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The Beijer Institute of Ecological Economics
The Royal Swedish Academy of Sciences
Box 50005 SE-104 05 Stockholm Sweden
Phone: +46 8 673 95 00 Fax: +46 8 15 24 64
E-mail: beijer@beijer.kva.se

Credible enforcement policies:

The role of ITQs in marine social-ecological systems

José María Da Rocha[1,2], Sebastian Villasante[2,3,4,5,6]*, Rafael Trelles González[1,4]

[1]Campus do Mar – International Campus of Excellence, Spain.

[2]Universita Autònoma de Barcelona and RGEA-Universidade de Vigo. Campus de la UAB, 08193, Bellaterra (Cerdanyola del Vallès), Spain.

[3]Department of Foundations of Economic Analysis, Faculty of Economics and Business Administration, University of Santiago de Compostela, Av. Burgo das Nacións s/n, 15782, Santiago de Compostela, Spain.

[4]Department of Applied Economics, Faculty of Economics and Business Administration, University of Santiago de Compostela, Av. Burgo das Nacións s/n, 15782, Santiago de Compostela, Spain.

[5]Centro Nacional Patagónico, CONICET, 9120 Puerto Madryn, Chubut, Argentina.

[6]Karl-Göran Mäler Scholar, The Beijer International Institute of Ecological Economics, The Royal Swedish Academy of Sciences, P.O. Box 50005, SE-104 05, Stockholm, Sweden.

*Corresponding author: Sebastian Villasante, University of Santiago de Compostela - Campus do Mar – International Campus of Excellence (Spain), Av. Burgo das Nacións s/n, 15782 A Coruña, Spain. Tel: +34 981563100, extension 11649. Fax: +34 981559965. E-mail: sebastian.villasante@usc.es

Abstract

Individual transferable quotas (ITQs) have shown themselves to be fairly effective in generating economic rents in fisheries. This paper shows how the introduction of ITQs can alter agencies' incentives to deviate when time consistency problem exists. Formally, we show that the introduction of ITQs increases agencies' potential benefits of deviating and therefore making difficult building up a reputation. In a one period economy, the government incentive to deviate fishing quotas is motivated by the fact that the collection of fines will only have a negative effect on fishermen's welfare and no effects on fishermen's harvest choices. Under this scenario, the introduction of ITQs reduces the welfare outcome associated with Nash equilibrium. In infinitively repeated economies, we study the set of possible values that the enforcement agency can attain with reputations, that is, the set of all credible enforcement policies. With the introduction of ITQs, the best subgame perfect equilibrium with ITQs is always worse than the best subgame perfect equilibrium without ITQs. Finally, we found a numerical example for which without ITQs it is possible to build a reputation by using worse continuation values than Nash equilibrium.

JEL Classification: 01, C7, D6, Q22

Keywords: marine social-ecological systems, enforcement policies, ITQs

1 Introduction

Humanity has entered the *Anthropocene* era, with human activity a major driving force behind many environmental changes on the planet (Rockström et al., 2009). As result, the future is uncertain and potential catastrophic threshold are in prospect, which will compromise the human welfare (Crépin et al., 2011; Westley et al., 2011; Leach et al., 2012).

In the case of marine social-ecological systems, capture fisheries and aquaculture supplied the world with about 148 million tonnes of fish in 2010, of which about 128 million tonnes was utilized as food for people, and data for 2011 indicate increased production of 154 million tonnes, of which 131 million tonnes was destined as food (FAO, 2012). As result of substantial demand for wild caught fish, the proportion of non-fully exploited stocks has decreased gradually since 1974 when the first FAO assessment was completed, a result of excessive fishing effort, which is estimated to exceed the optimum by a factor of three to four (Anticamara et al., 2011).

It is well known and established in the scientific literature that excessive fishing effort lead to overexploitation and economic waste of common pool resources (Gordon, 1954; Ostrom, 2000; Gelcich et al., 2010; Crépin et al., 2011a, Van Long and McWhinnie, 2012). This result is often considered as a crisis of governance of the oceans (Ostrom, 2000; Young et al., 2007; Österblom et al., 2011; Westley et al., 2011; Galaz et al., 2012).

The management of marine resources is moving away toward new fisheries management and several types of property rights regimes have been proposed and employed to alleviate the fisheries problem in which a range of flexible, multilevel and polycentric mechanisms commonly interact (Ostrom, 2000, 2006; Gutierrez et al., 2011;

Galaz et al., 2012). These include territorial use rights (TURFs), individual catch quotas and community fishing rights, among others (Arnason, 2002).

