q - x_{EU} - x_{LDC}) + \lambda_{EU,2} x_{EU} \; .$$

At least two Stackelberg equilibria exist when taking into consideration both parts of the reactional function (9), i.e., the LDC respond by a positive or null catch.

Case 1: the LDC still harvests. This Stackelberg equilibrium is defined by:

$$\begin{cases} x_{EU}^{Stack,L} = \dfrac{Q}{(1 - \alpha_{LDC})(1 + \beta_{EU} \tau)}, \;\; \lambda_{EU,1,2} = 0, \\ x_{LDC}^{Stack,F} = \dfrac{Q(\beta_{EU} \tau - \alpha_{LDC}(1 + \beta_{EU} \tau + \beta_{LDC} \tau))}{(1 - \alpha_{LDC})(1 + \beta_{EU} \tau)(1 + \beta_{LDC} \tau)}, \lambda_{LDC,1,2} = 0. \end{cases} \tag{10}$$

Case 2: the LDC does no longer catch fish in its own EEZ. This Stackelberg equilibrium is thus defined by:

$$\begin{cases} x_{EU}^{Stack,L} = \dfrac{Q}{(1 + \beta_{EU} \tau)}, \;\; \lambda_{EU,1,2} = 0, \\ x_{LDC}^{Stack,F} = 0, \;\; \lambda_{LDC,1} = 0, \;\; \lambda_{LDC,2} = \dfrac{(\alpha_{LDC} \beta_{EU} - \beta_{EU})(1 + \beta_{EU} \tau)}{Q \alpha_{LDC} \beta_{EU}}. \end{cases} \tag{11}$$

2.1. Existing condition. If $\alpha_{LDC} < \frac{\beta_{EU}\tau}{1+(\beta_{LDC}+\beta_{EU})\tau}$ then the LDC keeps on fishing and the Stackelberg equilibrium is defined by equation (10). Else, the LDC ceases to fish and the Stackelberg equilibrium is thus defined by equation (11).

Such a condition looks more realistic because it suits more to the usual proportion of the rent that is paid back to the LDC by the EU for the access right. Taking the same application numbers as in the Nash case, the value is around 8.5%, i.e., pretty much in line with those reported in several studies (Petersen 2003, Kaczinski and Fluharty, 2002). Above this threshold, the LDC might simply relinquish to harvest.

3. The 2-country model: Stackeberg equilibria with the LDC leader

Unlike previous Section we shall assume that the leadership is taken by the LDC and the EU becomes the follower of the game. This situation may happen in several cases, either because the LDC partner has also an important local fleet (Morocco, Senegal) or because it owns very fishy waters that cannot be ignored by the EU distant fleet (Mauritania, Seychelles).

In such a case, the resolution of this LCD leader Stackelberg game is given by the following two steps:

1. For any catch $x_{LDC} \le Q$, the EU will set $x_{EU} \le Q$ such that it solves:

$$\underset{0\le x_{EU}\le Q,\lambda_{EU\,1}\ge 0,\lambda_{EU,2}\ge 0}{\mathrm{Max}} \text{ with } L_{EU}$$

$$L_{EU} = U_{EU} + \lambda_{EU,1}(Q - x_{EU} - x_{LDC}) + \lambda_{EU,2}x_{EU}\,.$$

We know from Section 2 that this will give a reactional function for the EU defined by:

$$x_{EU} = \frac{(Q - x_{LDD})}{1+\beta_{EU}\tau} \equiv T_{EU}(x_{LDC}),\ \lambda_{LDC,1} = 0,\ \lambda_{LDC,2} = 0. \quad (14)$$

2. Integrating equation (14), the LDC-leader will set x^*_{LDC} which solves :

$$\underset{0\le x_{EU}\le Q,\lambda_{EU\,1}\ge 0,\lambda_{EU,2}\ge 0}{\mathrm{Max}} \quad L_{LDC} \text{ with}$$

$$L_{LDC} = U_{LDC} + \lambda_{LDC,1}(Q - T_{EU}(x_{LDC}) - x_{LDC}) + \lambda_{LDC,2}x_{LDC}\,.$$

Again, two kinds of Stackelberg equilibria exist depending on whether or not the LCD fishes.

