Sunk costs equal sunk boats? The effect of entry costs in a transboundary sequential fishery.

Abstract: Climate change is likely to result in the uncertain relocation of fish stocks. As a result new countries will emerge that compete for the resource. Although several authors have investigated this issue, most authors assume that entry is free. Although true for some fisheries, this ignores the fact that for other fisheries substantial sunk investments are needed. In this paper I investigate the effect of such sunk entry costs in a sequential fisheries. I model the uncertainty as a shock to the stock dependent fishing costs, in a two player game, where one of the players faces sunk entry costs. I find that, depending on parameters, sunk costs can i) increase the competitive pressure on the fish stock compared to a game where entry is free ii) act as a deterrence mechanism and iii) act as a commitment device. I conclude that entry costs can play a crucial role, and should not be ignored if they are thought to be present.

Keywords: Fisheries, transboundary, sequential fishing, extensive form game, entry costs, real options

JEL: Q22, Q54, D81

1 Introduction

In recent years there has been an increasing interest in the management of fish stocks that are likely to exhibit responses due to climate change. Climate change is expected to have a multitude of yet partly unknown impacts on fish stocks, such as shifts in distributions and changes in recruitment (Britten et al., 2016; Cheung et al., 2010; Rijnsdorp et al., 2009).

These changes pose challenges to the management of these fish stocks, especially when the stocks are transboundary, that is, shared between nations. Additionally, when fish stocks spend part of their life cycle or their full life cycle in the high seas they have to be managed, in principle, by regional fisheries management organizations (RFMOs). In such organizations every country that wants to join the fishery has to be accommodated. Therefore, in principle, they are also shared stocks, although the number of participants is typically larger than with transboundary stocks.

The difficulties in managing these shared stocks have been shown both theoretically for both transboundary fish stocks (see e.g. Clark, 1980; Munro, 1979 for early contributions) and regional fisheries management organizations (Pintassilgo et al., 2010; Pintassilgo and Lindroos, 2008), as well as empirically (McWhinnie, 2009). The literature on achieving cooperative outcomes in management of transboundary stocks and RFMOs is broad. Problems addressed include the influence of sequential fishing as opposed to joint fishing (e.g. Hannesson, 1995; Laukkanen, 2003; McKelvey, 1997), the potential of different sharing rules (e.g. Kronbak and Lindroos, 2007), the influence of marine protected areas (Punt et al., 2010; Punt et al., 2013; Sumaila, 2002), and the influence of the number of players (Hannesson, 1997). A broad overview of this literature can be found in Hannesson (2011) and Bailey et al. (2010). The general message of this literature is that it is hard to engage in cooperative management of fish stocks.

These difficulties in achieving a cooperative outcome are further exacerbated by the potential changes due to climate change. Several authors have looked into the potential effects of climate change-induced changes on stability of fisheries agreements. Ekerhovd (2010) studies how the stability of potential agreements for blue whiting changes with changes in stock distribution. He finds that it basically depends on the direction of the change. Brandt and Kronbak (2010) carry out a similar study for the cod stock in the Baltic. They find that climate change effects reduce the set of stable coalitions if it decreases the resource rents. Walker and Weikard (2016) investigate the influence of a changing stock location on the stability of fisheries agreements within RFMOs. They employ both internal stability and a farsighted solution, called farsighted downwards stability as solution concepts[1]. They find that farsightedness is more likely to result in stable coalitions than internal stability, but that it is also more vulnerable to changes in stock location.

A special case of such changes is a fishery where a new player emerges due to the stock redistribution. Early contributions in this respect come from Mason and Polasky (1994) and Mason and Polasky (2002). They consider an incumbent agent that worries about potential entry in a deterministic two-period model (Mason and Polasky, 1994) and deterministic continuous time (Mason and Polasky, 2002). In both cases they find that the incumbent has an incentive to deter entry by manipulating the current resource stock and future growth. If entry costs fall over time, the incumbent may even find it profitable to drive the resource to extinction (Mason and Polasky, 2002). Hannesson (2007) investigates a stock that stochastically changes its distribution from a sole owner, through a transition period to another sole owner. He finds that extinction is likely in the case of stock-independent harvest costs, and depletion in the case of stock-dependent harvest costs. Diekert and Nieminen (2016) analyze a similar situation with a fish war model[2]. They find that, as the shift progresses the receiving country will decrease its harvest and the losing player will increase its harvest, unless they are constrained by the share of stock available to them. They also investigate the possibilities for cooperation through sharing of the stock, and find that scope for cooperation increases if the shift is slower and less gradual. Ellefsen (2013) investigates the effect of new entrants on the stability of a fishing agreement of mackerel in the North-East Atlantic. He finds that new entrants destabilize fishing agreements, although the effects are mitigated if entry into the fishing agreement is restricted, or prices are heterogeneous. In a follow-up paper Ellefsen and co-authors allow for entry deterrence and ecological uncertainty. They show that entry deterrence has a positive influence on

[1] The difference between these concepts is that internal stability only considers single deviations by players, restricting the other players to the previously formed coalition. Farsighted downward stability also allows other players to respond in kind by leaving the coalition (Walker and Weikard, 2016).

[2] This model has been named after the article "The great fish war: an example using the dynamic Cournot-Nash solution" by Levhari and Mirman (1980) that first introduced this model.

rents compared to a scenario where entry deterrence is not possible, although both scenarios are worse than the cooperative solution. They also show that if countries disagree about the ecological state of the stock, negotiation of a self-enforcing agreement is difficult (Ellefsen et al., 2014).

An important aspect emphasized by these papers is that the possible shifts of stocks due to climate change are uncertain, and therefore future benefits and costs are uncertain. When combined with some kind of commitment or signaling device the uncertainty can be harnessed to deter entry, as is well known from the industrial organization literature[3], although much depends on the type of uncertainty and whether or not information is asymmetrical between incumbent and entrant. Maskin (1999), for example shows that uncertainty about future demand and costs combined with capacity limits entry deterrence possibilities compared to full certainty. Polasky and Bin (2001) show in a two period game that, if a firm has private information about a non-renewable resource stock, it can either use extraction rate to influence beliefs about stock size to deter entry or deter entry by making entry unprofitable. Creane and Miyagiwa (2009) show that a monopolist facing potential entry and uncertain future production costs for both players may forego a cost-reducing invention in order to deter entry.