Individual transferable quotas (ITQs) have shown themselves to be fairly effective in generating economic rents in fisheries (Arnason, 2002, Arnason, 2006; Chu, 2009). Many studies of ITQ systems in operation around the world demonstrate that economic efficiency does indeed improve with the implementation of ITQ schemes (Grafton, 2009).

Costello et al. (2008) recently compared the historical performance of 121 ITQs relative to over 11,000 non-ITQ fisheries. ITQs were associated with a reduced chance of stock collapse, defined by an annual catch falling to 10% of the recorded maximum for that fish stock. The authors argued that ITQs are a “win-win” proposition: fishermen can increase their profitability while halting, or even reversing, the global trend towards widespread collapse.

Bjorndal and Gordon (1993) stated that transferability of current fishing vessel quotas may improve flexibility and efficiency through its potential reduction of harvesting costs. Another benefit is enhanced safety, because the fixed catch shares prevent incentives to “race to fish” early in the season (Clark, 1990; Branch, 2009). Other positive effects of ITQs with respect to stock assessment are that under ITQs, Canadian sablefish TAC overages have been virtually eliminated since the introduction of the system (Munro et al., 2009). While a reduction in fishing effort also thought to have corresponded with a decrease in the fish mortality associated with ghost-fishing, by-catches and discards, the authors have asserted that the ITQ system have produced a dramatic improvement in the sustainability of the fishery (Furness et al., 2010).

However, some controversial issues remain unresolved. For example, Sumaila (2010) stated that whatever the potential economic benefits of ITQs, the system acts contrary to principles of equity and social justice in fishing communities wherever they have been tried, and therefore are not appropriate for managing certain fisheries. In particular, as long as only retained catch must be reported rather than total catch, ITQ programs may encourage high grading. The fisherman has the incentive to "high-grade" the catch, by discarding lower quality fish that count against the quota (Banks et al., 2011). Another concern is related to the initial allocation of quotas (Arnason, 2000, 2002, 2006; Sumaila, 2010). Even in the very liberal New Zealand ITQ system, that issue has been addressed administratively by generally limiting the quota concentration of each stock to 30% (Machal et al., 2009).

Regarding the relationship between fisheries management and enforcement, Hatcher (2005) demonstrated in an ITQ fishery that while lower quota prices are implied unequivocally by expected penalties which are a function of the absolute violation size, the expectation of penalties based upon relative violations of quota demands can, under certain situations, produce higher quota prices than in a compliant quota market. Parslow (2010) recently stated that ITQs in themselves will not prevent a “tragedy of the commons”, unless there is sufficient compliance monitoring and enforcement to deter hidden catches. At empirical level and by using local experiments, Vélez et al. (2012) also recently carried out a local experiment in Colombia and they concluded that if the quota is not enforced well, individual harvesters will always prefer increased enforcement -either increased monitoring or increased penalties- of the quota.

In Europe, management of marine populations are in trouble due to the fact that three out of four stocks are overfished as a consequence of the widespread overfishing in many of them. Overfishing is stems primarily from the overcapacity of the European fishing fleet (Villasante and Sumaila, 2010; Anticamara et al., 2011; European Commission, 2011).

As result, the European fisheries need a radical reform due to the unsuccessful of the Common Fisheries Policy in ecological, economic and social dimensions (CFP) (Markus, 2010; Froese, 2011; Froese and Proels, 2011; Österblom et al., 2011; Da Rocha et al., 2012). Collusion between national fisheries advisers and industry has been suggested as one of the determinants of CFP failure (O'Leary et al., 2011; Froese and Quaas, 2011; Da Rocha et al., 2012). Enforcement— known as adherence to rules and agreements and punishing infractions when they are detected— is an essential component of a successful conservation policy (Ostrom, 2000; Arnason, 2007; Keane et al., 2008; Nøstbaken, 2008).

Froese (2011) and Froese and Quaas (2011) documented the recovery plan for the Atlantic cod fisheries as a case study to illustrate the level of collusion between national fisheries advisers and the industry. Da Rocha et al. (2012) showed that there is a clear pattern between the TAC approved and the reported landings. There is a regular lack of enforcement at national fisheries authority level which affects most of the stocks analysed. Member States fisheries enforcement is lax, with cases where actual catches exceeded the agreed amount by more than 100% (Froese and Proels, 2011).

A number of countries have introduced ITQs in selected fisheries. Canada was among the first countries to implement ITQs in the late 1970s, followed by Zealand (1984) and Iceland (1991) to move towards ITQ-based fisheries management (Arnason, 2006). In Europe, Within the European Union, the Netherlands adopted an ITQ scheme for the important sole and plaice fisheries as early as 1976. In Denmark, an ITQ system for the entire fishery has been in force since 2007 (Andersen et al., 2010).