3.1. LCD-leader Stackelberg equilibria with fishing. This outcome is defined by:

$$\begin{cases} x_{EU}^{Stack,F} = \dfrac{Q\beta_{LDC}\tau}{(1+\beta_{LDC}\tau)(1-\alpha_{LDC}+\beta_{EU}\tau)},\ \lambda_{EU,1,2} = 0, \\ x_{LDC}^{Stack,L} = \dfrac{Q(1-\alpha_{LDC}(1+\beta_{LDC}\tau)+\beta_{EU}\tau)}{(1+\beta_{LDC}\tau)(1-\alpha_{LDC}+\beta_{EU}\tau)}\ \lambda_{LDC,1,2} = 0. \end{cases} \quad (12)$$

3.2. LCD leader Stackelberg equilibria without fishing. This outcome is defined by:

$$\begin{cases} x_{EU}^{Stack,F} = \dfrac{Q}{1+\beta_{EU}\tau},\ \lambda_{EU,1,2} = 0, \\ x_{LDC}^{Stack,L} = 0,\ \lambda_{LDC,1} = 0,\ \lambda_{LDC,2} = \dfrac{1+\beta_{EU}\tau - \alpha_{LDC}(1+\beta_{LDC}\tau)}{Q\alpha_{LDC}}. \end{cases} \quad (13)$$

3.3. Existing condition. If $\beta_{EU} \ge \beta_{LDC}$ then the LCD keeps on fishing (equilibrium defined in 3.1). If $\beta_{EU} < \beta_{LDC}$ then, if $\alpha_{LDC} < \frac{1+\beta_{EU}\tau}{1+\beta_{LDC}\tau}$, the LDC keeps on fishing and the Stackelberg equilibrium is defined by 3.1, otherwise the LDC ceases to fish and the Stackelberg equilibria is defined by 3.2. Thus, the greater β_{EU} and the more likely the condition for the LDC to fish will be met as long as the value of β_{LDC} will be lower than that of EU.

Note that, although less realistic than the previous case where the EU was leader, the conditions for LDC fishing are met for many values of alpha (with previous numerical figures, alpha must be simply lower than 0.89).

4. Comparison between Nash and Stackelberg equilibria

4.1. Harvesting conditions. For a given α_{LDC} these conditions can be reduced to:

Nash: $\beta_{LDC} < \frac{\beta_{EU}}{\alpha_{LDC}}$,

Stackelberg EU leader: $\beta_{LDC} < \frac{\beta_{EU}}{\alpha_{LDC}} - \left(\frac{1}{\tau} + \beta_{EU}\right)$,

Stackelberg LCD leader: $\beta_{PVD} < \frac{\beta_{UE}}{\alpha_{PVD}} + \left(\frac{1-\alpha_{PVD}}{\tau\alpha_{PVD}}\right)$.

It is possible to rank these conditions in terms of difficulty (from the less to the more difficult) to meet if the LDC wants to keep on fishing: Stackelberg LDC leader, Nash, Stackelberg EU leader. In other words, even though the LDC may still harvests if he acts as a Stackelberg leader, he may not do so if he plays Stackelberg follower or Nash. The Figure 4 highlights this result (the dark grey part corresponds to the Stackelberg EU leader case, the black one to the Nash case (it includes the dark grey) and the grey one to the Stackelberg LDC leader case (it includes black and dark grey parts)).