However, uncertainty is not necessary to be able to deter entry. Another possible mechanism is the existence of sunk entry costs. This aspect has received relatively less attention in the renewable resource literature. Mason and Polasky (1994) and Mason and Polasky (2002) show the importance of sunk entry costs in a deterministic framework, with the above mentioned conclusions. Espínola-Arredondo and Muñoz-García (2013) investigate a similar setting with multiple firms instead of two. They find that entry deterrence is welfare improving relative to when there is no entry threat if the resource is scarce, but welfare losses may arise when the resource is abundant.

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[3] See Gilbert (1989) for an early overview of uncertainty and other possible ways to deter entry in the industrial organization literature.

Although entry costs are thus important in a deterministic framework, because they increase the possibility for entry deterrence, they are even more important in the presence of uncertainty. The reason is that in the presence of uncertainty it may pay to wait with incurring sunk costs until some or all of the uncertainty is resolved, known as the option value in the real option literature (e.g. Dixit and Pindyck, 1994). If, on the other hand, there is competition, this value may be reduced or removed (Dixit and Pindyck, 1994). The literature dealing with the optimal timing of investments in the presence of uncertainty, flexibility and oligopoly is the real option games literature, recently reviewed by Azevedo and Paxson (2014). However, this literature typically deals with continuous time and two potential investors rather than an incumbent and a potential entrant (Azevedo and Paxson, 2014). Finally, sunk costs in combination with uncertainty may act as a commitment device for potential entrants, thereby reducing the threat of entry deterrence by incumbents (Cabral and Ross, 2008).

In this paper I will therefore study the effect of entry costs on a stochastic sequential fishery. I focus on a sequential fishery to simplify the analysis in terms of timing. In addition, whether a fishery is better modeled as sequential or simultaneous fishing is an empirical question because both types exist. My contribution to the literature is that I show the importance and possible effects of entry costs in such a fishery. In such a fishery I find all effects described above, that is, i) the possibility for entry deterrence and, related, overly aggressive harvesting by the incumbent, ii) the possibility of an option value for the entrant, and, related, less aggressive harvesting by the incumbent, and iii) the possibility for commitment, and, related, less aggressive harvesting by the incumbent. Which of these effects dominates is an empirical question.

2 The model

2.1 Preliminaries

Consider a fish stock that currently migrates between the Exclusive Economic Zones (EEZs) of two countries. Until recently the stock could only be profitable exploited by country 1, but recent changes in the climate make fishing potentially profitable for country 2 as well. In addition, a further shock to the distribution of the stock is expected in the future. Fishing, if done by both countries, is sequential: country 1 fishes first, then country 2, and after that the stock regenerates, according to the recruitment function $G(S_{t-1})$, where S_{t-1} is the stock left-over after fishing. Such a setting is most naturally modelled in discrete time.

The price of fish p is infinitely elastic and therefore considered fixed by both countries. Fishing costs are stochastic, and dependent on stock, country and time. I use the discrete version of the Gordon-Schaefer model (see e.g. Clark, 2010), using escapement by country i at time t, E_{it} as the strategic variable. Throughout the paper I use superscript O to denote single country optimal solution levels, A for acquiescence solution levels, E for exclusion levels, and D for deterrence levels. In addition I suppress the time subscript for steady state solutions. I denote the instant cost per unit of harvest of country i at time t by $\frac{c_{it}}{S_t}$. The stochasticity is modeled as a one-time shock, between period one and two, where the costs c_1 of country 1 go up by u_1 per cent with probability q, or go down by d_1 per cent with probability (1-q) and reversed for country 2[4]. Hereafter, costs do not change, and the fishery is assumed to enter into a steady state. Country 2 has the option to enter now, or it can delay its entry, and enter in period 2, after the shock has taken place. If it decides to enter it pays the sunk investment costs F, and can start fishing after country 1 has fished. The resulting extensive form game is illustrated in Figure 1.

[4] For analytical convenience I have chosen to model the effect of climate change as a shock to costs rather than to the stock. This assumption can for example be defended on the grounds that if a stock spends a longer time within the calendar year within one EEZ, fishing the stock there becomes easier and hence, per unit of harvest, cheaper.

Figure 1: About here

Countries are considered to be risk-neutral. The profits for country 1 Π_1 are given by:

$$\Pi_1 =$$
$$\int_{E_{11}}^{G(S_0)} \left(p - \frac{c_1}{v}\right) dv + \frac{q}{\delta}\left(\max\left(\int_{E_{12}}^{G(S_1)} \left(p - \frac{(1+u_1)c_1}{v}\right) dv\,;0\right)\right)$$
$$+\frac{(1-q)}{\delta}\left(\max\left(\int_{E_{12}}^{G(S_1)} \left(p - \frac{(1-d_1)c_1}{v}\right) dv\,;0\right)\right) = \tag{1}$$
$$p(G(S_o) - E_{11}) - c_1 \ln\left(\frac{G(S_o)}{E_{11}}\right)$$
$$+\frac{1}{\delta}\left(\max\left(p(G(S_1) - E_{12}) - (q(1+u_1)c_1 + (1-q)(1-d_1)c_1) \ln\left(\frac{G(S_1)}{E_{12}}\right); 0\right)\right),$$

where δ denotes the discount rate, and the maximum statements represent the fact that it is possible that entry by country 2 makes it unprofitable for country 1 to fish at all.