In this paper we assume that the enforcement authority cannot commit on the initial quotas recommended by scientific committees. We build upon Stranlund and Dhanda (1999) and Chavez and Salgado (2005) to analyse the enforcement authority behavior in a model where the fisherman level of quota violation, non-compliance, is endogenous. As Stranlund and Dhanda (1999) quota violation is induced by an enforcement technology which is insufficient to guarantee full complacence. Unlike previous works, we assume that the enforcement authority chooses sequentially. That is, fisherman's choices are based on their expectations about the enforcing policy.

The enforcement authority is ex-ante interested in reducing illegal captures for increasing the resource productivity. Imperfect enforcement technology induces illegal fishing (Nielander and Sullivan, 2000). Therefore the authority's optimal policy is to use of sanctions. Once quotas have been announced, setting sanctions does not alter fleets' capture levels. As result, the establishment of quotas only reduces fleets' welfare, provided that decisions on capture levels were taken beforehand. Furthermore, once quotas were announced, the agency has incentives to reduce sanctions by increasing the quotas announced and legalize some of the illegal captures.

This paper shows how the introduction of ITQs can alter agencies' incentives to deviate when time consistency problem exists. Formally, we show that the introduction of ITQs increases the potential benefits for agencies of deviating and therefore makes it difficult building up a reputation. In this sense, the introduction of ITQs does not help building up credible threats (that are subgame perfect equilibrium). Optimal policies that prevent governments from deviating become useless when ITQs are introduced.

This paper is organized as follows. Section 2 builds upon Stranlund and Dhanda (1999) and Chavez and Salgado (2005) in establishing the role of commitment in a model of compliance. Section 3 shows the role of Individual Transferable Quotas. The results are illustrated in Section 4. Section 5 concludes.

2 The One Period Economy

Although we assume that fishermen and the enforcement agency live in an infinitively repeated economy, we start by describing the one-period economy and showing that in an infinitively repeated economy the enforcement agency will behave opportunistically the last period, implying that nothing better than a Nash outcome can be supported. There is a continuum of identical fishermen, each of whom take the average fisherman's choices as given. Moreover we assume that fishermen's behavior can be summarized as a competitive equilibrium that responds non-strategically to the enforcement agency's behaviour, i.e., the only strategic agent in the model is the enforcement agency.

Assume that fishermen's profits are given by

$$h(e)-\frac{c}{2}e-\theta f(\upsilon)+T$$

where the harvest level $h(e)=\sqrt{Ae}$, which is strictly increasing in fishing effort, the marginal cost of harvesting is constant and equal to *c*, υ is the quota violation, $\upsilon=h(e)-q\geq 0$ and, finally, *T* is a lump sum transfer received by fishermen from the enforcement agency. Note that the average quota per vessel is non transferable.

We assume that total factor productivity, $A>0$, is a public good. Although fishermen take it as given, it is determined by total harvesting. We assume that stock productivity decreases as total harvesting increases, that is:

$$A=h^{-\beta}$$

Assume that the technology of detection, θ, is not sufficient for guarantying full compliance and that penalties $f(\upsilon)$, are imposed by courts (with backdating being forbidden). As in Stranlund and Dhanda (1999), we assume that the penalty function, $f(\upsilon)$ is zero for zero quota violation, $\upsilon = h(e) - q = 0$, and strictly increasing and convex for a positive quota violation, $\upsilon = h(e) - q > 0$. We assume as Chavez and Salgado (2008) that $f(\upsilon) = \left(\frac{\alpha}{2}\right)\upsilon^2 + \gamma\upsilon$, with and γ greater than zero. Therefore, the enforcement agency only chooses that average quota per vessel, $\bar{q}$.

2.1. Competitive Equilibrium

When a fisherman believes that the enforcement agency's choice is $\bar{q}$, the fisherman chooses his fishing effort e, and his quota violation υ by solving

$$\left.\begin{array}{l} \max_{e,\upsilon} \sqrt{Ae} - \frac{c}{2}e - \theta f(\upsilon) + T \\ s.t \{A, \bar{q}, T are given \end{array}\right\} \quad (1)$$

A Competitive Equilibrium for this economy is a fishing effort e and quota violation such that:

a) Given fishermen's (rational) expectations on $\bar{q}$ and A fishing effort e and quota violation υ solves the fishermen problem equation (1).

b) Total factor productivity is given by total harvest, i.e., $A = h^{-\beta}$.