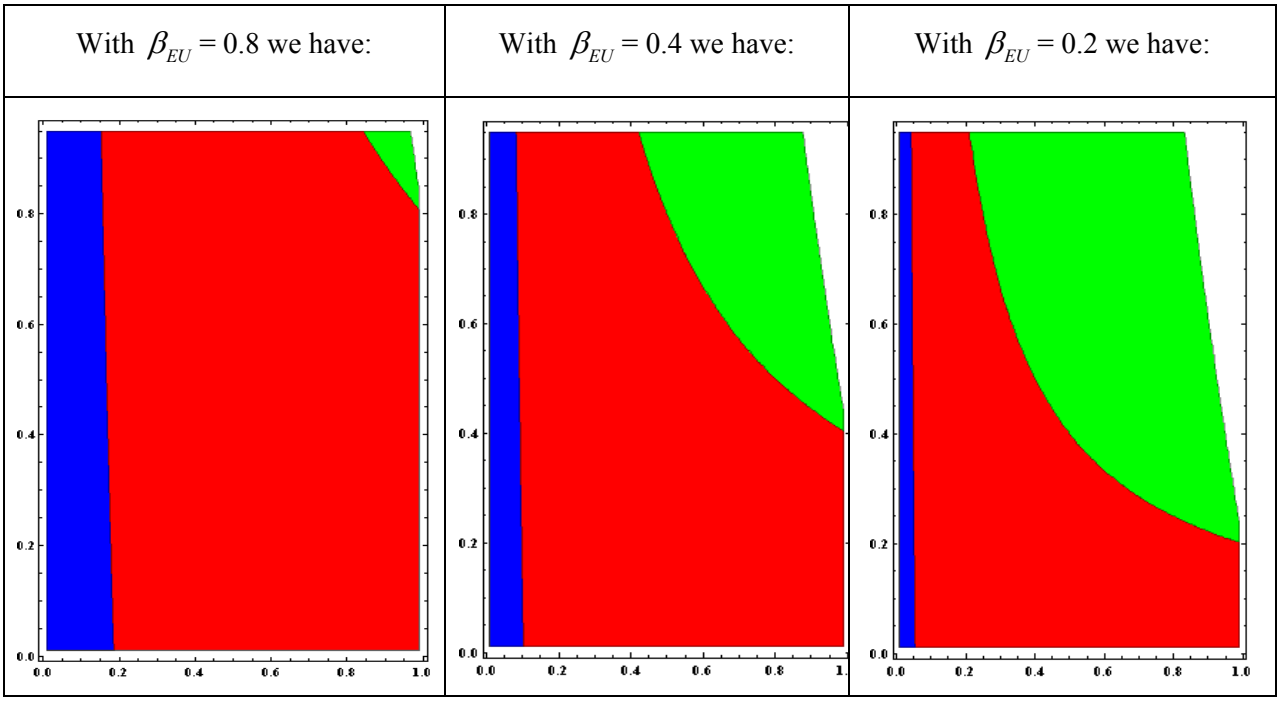
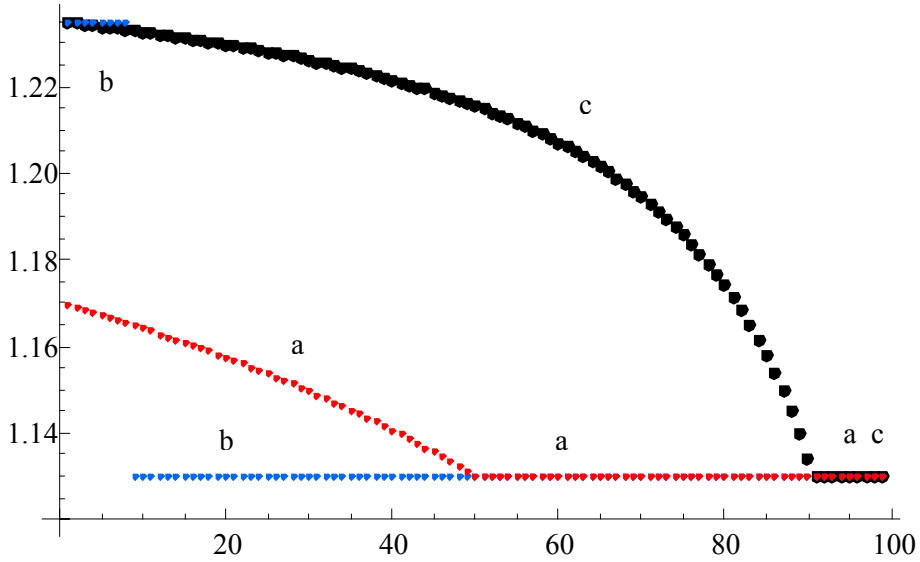


Fig. 4. Evolution of the couple (β_{LDC} , α_{LDC}) compatible with a LDC harvesting

It is easy to check that a decrease of β_{EU} reduces the likelihood of fishing for the LDC to fish.

4.2. Comparison of catches if the LCD harvests. It is possible to check that we always have $x_{LDC}^{Stack,L} > x_{LDC}^{N} > x_{LDC}^{Stack,F}$. That is, the LDC catches will be higher when he acts as a leader than when playing the Nash equilibrium and, even worse, when he acts as a follower of a Stackelberg game. As for the LDC, it is possible to check that we always have $x_{EU}^{Stack,L} > x_{EU}^{N} > x_{EU}^{Stack,F}$. That is, the EU catches will be higher when he acts as a leader than when playing the Nash equilibrium and, when he acts as a follower of a Stackelberg game.