Should there be no threat of entry the optimal escapement levels E_{11}^{O} for the first period and $E_1^{O,q}$ and $E_1^{O,1-q}$ for the q and non-q branch are the solutions to the implicit equations:

$$\frac{G'\left(E_{11}^{O}\right)}{1+\delta} = \frac{p - c_1/E_{11}^{O}}{p - \left(c_1\left(q(1+u_1) + (1-q)(1-d_1)\right)\right)/G(E_{11}^{O})}$$
$$\frac{G'\left(E_1^{O,q}\right)}{1+\delta} = \frac{p - (1+u_1)c_1/E_1^{O,q}}{p - (1+u_1)c_1/G\left(E_1^{O,q}\right)} \tag{2}$$
$$\frac{G'(E_1^{O,1-q})}{1+\delta} = \frac{p - (1-d_1)c_1/E_1^{O,1-q}}{p - (1-d_1)c_1/G(E_1^{O,1-q})}$$

These equations are modifications of the well-known golden rule of fisheries (see e.g. Clark, 2010). On the left hand side and in the denominator on the right hand side we see the marginal benefit of leaving a marginal unit in the sea in the form of extra growth next year, and reduced expected fishing costs, discounted. In the numerator on the right hand side we have the marginal costs of leaving that unit in the sea in the form of forgone profits.

The profits of country 2, Π_2, are dependent on when it enters the fishery, if at all. They are therefore given by:

$$\Pi_2 =$$

$$\begin{cases} \left.\begin{array}{l} \max\left(p(E_{11}-E_{21}) - c_2 \ln\left(\frac{E_{11}}{E_{21}}\right); 0\right) \\ +\frac{q}{\delta}\left(\max\left(p(E_{12}-E_{22}) - (1-d_2)c_2 \ln\left(\frac{E_{12}}{E_{22}}\right); 0\right)\right) \\ +\frac{(1-q)}{\delta}\left(\max p(E_{12}-E_{22}) - (1+u_2)c_2 \ln\left(\frac{E_{12}}{E_{22}}\right); 0\right) - F \end{array}\right\} \text{Entry period 1} \\ \left.\begin{array}{l} \frac{q}{1+\delta}\left(\max\left(\frac{1+\delta}{\delta}\left(p(E_{12}-E_{22}) - (1-d_2)c_2 \ln\left(\frac{E_{12}}{E_{22}}\right)\right) - F; 0\right)\right) \\ +\frac{(1-q)}{1+\delta}\left(\max\left(\frac{1+\delta}{\delta}\left(p(E_{12}-E_{22}) - (1+u_2)c_2 \ln\left(\frac{E_{12}}{E_{22}}\right)\right) - F; 0\right)\right) \end{array}\right\} \text{Entry period 2} \\ \qquad\qquad 0 \qquad\qquad \} \quad \text{No entry} \end{cases} \tag{3}$$

The possibility for an option value arises because in case the fishing costs go up in the future, the country has the option not to enter the fishery. As such it may pay to wait, rather than invest now. Should country 1 cease fishing the optimal solutions for country 2 are:

$$\begin{aligned} \frac{G'\left(E_{21}^{O}\right)}{1+\delta} &= \frac{p - c_2/E_{21}^{O}}{p - \left(c_2\left(q(1-d_2) + (1-q)(1+u_2)\right)\right)/G(E_{21}^{O})} \\ \frac{G'\left(E_2^{O,q}\right)}{1+\delta} &= \frac{p - (1-d_2)c_2/E_2^{O,q}}{p - (1-d_2)c_2/G\left(E_2^{O,q}\right)} \\ \frac{G'(E_2^{O,1-q})}{1+\delta} &= \frac{p - (1+u_2)c_2/E_2^{O,1-q}}{p - (1+u_2)c_2/G(E_2^{O,1-q})} \end{aligned} \tag{4}$$

The interpretation of these conditions is analogous to those in equation (2).

2.2 Analysis

2.2.1 Period two

I solve the game through backward induction. At the end of the game in Figure 1, all uncertainty has been resolved. If both countries are active in the fishery, that is, country 2 entered either in period 2 or in period 1, then the countries play a standard sequential fishery game, as analyzed in Hannesson (1995). The interior Nash equilibrium of such a game is for each country to maximize its current profits, without regard for future growth. The corresponding escapement levels are: $E_1^{A,q} = \frac{(1+u_1)c_1}{p}, E_2^{A,q} = \frac{(1-d_2)c_2}{p}$, for a q-move, and $E_1^{A,1-q} = \frac{(1-d_1)c_1}{p}, E_2^{A,1-q} = \frac{(1+u_2)c_2}{p}$ for a non-q move. The reason for such behavior is that there is no point in leaving fish to grow since anything left-over will be caught by the other country, if profitable to do so. In cases where country 2's Nash escapement is above E_1^A or where country 1's Nash escapement is above $G(E_2^A)$ we have corner solutions where one country can exclude the other, even without sunk entry costs[5]. In those cases the corresponding escapement levels are $E_1^{E,q} = \min\left(\frac{(1-d_1)c_2}{p}, E_1^{O,q}\right), E_1^{E,1-q} = \min\left(\frac{(1+u_2)c_2}{p}, E_1^{O,1-q}\right)$ for country 1 and $E_2^{E,q} = \min\left(G(E_2) = \frac{(1+u_1)c_1}{p}, E_2^{O,q}\right), E_2^{E,1-q} = \min\left(G(E_2) = \frac{(1-d_1)c_1}{p}, E_2^{O,1-q}\right)$ for country 2.