Note that a Competitive Equilibrium satisfies fisherman's choices, $h = \upsilon + \bar{q}$, and is the best response for the enforcement agency's choice, $\bar{q}$. Then,

Lemma 1. *The set of Competitive equilibrium is*

$$C = \left\{ (h, \bar{q}) \,\middle|\, h = g(\bar{q}) \right\}$$

where the fisherman's best response to the enforcement agency's choice is given by

$$1 - c(\upsilon + \bar{q})^{1+\beta} - \theta f'(\upsilon) = 0$$

Figure 1 illustrates how the competitive equilibrium depends on the level of quota. As in Chavez and Salgado (2005), as quota increases, illegal fishing decreases but total harvest increases.

[INSERT FIGURE 1 ABOUT HERE]

Moreover, average productivity of the resource decreases as the quota increases. As a result, there exists an interior quota for which the private marginal benefits of increasing harvest are equal to the marginal social cost (associated with lower total productivity of the resource).

2.2 Ramsey problem

Assume that the enforcement agency commits itself to a quota $\bar{q} \in Q$.We assume that a fraction, λ, of the fines collected by the government, $\theta f(\upsilon)$, is used to pay the costs. Therefore, the transfer made to fishermen is

$$T = (1-\lambda)\theta f(\upsilon) - \psi\bar{q} \tag{2}$$

where, ψ, is a cost associated with using quotas. Given that for each quota, fishermen choose $\upsilon = g(\bar{q})$, the enforcement agency evaluates quotas, $\bar{q}$, by solving

$$\max_{\bar{q}} \pi\left(g(\bar{q})\right) - \lambda\theta f(g(\bar{q}) - \bar{q}) - \psi\bar{q} \tag{3}$$

Note that fishermen's net profits

$$\pi\big(g(\bar{q})\big) = g\bar{q} - \frac{c}{2}\,\pi\big(g(\bar{q})\big)^{2+\beta}$$

depend on total harvest $h = g(\bar{q})$. Denote the enforcement agency pay off associated with the solution of equation (3), $\bar{q}^R$, as $r^R = r(g(\bar{q}^R), \bar{q}^R)$.

Proposition 1. *Assume that equation (3) has an interior solution. Then,* if $\psi \longrightarrow 0$, *fishermen's net profits decrease with harvest, i.e.,* $\frac{\partial \pi}{\partial h} < 0$.

Proposition (1) reveals that the government agency finds it optimal to increase quotas so as to reduce the fines associated with the illegal fishing. Given the existing lack of commitments, the enforcement agency finds a "time consistency problem". That is, the enforcement agency can announce $\bar{q}^R$ and induce fishermen's to choose a level of illegal fishing $g(\bar{q}^R) - \bar{q}^R$. The agency deviates from $\bar{q}^R$ after fisherman choose $h^R = g(\bar{q}^R)$. Note that in general $\hat{q} \neq q^R$, where

$$\hat{q} = arg\max_{\bar{q}} r(g\bar{q}^R),\ \bar{q}$$

Note that the government incentive to deviate is motivated by the fact that the collection of fines will only have a negative effect on fishermen's welfare and no effects on fishermen's harvest choices. Therefore the enforcement agency finds it optimal to legalize illegal fishing by using more quotas. That is $\hat{q} > \bar{q}^R$.

2.3 Nash equilibrium

Given that the enforcement agency finds a "time consistency problem", Ramsey plans are non credible. That implies that although the enforcement agency announced q^R, fishermen forecast that the agency will set a quota q, solving

$$\max_{\bar{q}} - \lambda\theta f(h - \bar{q}) - \psi\bar{q} \tag{4}$$

Therefore, Nash equilibrium is the natural outcome when fisherman choose first, forecasting that the agency will respond to the optimal harvest, $h = g(\bar{q})$, by setting the optimal quota $\bar{q} = G(\upsilon)$. Therefore a Nash equilibrium, $(\upsilon^N, \bar{q}^N)$, satisfies the following:

a) It is a Competitive equilibrium $(h^N, \bar{q}^N) \epsilon\, C = \{(h, \bar{q}) | h = g(\bar{q})\}$. That is, given fishermen's (rational) expectations on $\bar{q}$ and ω, fishing harvest e, quota demand q and quota violation υ solves the fishermen problem equation (1).

b) Given h^N, enforcement agency chooses a quota $\bar{q}^N$, by solving equation (4). Equation (4) can be used to define the enforcement agency's best response function $\bar{q} = G\,(h)$.