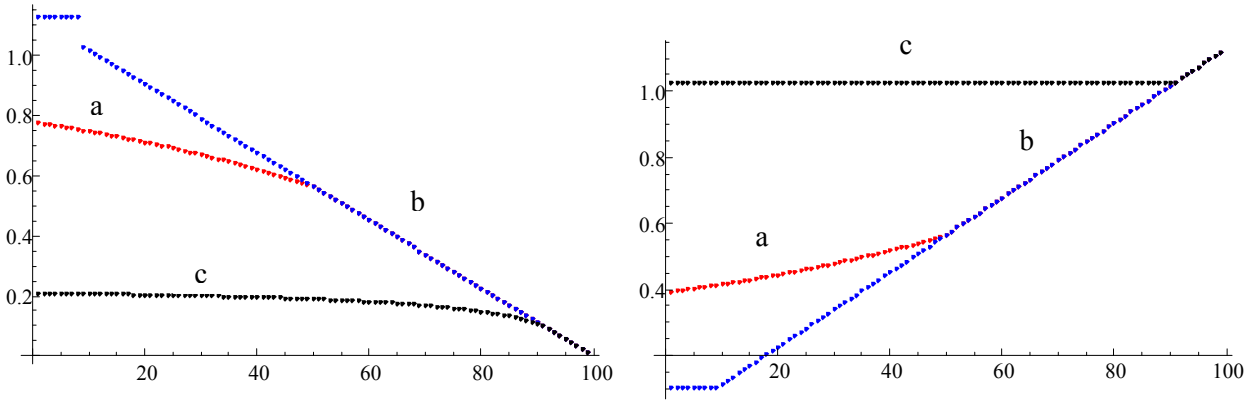
From the total catches point of view we have $(x_{EU}^{Stack,L} + x_{LDC}^{Stack,F}) > (x_{EU}^{Stack,F} + x_{LDC}^{Stack,L}) > (x_{EU}^{N} + x_{LDC}^{N})$ (Figure 4). That is, the total amount of catch will always be higher under Stackelberg equilibrium than under Nash one when everyone is fishing. And, from the Stackelberg point of view, the higher amount is obtained when the EU is the leader. This is normal since we assumed a lower time preference for the future for the EU than for the LDC if we want both partners to fish.



Notes: a – Nash, b – Stackelberg LDC leader, c – Stackelberg EU leader.

Fig. 5. Evolution of the total catches under different values of monetary transfer with Q = 1.259, τ = 0.2852, β_{EU} = 0.4 and β_{LDC} = 0.8

Although the EU catches increase with the monetary transfer value, the net EU catches are almost constant when everyone is fishing under the Stackelberg equilibria. To be a leader allows the LDC to get a high constant value of its net catches (Figure 5).



Notes: a – Nash, b – Stackelberg LDC leader, c – Stackelberg EU leader.

Fig. 6. Evolution of the net catches under different values of monetary transfer with $Q = 1.259$, $\tau = 0.2852$, $\beta_{EU} = 0.4$ and $\beta_{LDC} = 0.8$.

Conclusion

The economic issues at stake within the fishing agreements negotiated between the EU and LDC are broader than the mere fishing industry and embody larger macroeconomic considerations. Beyond the rent-sharing problem between local small-scale fleets and foreign industrial vessels, some small LDC states may rely to a large extent on the financial contribution of the EU as public revenues for other uses than fisheries management. In addition to access-to-resource conditions, the fishing agreements often include as well access-to-market clauses if the LDC exports to the big EU fish markets, for instance through duty-free arrangements or the so-called rule of origin for raw materials utilised by the local processing industry (Oceanic Development, 2005; Campling et al., 2007). In such circumstances, the LDCs become highly vulnerable when negotiating the fishing agreements with the EU and can hardly move towards a more sustainable management of their resources.

To deal with this macroeconomic dependence, the well-known fish war model (Levhari and Mirman, 1980) has been revisited by including a monetary transfer term proportional to the catch of the EU in the LDC exclusive economic zone (EEZ). In a Nash equilibrium context and assuming a long-term interest of the LDC for its own resources than the EU having a higher discount rate, an algebraic condition is defined between the transfer rate and the relative time preferences of the two partners if the LDC still wants to fish in its own EEZ. The derivatives give the partners' welfare and total EEZ catch variations if the claim of the LDC for the fishery (in terms of monetary transfer or more catches) changes.

A more realistic game theoretical framework of Stackelberg leadership either for the EU (first case) or for the LDC (second case) adds complexity to the conditions under which the LDC will continue to fish its own resources. Unsurprisingly, the likelihoodof LDC fishing decreases respectively with a Stackelberg LDC leader, a Nash and a Stackelberg LDC follower status. However, the time preference of the EU also matters significantly. More interestingly, total catch in the EEZ will be more limited in a Nash setting situation than any of the Stackelberg contexts. Further research is needed to test empirically for these preliminary theoretical findings with a comparative set of EU-LDC fishing agreements. In particular, a relationship should be found between the macroeconomic dependence of LDCs vis-à-vis the EU financial contribution and the rent-sharing of resources between local and EU fleets.

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