If country 2 has not entered in period 1, it will enter only if the benefits of entry exceed the costs. Therefore, provided country 2 cannot exclude country 1, on a q branch country 2 will enter if:

[5] To avoid inconsistencies with the probability calculations, I will assume that country 2 cannot exclude country 1 with its harvest decision in period 1. The inconsistency is the following: if country 2 can exclude country 1 on the q-branch, but not on the non-q branch, then the optimal choice for country 2 involves weighing these possibilities by their respective probabilities. This in turn will result in a weighed optimal escapement, but this weighed escapement itself may result in non-exclusion on the q-branch, thus making the calculation invalid. The first time country 2 can exclude country 1 is therefore at the end of period 2.

$$p(E_{12} - E_{22}) - (1 - d_2)c_2 \ln\left(\frac{E_{12}}{E_{22}}\right) + \frac{1}{\delta}\left(p(E_1 - E_2) - (1 - d_2)c_2 \ln\left(\frac{E_1}{E_2}\right)\right) > F \tag{5}$$

And similarly on a 1-q branch:

$$p(E_{12} - E_{22}) - (1 + u_2)c_2 \ln\left(\frac{E_{12}}{E_{22}}\right) + \frac{1}{\delta}\left(p(E_1 - E_2) - (1 + u_2)c_2 \ln\left(\frac{E_1}{E_2}\right)\right) > F \tag{6}$$

If country 2 can exclude country 1, the steady state escapement of country 1 in (5) and (6) is replaced with $G(E_2)$.

These two inequalities show the larger potential for country 1 to deter entry, compared to the absence of entry costs. When there are no entry costs, the only way to keep country 2 out is, if country 1 is at least as efficient as country 2, and can set $E_{12} \leq \frac{(1-d_2)c_2}{p}$ for a q branch and $E_{12} \leq \frac{(1+u_2)c_2}{p}$ for a 1-q branch, making it unprofitable for country 2 to fish at all. This is no longer the case with entry costs; clearly higher levels of E_{12} are now also going to result in (5) and (6) not being satisfied. If country 1 can deter entry in this period it will be able to do so forever as the game is in a steady state. An additional implication of entry costs is that in certain cases country 1 will engage in even more aggressive fishing than under acquiescence.

Lemma 1: If $\frac{1}{\delta}\left(p(E_1 - E_2) - (1 - d_2)c_2 \ln\left(\frac{E_1}{E_2}\right)\right) < F$ and $\frac{(1+u_1)c_1}{p} > E_{12}^D > \frac{(1-d_2)c_2}{p}$ on a q-branch or $\frac{1}{\delta}\left(p(E_1 - E_2) - (1 + u_2)c_2 \ln\left(\frac{E_1}{E_2}\right)\right) < F$ and $\frac{(1-d_1)c_1}{p} > E_{12}^D > \frac{(1+u_2)c_2}{p}$ on a (1-q) branch, where E_{12}^D denotes the escapement level that will deter entry by country 2 in period 2, then if present losses of deterrence are not too high and country 1 is patient, it will set its escapement below the level of current profit maximization, and deter entry forever.

Proof: On the q-branch, given that $\frac{1}{\delta}\left(p(E_{12} - E_{22}) - (1 - d_2)c_2 \ln\left(\frac{E_{12}}{E_{22}}\right)\right) < F$ entry is determined only by current level profits of country 2, and given that $\frac{(1+u_1)c_1}{p} > \frac{(1-d_2)c_2}{p}$, country 2 will always harvest the stock down to $\frac{(1-d_2)c_2}{p}$, if it enters. Country 1 compares the profits of acquiescence with those of entry deterrence:

Acquiescence profits:

$$p\left(G(S_1)-\frac{(1+u_1)c_1}{p}\right)-(1+u_1)c_1\ln\left(\frac{G(S_1)}{\frac{(1+u_1)c_1}{p}}\right)+\frac{1}{\delta}\left(p\left(G\left(\frac{(1-d_2)c_2}{p}\right)-\frac{(1+u_1)c_1}{p}\right)-(1+u_1)c_1\ln\left(\frac{G\left(\frac{(1-d_2)c_2}{p}\right)}{\frac{(1+u_1)c_1}{p}}\right)\right).$$

Deterrence profits:

$$p(G(S_1)-E_{12}^D)-(1+u_1)c_1\ln\left(\frac{G(S_1)}{E_{12}^D}\right)+\frac{1}{\delta}\left(p(G(E_{12}^D)-E_{12}^D)-(1+u_1)c_1\ln\left(\frac{G(E_{12}^D)}{E_{12}^D}\right)\right).$$

Given that $E_{12}^D>\frac{(1-d_2)c_2}{p}$ implies $G(E_{12}^D)>G\left(\frac{(1-d_2)c_2}{p}\right)$, and thus an increase in future returns. This increase comes at a cost since $p\left(G(S_1)-\frac{(1+u_1)c_1}{p}\right)-(1+u_1)c_1\ln\left(\frac{G(S_1)}{\frac{(1+u_1)c_1}{p}}\right)>p(G(S_1)-E_{12}^D)-(1+u_1)c_1\ln\left(\frac{G(S_1)}{E_{12}^D}\right)$, given that $E_{12}=\frac{(1+u_1)c_1}{p}$ maximizes current profits. Which effect dominates depends on parameter values, and crucially on the discount rate versus the growth function of the stock. The proof is similar for the 1-q branch.⌂

The intuition for this result is shown in Figure 2. As a result of the deterrence, growth in future periods is higher, resulting in a gain, but this future growth comes at the cost of current losses as country 1 is overfishing. Of course, since this is future growth, whether or not country 1 chooses to deter depends on the discount rate and the size of the future rewards in the form of additional growth. A similar result is found in the industrial organization literature on limit pricing with capacity, where firms will produce more output to prevent entry than they would under acquiescence in certain cases (see e.g. Gilbert, 1989, p. 484). Moreover, from a welfare perspective, if country 2 would have been active it could have captured these fish without losses. Finally, note that it is even more likely that lemma 1 holds when country 2 can exclude country 1. In that case the acquiescence profits are zero, and as long as an E_{12}^{D} exists that will deter country 2 and results in profitable fishing for country 1, country 1 will deter entry.