Lemma 2. *The enforcement agency's best response function $\bar{q} = G(h)$ is*

$$\lambda\theta f'^{(h-\bar{q})} = \psi$$

Therefore the Nash equilibrium is

$$h = \left(\frac{1-(\psi/\lambda)}{c}\right)^{\frac{1}{1+\beta}}$$
$$\upsilon = \left(\frac{\psi}{\theta\lambda} - \gamma\right)\frac{1}{\alpha}$$
$$\bar{q} = h - \upsilon$$

Note that in a Nash equilibrium everyone has rational expectations. Given that individual fishermen expect an aggregate of h^N and a quota $\bar{q}^N$, they respond by setting $h^N = h\,(\bar{q}^N)$. The enforcement agency expects h^N, and responds setting $\bar{q}^N = G(h^N)$. Denote the enforcement agency payoff associated with the solution of equation (4), $\bar{q}^N$, as $r(h^N, \bar{q}^N)$. It is clear that

$$r(g(\bar{q}^R), \bar{q}^R) \geq r(h^N, \bar{q}^N)$$

Figure 2 shows the welfare outcome values associated with Ramsey, Nash and the “time consistency" problem. Note that the welfare outcome associated to the “time consistency" problem, that is when the enforcement agency deviates, is greater than the outcome value associated with Ramsey. However, welfare outcome values associated with Nash are smaller than outcome values associated with Ramsey.

[INSERT FIGURE 2 ABOUT HERE]

3 The role of ITQ’s

Consider now that individual quotas are transferable. That is, as in Chavez and Salgado (2005) fishermen’s profits are given by

$$h(e) - \frac{c}{2}\, e - \theta f(\upsilon) - \omega q + T$$

where q is the individual quota demand and ω is the quota price. When a fisherman believes that the enforcement agency's choice is $\bar{q}$, the fisherman chooses his fishing effort e, his quota demand q and his quota violation υ by solving

$$\left.\begin{array}{c} \max\limits_{e,q,\upsilon} \sqrt{Ae} - \frac{c}{2}\, e - \ \theta f(\upsilon) - \ \omega q + T \\ s.t \begin{cases} \upsilon = \sqrt{Ae} - q \geq 0, \\ A, \omega, \theta, T \ are \ given. \end{cases} \end{array}\right\} \tag{5}$$

A Competitive Equilibrium for this economy comprises a fishing effort e, quota demand q and quota violation υ such that:

a) Given fisherman's (rational) expectations on $\bar{q}$ and ω, fishing effort e, quota demand q and quota violation υ solves the fisherman problem equation (5).

b) The quota market clears, i.e., $q = \bar{q}$.

c) Total factor productivity is given by total harvest, i.e., $A = h^{-\beta}$.

The following lemma shows that the fisherman's best response for the enforcement agency's choice, $\bar{q}$, i.e. the set of competitive equilibrium, is not affected by the creation of ITQ's.

Lemma 3. *TQ's do not modify the fisherman's best response to the enforcement agency's choice when quotas are non transferable. Formally the set of competitive equilibrium with ITQ's C_{itq} is equal to C. ITQ's prices associated with the competitive equilibrium are given by $\omega = \theta f'(\upsilon)$.*

Note that as in Chavez and Salgado (2005) quota price, ω, is decreasing in illegal fishing. The existence of ITQs, modifies government transfers.

$$T = (1-\lambda)[\theta f(g(\bar{q}) - \bar{q}) + \omega(\bar{q})\bar{q}] - \psi\bar{q}$$

Therefore, the enforcement agency evaluates quotas, θ, by solving

$$\max_{\bar{q}} \pi\left(g(\bar{q})\right) - \lambda\left[\theta f\left(g(\bar{q} - \bar{q})\right) + \omega\left(g(\bar{q})\right)\bar{q}\right] - \psi\bar{q} \tag{6}$$

Denote the enforcement agency payoff associated with the solution of equation (6), $\bar{q}_{itq}$, as $r_{itq}^R = r_{itq}\left(g\left(\bar{q}_{itq}^R\right), \bar{q}_{itq}^R\right)$.

The following proposition shows that the introduction of ITQs increases the incentive to deviate from θ_{itq}^R.

Proposition 2. *Assume that* $\psi \longrightarrow 0$, *then under ITQ's the enforcement agency's best response function* $\bar{q} = G(h)$ *is*

$$\bar{q} = h$$

Proposition 2 reveals that the introduction of ITQs increases the incentive to deviate. Where there are no ITQs, the government agency that cannot commit has the incentive to legalizing a fraction of the illegal fishing and reduce fines. With ITQs, the government agency faces a new incentive to legalizing the illegal fishing: by doing so can reduce ITQs prices. When this new incentive appears, the Nash equilibrium under the ITQs regime is worse than the one without ITQs (Figure 3).

Lemma 4. *Under ITQs, the Nash equilibrium is*

$$h = \left(\frac{1-\theta\gamma}{c}\right)^{\frac{1}{1+\beta}}$$
$$v = 0$$
$$\bar{q} = h$$

The welfare outcome associated to the Nash equilibrium is lower with ITQs than without them, that is

$$r(h^N, \bar{q}^N) \geq r\left(h^N_{itq}, \bar{q}^N_{itq}\right)$$

[INSERT FIGURE 3 ABOUT HERE]

4 Infinitely repeated economy

This section extends the analysis of the one period economy to an infinitively lived economy. That is, the preceding one-period economy is repeated forever. Each fisherman and the enforcement agency, respectively, evaluate paths, $\vec{h} = \{h_t\}_{t=1}^{\infty}, \vec{\bar{q}} = \{\bar{q}_t\}_{t=1}^{\infty}$, according to

$$V_f\left(\vec{h}, \vec{\bar{q}}\right) = \frac{1-\delta}{\delta} \sum_{t=1}^{\infty} \delta^t\, v(\xi, h_t, \bar{q}_t)$$

$$V_g\left(\vec{h}, \vec{\bar{q}}\right) = \frac{1-\delta}{\delta} \sum_{t=1}^{\infty} \delta^t\, r(h_t, \bar{q}_t)$$

where $r(h_t, \bar{q}_t) = v(\xi, h_t, \bar{q}_t)|\xi = h$, and $\delta \in (0,1)$ is the discount rate.

Rather than focusing on strategy profiles, we follow the approach developed by Abreu et al. (1986, 1990) who characterize reputational equilibrium as solutions of a recursive problem. We seek to determine under which conditions the government agency might sustain Ramsey equilibrium, based on a system of history dependent expectations interpretable as “reputation". For each period the enforcement agency makes its choice taking into account that its decisions determine a first-period return and a reputation continuation value to pass on to the next period. We study the set of possible values that the enforcement agency can attain with reputations, i.e., that is, the set of all credible enforcement policies.

4.1. Reputational mechanisms

The key idea of the method described by Abreu et al. (1986) is that associated with the continuation values $(V_1, V_2) \in V \times V$ there is a possible subgame perfect equilibrium (SPE), σ, with value $\nu \in V$. That is, the value associated with all SPE plays a central role in the reputational methods of Abreu et al. (1986, 1990).

Following Ljungqvist et al. (2004), let us start by defining the set of SPE,

$$V = \{V_G(\sigma) | \sigma \; is \; SPE\}$$

Such that:

1. $V \subset R,$
2. for a given competitive equilibrium $(h, \bar{q}) \in R$, there exists a SPE σ, with $h = \sigma_1^f$ and $\bar{q} = \sigma_1^g$ with value $\nu \in V$,

$$\nu = (1 - \delta) r(h, \theta) + \delta v_1$$

if and only if there exists two continuation values $(V_1, V_2) \in V \times V$ such that

$$(1-\delta)r(h,\bar{q})+\delta v_1 \geq (1-\delta)r(h,\eta)+\delta v_2, \qquad \forall \eta \in Q$$

In order to characterize the set of all SPE we start by defining the set of potential admissible values, $W \subset R$. Let the 4-tuple $(h,\bar{q},\ w_1,w_2)$ be admissible respect to $W\ if (h,\bar{q}) \in C, (w_1,w_1) \in W \times W$ and

$$(1-\delta)r(h,\bar{q})+\delta w_1 \geq (1-\delta)r(h,\eta)+\delta w_2, \qquad \forall \eta \in Q$$

Notice that when $W \subset V$, the admissible 4-tuple $h,\bar{q},w_1,w_2$ determines a SPE with a strategy profile $\sigma_1 = (h,\bar{q}), \sigma\big|_{(h,\bar{q})} = \sigma^1, \sigma\Big|_{(h,\eta)} = \sigma^2$, if $(h,\bar{q}) \neq (h,\eta)$ where $w_i = V_g(\sigma^i)$ and $V_g(\sigma) = (1-\delta)r(h,\bar{q})+\delta w_1$.

The set of values of all SPE can be found by applying dynamic programming methods. Let $W_0 = [\underline{w}_0, \overline{w}_0]$ be a set of candidate continuation values. Let $B(W_0) = [\underline{w}_1, \overline{w}_1]$ be the set of possible values attained with admissible continuation draws from W. Note that $\overline{w}_1 1$ is the best sustainable value associated with the worst value $\underline{w}_0$,

$$\overline{w}_1 \equiv \max_{(h,\bar{q})\in C} (1-\delta)r(h,\bar{q})+\delta\overline{w}_0$$

$$s.t\ (1-\delta)r(h,\bar{q})+\delta\overline{w}_0 \geq (1-\delta)r(h,\eta)+\delta\underline{w}_0, \ \ \forall \eta \in Q$$

and $\underline{w}_1$, is the worst sustainable value

$$\underline{w}_1 \equiv \min_{(h,\bar{q})\in C (w_1,w_2)\in W_0} (1-\delta)\, r(h,\bar{q})+\delta w_1$$

$$s.t\ (1-\delta)r(r,\bar{q})+\delta w_1 \geq (1-\delta)r(h,\eta)+\delta w_2, \ \ \forall \eta \in Q$$