Figure 2: About here

Summarizing there are four possible outcomes at this stage of the game:

1. Exclusion of country 1 provided that country 2 has entered in period one or country 1 acquiesces in period two and:
    a. On a q-branch: $\frac{(1+u_1)c_1}{p} > G\left(\frac{(1-d_2)c_2}{p}\right)$, with corresponding escapement level $E_2^{E,q} = \min\left(G(E_2) = \frac{(1+u_1)c_1}{p}, E_2^{O,q}\right)$
    b. On a (1-q)-branch $\frac{(1-d_1)c_1}{p} > G\left(\frac{(1+u_2)c_2}{p}\right)$ with corresponding escapement level $E_2^{E,1-q} = \min\left(G(E_2) = \frac{(1-d_1)c_1}{p}, E_2^{O,1-q}\right)$
2. Sequential fishing provided that country 2 has entered in period one or country 1 acquiesces in period two and:
    a. On a q-branch: $G\left(\frac{(1-d_2)c_2}{p}\right) > \frac{(1+u_1)c_1}{p} > \frac{(1-d_2)c_2}{p}$, with corresponding escapement levels $E_{12} = E_1 = \frac{(1+u_1)c_1}{p}$ and $E_{22} = E_2 = \frac{(1-d_2)c_2}{p}$.
    b. On a (1-q)-branch: $G\left(\frac{(1+u_1)c_2}{p}\right) > \frac{(1-d_1)c_1}{p} > \frac{(1+u_2)c_2}{p}$, with corresponding escapement levels $E_{12} = E_1 = \frac{(1-d_1)c_1}{p}$ and $E_{22} = E_2 = \frac{(1+u_2)c_2}{p}$.
3. Entry deterrence by country 1 provided that country 2 has not entered in the first period and
    a. On a q-branch: country 1 can set $E_{12}=E_1=E_1^{D,q}$ such that (5) is not satisfied and the profits of doing so exceed the profits of acquiescence.
    b. On a 1-q-branch: country 1 can set $E_{12}=E_1^{D,1-q}$ such that (6) is not satisfied and the profits of doing so exceed the profits of acquiescence.

4. No threat of entry by country 2 because entry is not profitable even if country 1 chooses not to deter, that is, (5) and (6) are not satisfied even when country 1 sets escapement levels to $E_1^{O,q}$ or $E_1^{O,1-q}$. Entry is blockaded.

2.2.2 Period one

The outcomes described above for period two obviously have an influence on the outcomes in the first stage. When country 2 considers entry, it compares the payoffs of entry now with delayed entry, weighed by the respective probabilities. This implies that country 2 will enter if and only if:

$$\begin{pmatrix} \max\left(p(E_{11}-E_{21})-c_2\ln\left(\frac{E_{11}}{E_{21}}\right);0\right)+ \\ \frac{q}{\delta}\max\left(p(E_{12}-E_{22})-(1-d_2)c_2\ln\left(\frac{E_{12}}{E_{22}}\right);0\right)+ \\ \frac{(1-q)}{\delta}\max\left(p(E_{12}-E_{22})-(1+u_2)c_2\ln\left(\frac{E_{12}}{E_{22}}\right);0\right)-F \end{pmatrix}$$
$$> \begin{pmatrix} q\max\left(\frac{\left(p(E_{12}-E_{22})-(1-d_2)c_2\ln\left(\frac{E_{12}}{E_{22}}\right)\right)}{\delta}-\frac{F}{1+\delta};0\right)+ \\ (1-q)\max\left(\frac{\left(p(E_{12}-E_{22})-(1+u_2)c_2\ln\left(\frac{E_{12}}{E_{22}}\right)\right)}{\delta}-\frac{F}{1+\delta};0\right) \end{pmatrix} \tag{7}$$

The decision of escapement by country 1 in the second period is influenced by the decision of country 2 to enter in the first stage. For example, if country 1 can deter entry on a 1-q branch, but country 2 enters in period one, then country 1 no longer has the possibility to deter and hence its escapement in period 2 depends on country 2's decision in period one.

To keep things interesting and tractable, I will make the following three additional assumptions:

A.i) Late entry on a 1-q branch is not profitable, either because country 1 will deter, or because the upward shift is so large that entry does not pay in the first place, A.ii) Country 1 cannot prevent entry on the q-branch, and will acquiesce,

A.iii) Upon entry in period one some fishing is profitable.

Basically, A.i and A.ii together imply the possibility, but not the necessity, of an option value. If entry was profitable in both cases waiting has no value and if entry was not profitable in both cases there would be no reason to enter in the first place. Assumption A.iii is made for analytical convenience, and implies that country 2 is more efficient already than country 1 in period one, that is $c_2 < c_1$. In case these three assumptions hold, the entry decision at (7) simplifies to:

$$p(E_{11} - E_{21}) - c_2 \ln\left(\frac{E_{11}}{E_{21}}\right) + \frac{(1-q)}{\delta}\left(p(E_{12} - E_{22}) - (1+u_2)c_2 \ln\left(\frac{E_{12}}{E_{22}}\right)\right) > \left(1 - \frac{q}{1+\delta}\right)F \quad (8)$$

Expression (8) clearly illustrates the option value. The two parts on the left hand side are the gains from investment now: profits in period one, and access to profits in period two, should nature decide on the 1-q branch. On the right hand side we see the gains from waiting in the form of reduced investment costs. The reduction stems from two sources: future costs are discounted, and if country 2 waits, it will only invest on the q-branch. The fact that only the profits on the (1-q) branch matter is an illustration of the "Bad News Principle" (Dixit and Pindyck, 1994, p. 40). Profits under good news do not matter because investment will take place anyway. These profits on the 1-q branch may be small if entry is not profitable at all on the 1-q branch, but considerable if the delayed option is destroyed by country 1 in an entry deterrence strategy. This is a demonstration of the commitment effect of entry costs identified by (Cabral and Ross, 2008).

This commitment effect raises another interesting question: given that country 1 can deter entry on the 1-q branch, can it also deter entry in period 1? I now show that this is not necessarily true:

Proposition 1: The fact that country 1 can deter entry on a 1-q branch of the game does not imply that it can always deter entry in period one as well.

Proof: See appendix.

Lemma 1 described at the second period of the game equally applies in the first period. Country 1 may set its escapement under deterrence in period one lower than under acquiescence in period one. This especially applies if country 2 would be able to exclude country 1 from the fishery in period two, should country 1 acquiesce. In this case, however, not just the discount rate and growth, but also the probability of the q-branch versus the non-q branch plays an important role, as the future profits are weighed by their respective probabilities.

Summarizing, I find the following possibilities for the full game with entry costs:

1. Entry is blockaded by entry costs. There is no threat of entry for country 1 and it can continue to fish at its single country optimal levels with escapements E_{11}^{O} for the first period and $E_1^{O,q}$ and $E_1^{O,1-q}$ on the q and non-q branch respectively.
2. Entry costs allow entry deterrence forever by country 1. Country 1 sets $E_{11}{}^{D}$ such that (8) is not met, and depending on nature's move, $E_1{}^{D,q}$ and $E_1{}^{D,1\text{-}q}$ such that (5) and (6) are not met. Depending on parameter values these escapements may be more aggressive than those under acquiescence.
3. Entry costs delay entry in period 1, and will let country 2 enter only if it faces a positive shock in period 2. The option value dominates. Country 1 sets $E_{11}{}^{D}$ such that (8) is not met, and depending on nature's move country 2 either:
    a. Enters on the q branch followed by sequential fishing with corresponding escapement levels $E_{12} = E_1 = \frac{(1+u_1)c_1}{p}$ and $E_{22} = E_2 = \frac{(1-d_2)c_2}{p}$, or
    b. Enters on the q branch followed by exclusion of country 1 with $E_2^{E,q} = \min\left(G(E_2) = \frac{(1+u_1)c_1}{p}, E_2^{O,q}\right)$

    c. Does not enter on the 1-q branch followed by country 1 escapements of E_{12}=$E_1^{D,1-q}$. Entry is deterred.
    d. Does not enter on the 1-q branch followed by country 1 escapements of E_{12}=$E_1^{O,1-q}$. Entry is blockaded.
4. Entry costs act as a commitment device in period one, as country 1 would be able to deter entry on the 1-q branch. Therefore incurring entry costs makes sure that country 2 can also fish in period two and following if it faces a negative shock in period 2. We have sequential fishing in period one with escapements of $E_{11} = \frac{c_1}{p}$ and $E_{21} = \frac{c_2}{p}$, and in period two either:
    a. Sequential fishing on the q branch with corresponding escapement levels $E_{12} = E_1 = \frac{(1+u_1)c_1}{p}$ and $E_{22} = E_2 = \frac{(1-d_2)c_2}{p}$,
    b. Exclusion of country 1 on the q-branch with $E_2^{E,q} = \min\left(G(E_2) = \frac{(1+u_1)c_1}{p}, E_2^{O,q}\right)$
    c. Sequential fishing on the 1-q branch with corresponding escapement levels $E_{12} = E_1 = \frac{(1-d_1)c_1}{p}$ and $E_{22} = E_2 = \frac{(1+u_2)c_2}{p}$.
5. Entry costs are too small to play a role at all. Country 2 enters in period one and sequential fishing takes place afterwards.

These findings are in contrast with the literature, which finds that when such shifts take place, entry will definitely occur and aggressive overharvesting will take place by the incumbent and the entrant. I show that the existence of entry costs can, but do not necessarily lead to this outcome.

2.2.3 Numerical example

I now demonstrate these outcomes in a numerical example. The recruitment function used is the logistic function:

$$G(S_{t-1}) = S_{t-1}(1 + r\left(1 - \frac{S_{t-1}}{K}\right)$$

Table 1 shows the outcome of the game when all parameters are fixed except the entry costs. This table clearly illustrates the possibilities. As entry costs decrease from high to low the country 2 goes from “wait”, through “deterred” to “entry”, and country 1’s strategy goes from sole-owner, through “delay”, an escapement level below the sole-owner optimum, but above the level required for maximization of current profits, and “fight”, an escapement level below the level required for maximization of current profits, until acquiesce. We also see that country 1 generally tries to keep country 2 out of the fishery for the first period. The reason is that the options available to country 1 are dependent on the state of the world and as such it prefers to keep the possibilities open. Only if it cannot prevent entry in period 1, because of low entry costs, it will allow entry in the first period.

Table 1: About here

3 Discussion and conclusions

Motivated by the uncertain relocation of fish stocks due to climate change, I analyzed the influence of sunk entry costs in a two-player sequential stochastic game in this paper. I find that entry costs can have a range of effects, in line with the existing literature on real option games and industrial organization. Entry costs can act both as deterrence method for the incumbent country and as commitment mechanism for a new entrant. Therefore, entry costs can act as real game changers compared to the case where they do not exist.

In contrast with the existing literature on this issue of shifting stocks I find that the emergence of a new potential fishing nation due to climate change not necessarily leads to overfishing when entry costs exist. If entry costs are high enough overfishing will not occur. Also, entry costs can act as a commitment device and force the incumbent to acquiesce rather than fight off the new entrant. However, medium-high entry costs can induce overfishing by the incumbent, even beyond the level of current-profit maximization, in order to secure future sole-owner access to the stock.

The game I analyze only consists of two periods with one shock. However, in practice such games will be played over longer time spans, with a potential shocks for a number of period. The importance of the transition period and its effects in a setting without entry costs have been shown by Diekert and Nieminen (2016) and is an important aspect to be addressed in future research.

The sequential and discrete nature of this game simplifies parts of the analysis, and allows me to draw sharp conclusions. Some fisheries are perhaps better modeled as simultaneous extraction in continuous time. However, as shown in the literature on real option games, the issue of timing of the investment is problematic in continuous time (Azevedo and Paxson, 2014). The case of simultaneous extraction has been explored by Mason and Polasky (1994) and Mason and Polasky (2002), albeit without uncertainty. I expect much of the results to hold under uncertainty, although with possibly a richer set of potential solutions.