Note that B is an operator which is analogous to standard operator associated with the ordinary dynamic programming. The set of SPE satisfy $W = B(W)$. That is, the mapping B of admissible 4-tuples, maps the set of values W tomorrow into a new set $B(W)$ of values today[1]. Finally, note that the initial guess $W_0 = [\underline{w}_0, \overline{w}_0]$, is such that

$$\overline{\omega}_0 \equiv \max_{(h,\overline{q})\in C} r(h,\overline{q}),$$

and

$$\overline{\omega}_0 \equiv \min_{(h,\overline{q})\in C} r(h,\overline{q}),$$

4.2. The effect of ITQ's on recursive strategies

We start by computing that the value form infinite repetition of the Nash outcomes as a continuation values to deter deviations from the Ramsey outcome. Assume that there exists a $\delta \in (0,1)$, such that the one period return from deviating

$$\Delta r = \lambda\theta[f(v^R) - f(v^N)] - \psi(\bar{q}^N - \bar{q}^R)$$

is lower than the punishment associated to reverting forever to the Nash equilibrium

$$\frac{\delta}{1-\delta}[r^N(h^N,\bar{q}^N) - r^N(h^N,\bar{q}^N)]$$

This can be solved for the minimum δ that allows Ramsey to be sustained by infinite reversion to Nash

$$\Delta r = \frac{\delta}{1-\delta}[\pi(h^R) - \pi(h^N)]$$

Now, consider the existence of ITQs. The one period return from deviating is

$$\Delta r_{itq} = \lambda\theta\left[f\left(v_{itq}^R\right) + f'\left(v_{itq}^R\right)\bar{q}_{itq}^R - f'(0)\bar{q}_{itq}^N\right] - \psi(\bar{q}^N - \bar{q}^R)$$

The following proposition shows that with ITQs, higher δ is required to deter deviations

[1] Numerically, given an initial guess, W_j, and having constructed W_{j+1}, continue to iterate until the set converse, $W_{j+1} = B(W_j) \subseteq W_j$.

from the Ramsey outcome.

Proposition 3. *Let δ and δ_{itq} such that*

$$\Delta r = \frac{\delta}{1-\delta}\left[\pi(h^R) - \pi(h^N)\right]$$

and

$$\Delta\, r_{itq} = \frac{\delta_{\ itq}}{1-\delta_{itq}}\left[\pi\left(h^R_{itq}\right) - \pi\left(h^N_{itq}\right)\right]$$

If $\psi \to 0$ and $\gamma\theta < \alpha$, then $\delta < \delta_{itq}$.

Proposition 3 suggests that with ITQs, lower values (associated to SPE) can be supported. Figure 4 shows the best SPE with and without ITQs obtained by applying the numerical dynamic programming methods[2]. Note that the best SPE with ITQs is always worse than the best SPE without ITQs.

Moreover, we compute the discount associated with the use of trigger strategies based on infinite repetition of the Nash outcomes as continuation values, to deter deviations from the Ramsey outcome. Formally

$$\delta_{itq} = \frac{\Delta r_{itq}}{\Delta r_{itq} + \left[\pi\left(h^R_{itq}\right) - \pi\left(h^N_{itq}\right)\right]}$$

is 0.49 and higher than

$$\delta = \frac{\Delta r}{\Delta r + \left[\pi(h^R) - \pi(h^N)\right]}$$

which is 0.23.

[2] Code was written in Matlab and is available from author by request.

The numerical example (Figure 4) shows that without ITQs it is possible to build a reputation using worse continuation values than Nash equilibrium. However, the introduction of ITQs constraints the set of the SPE values. Nash is the worst equilibrium, and for discount rates lower than δ_{itq} Ramsey is not sustainable.

[INSERT FIGURE 4 ABOUT HERE]

5 Conclusions

Marine social-ecological systems in Europe are in trouble due to the fact that three out of four stocks are overfished as a consequence of the widespread overfishing in many of them. As result, the management of marine resources is moving away toward new fisheries management, and several types of property rights regimes have been employed to alleviate the fisheries problem. Individual transferable quotas (ITQs) have shown themselves to be fairly effective in generating economic rents in fisheries.

This paper shows how the introduction of ITQs can alter agencies' incentives to deviate when time consistency problem exists. Formally, we show that the introduction of ITQs increases agencies' potential benefits of deviating and therefore making difficult building up a reputation.