Entry costs are not always relevant because for some fishing nations it may be easy to switch from one stock to another, especially if similar gear is needed. However, when this is not the case, for example when a fleet has to be retrofitted from trawler to demersal fishing or vice versa, these entry costs turn out to have important strategic implications. How large the entry costs are is an empirical question that depends both on the nations and fish stocks involved. The important point that I have shown in this paper is that sunk entry costs should not be ignored if they can reasonably assumed to exist.

Appendix

Proof of proposition 1.

For deterrence in period two on a 1-q branch country 1 has to set the escapement level E_{12} such that:

$$p(E_{12}-E_{22})-(1+u_2)c_2\ln\left(\frac{E_{12}}{E_{22}}\right)+\frac{1}{\delta}\left(p(E_{12}-E_{22})-(1+u_2)c_2\ln\left(\frac{E_{12}}{E_{22}}\right)\right)<F$$

For entry deterrence in period one country 1 needs to set E_{11} such that:

$$p(E_{11}-E_{21})-c_2\ln\left(\frac{E_{11}}{E_{21}}\right)+\frac{(1-q)}{\delta}\left(p\left(\frac{(1-d_1)c_1}{p}-\frac{(1+u_2)c_2}{p}\right)-(1+u_2)c_2\ln\left(\frac{(1-d_1)c_1}{(1+u_2)c_2}\right)\right)<\left(1-\frac{q}{1+\delta}\right)F.$$

Note that the fact that country 1 chooses to deter on the 1-q branch implies that fishing is profitable for country 2 and therefore, should country 2 enter in period one, they will play a standard sequential fishing game in period two. Consequently the future profits of country 2 of entry in period 1 are fully determined.

These two inequalities result in the following implicit inequalities for E_{12} and E_{11} respectively:

$$E_{12}-\frac{(1+u_2)c_2}{p}\ln(E_{12})<\frac{\delta}{(1+\delta)p}F+E_{22}-\frac{(1+u_2)c_2}{p}\ln(E_{22})$$

$$E_{11}-\frac{c_2}{p}\ln(E_{11})<\frac{1+\delta-q}{(1+\delta)p}F+E_{21}-\frac{c_2}{p}\ln(E_{21})-\frac{(1-q)}{\delta p}\left(p\left(\frac{(1-d_1)c_1}{p}-\frac{(1+u_2)c_2}{p}\right)-(1+u_2)c_2\ln\left(\frac{(1-d_1)c_1}{(1+u_2)c_2}\right)\right).$$

Generally these equations are easier to satisfy if the right hand side is larger, or the left hand side is smaller. However, there is a mixture of effects here. Consider the right hand side: the term involving entry costs is higher in the second inequality, but $E_{22}=\frac{(1+u_2)c_2}{p}>\frac{c_2}{p}=E_{21}$, and causes effects in opposite directions for the second and third term. A third term appears in the right hand side of the second inequality representing future profits, decreasing the right hand side. The left hand side decreases faster in E_{12} then it does in E_{11} implying that deterrence is easier in the second period. The latter effect is further strengthened by the fact that fishing costs of country 1 are lower on the 1-q branch in period two. Thus if future profits of country 2 are large, country 1 will not always be able to deter entry in period 1 even if it could deter entry in period 2.

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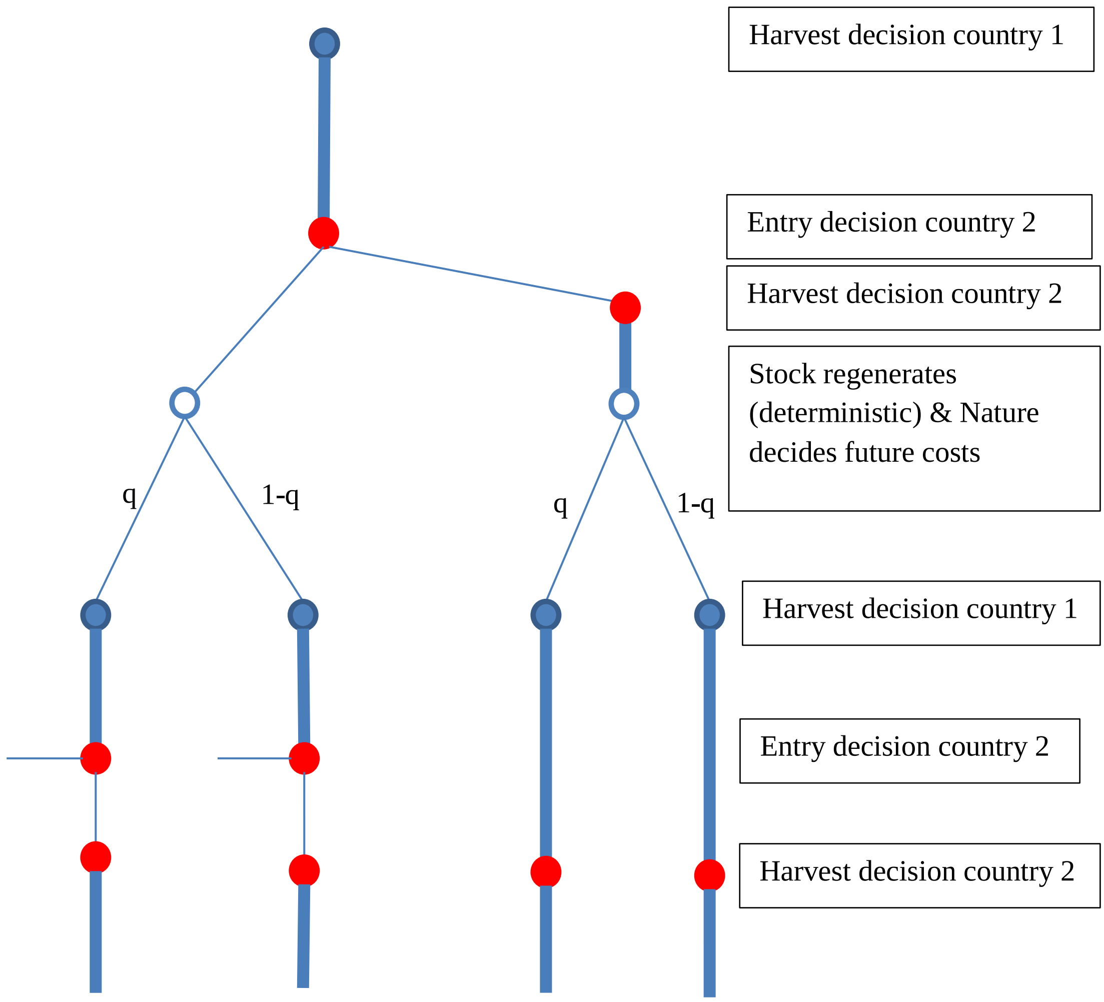

Figure 1: Extensive form game. Blue nodes correspond to country 1 decisions, red nodes to country 2 decisions, and colorless nodes to decisions by nature. Thick branches denote escapement decisions (infinitely many possibilities); branches without nodes signify that the game enters into a steady state afterwards.

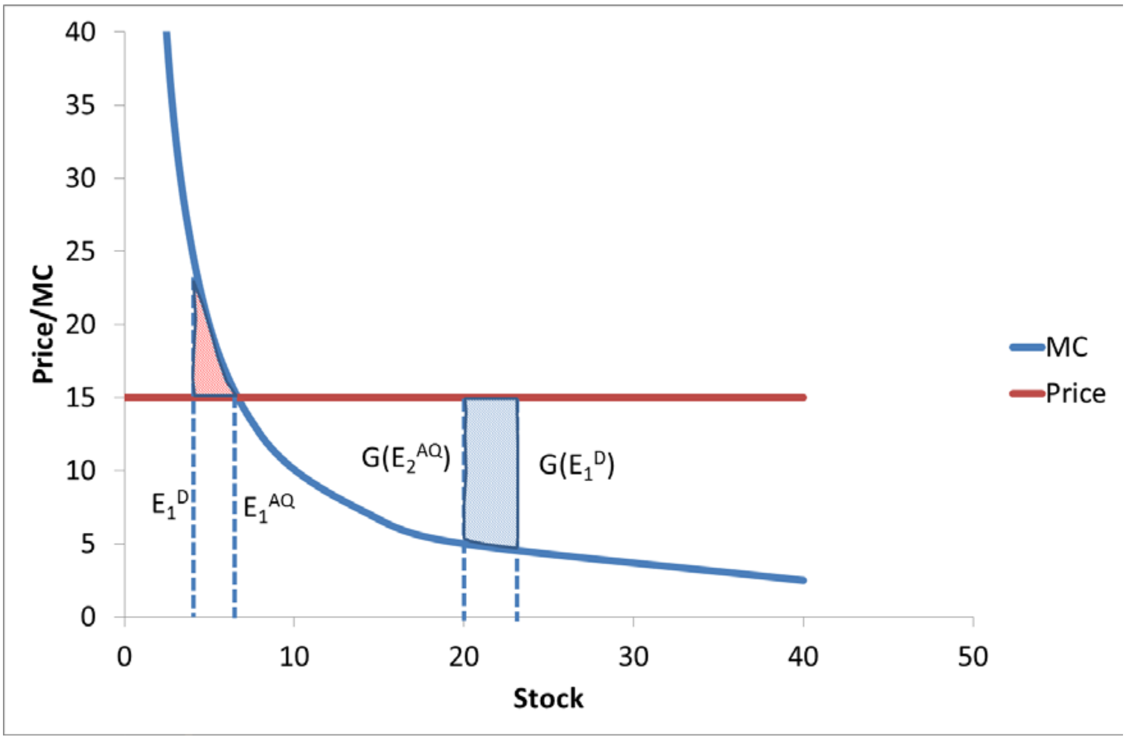

Figure 1: Illustration of lemma 1. Y axis shows the price and marginal costs, the x axis shows stock level. The future gains from deterrence is the area in blue from $G(E_2^{AQ})$ to $G(E_1^{D})$, the current loss is the area in red from E_1^{D} to E_1^{AQ}.

Table 1: Illustration of game outcomes

		Game 1	Game 2	Game 3	Game 4	Game 5	Game 6
Parameter							
p		1	1	1	1	1	1
c_1		0.5	0.5	0.5	0.5	0.5	0.5
c_2		0.4	0.4	0.4	0.4	0.4	0.4
$(1+u_1)c_1$		0.55	0.55	0.55	0.55	0.55	0.55
$(1-d_1)c_1$		0.45	0.45	0.45	0.45	0.45	0.45
$(1+u_2)c_2$		0.42	0.42	0.42	0.42	0.42	0.42
$(1-d_2)c_2$		0.35	0.35	0.35	0.35	0.35	0.35
r		0.9	0.9	0.9	0.9	0.9	0.9
K		1	1	1	1	1	1
δ		11,11%	11,11%	11,11%	11,11%	11,11%	11,11%
q		0.5	0.5	0.5	0.5	0.5	0.5
F		0.15	0.1	0.05	0.015	0.01	0.005
Solution							
Period 1:		Country 1 follows sole-owner optimum, Country 2 waits	Country 1 delays entry, Country 2 deterred	Country 1 delays entry, Country 2 deterred	Country 1 fights, Country 2 deterred	Country 1 fights, Country 2 deterred	Country 1 Acquiesce, Country 2 Enters because otherwise it will be fought on the non-q branch
Period 2	Q branch	Country 1 fights	Country 1 fights	Country 2 enters, sequential harvesting	Country 2 enters, sequential harvesting	Country 2 enters, sequential harvesting	Sequential harvesting
	Non-Q branch	Country 1 delays entry forever	Country 1 delays entry forever	Country 1 delays entry forever	Country 1 delays entry forever	Country 1 fights forever	

For the purpose of this table we define "Fight" as setting an escapement level below the level required for maximization of current profits. "Delay" refers to an escapement level below the sole-owner optimum, but above the level required for maximization of current profits.