In a one period economy, the government incentives to deviate fishing quotas is motivated by the fact that the collection of fines will only have a negative effect on fishermen's welfare and no effects on fishermen's harvest choices. Under this scenario, the introduction of ITQs reduces the welfare outcome associated with Nash equilibrium. In infinitively repeated economies, we study the set of possible values that the enforcement agency can attain with reputations, that is, the set of all credible enforcement policies. With the introduction of ITQs, the best subgame perfect equilibrium with ITQs is always worse than the best subgame perfect equilibrium without ITQs. As result, ITQs does not help building up credible threats adopted by the government agency. Finally, we found a numerical example for which without ITQs it is possible to build a reputation by using worse continuation values than Nash equilibrium. However, the implementation of ITQs constraints the set of the subgame perfect equilibrium values.

Acknowledgements

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Supplementary Material

Supplementary information associated with this article can be found in the online version.

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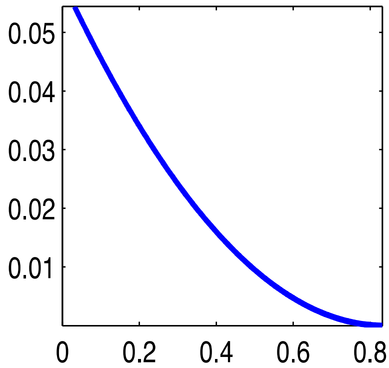

Figure 1. Competitive Equilibrium as a function of the quota, $\bar{q}$. Numerical example with α = .18, γ = .0008, θ = .5, c = 1.5, and β = 1.2.

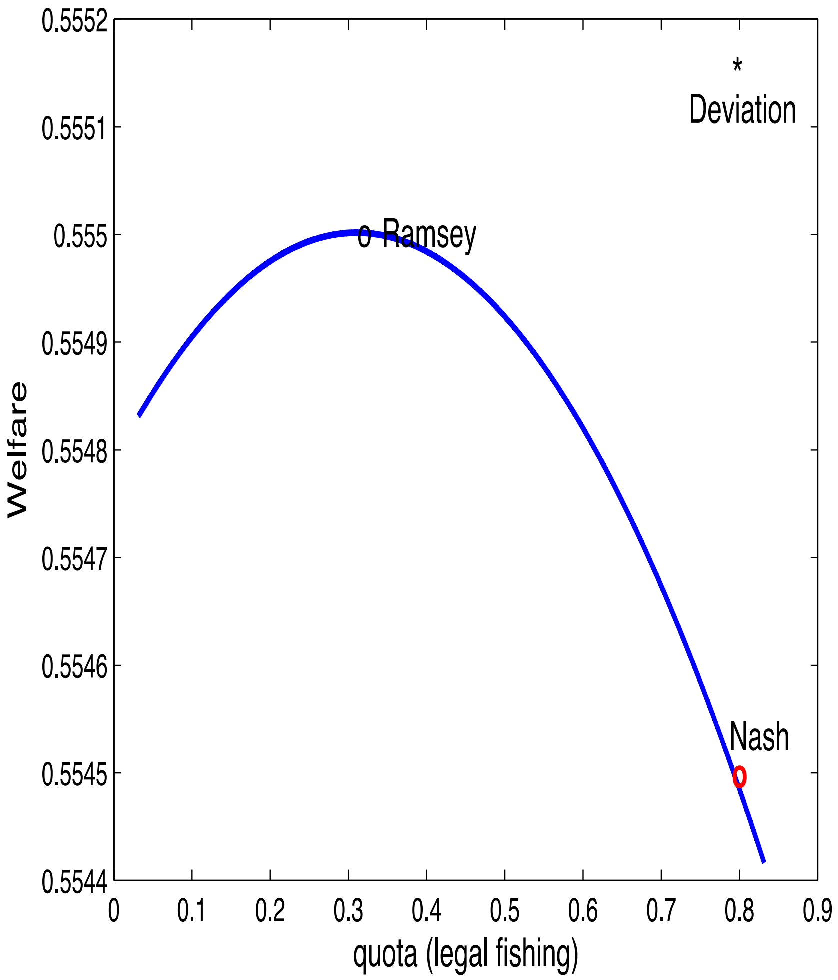

Figure 2. Welfare outcomes with and without ITQ's. Numerical example with α = .18, γ = .0008, θ = .5, c = 1.5, β = 1.2, ψ = 6.0000e -005, and λ = 0.0150. Solid line depicts the welfare outcomes associated to the set of competitive equilibrium, $C = C_{itq}$. Ramsey outcomes are marked with a circle. Nash equilibrium is represented with a bold circle. Deviation from Ramsey outcome, the "time consistency" problem is identified with asterisks.

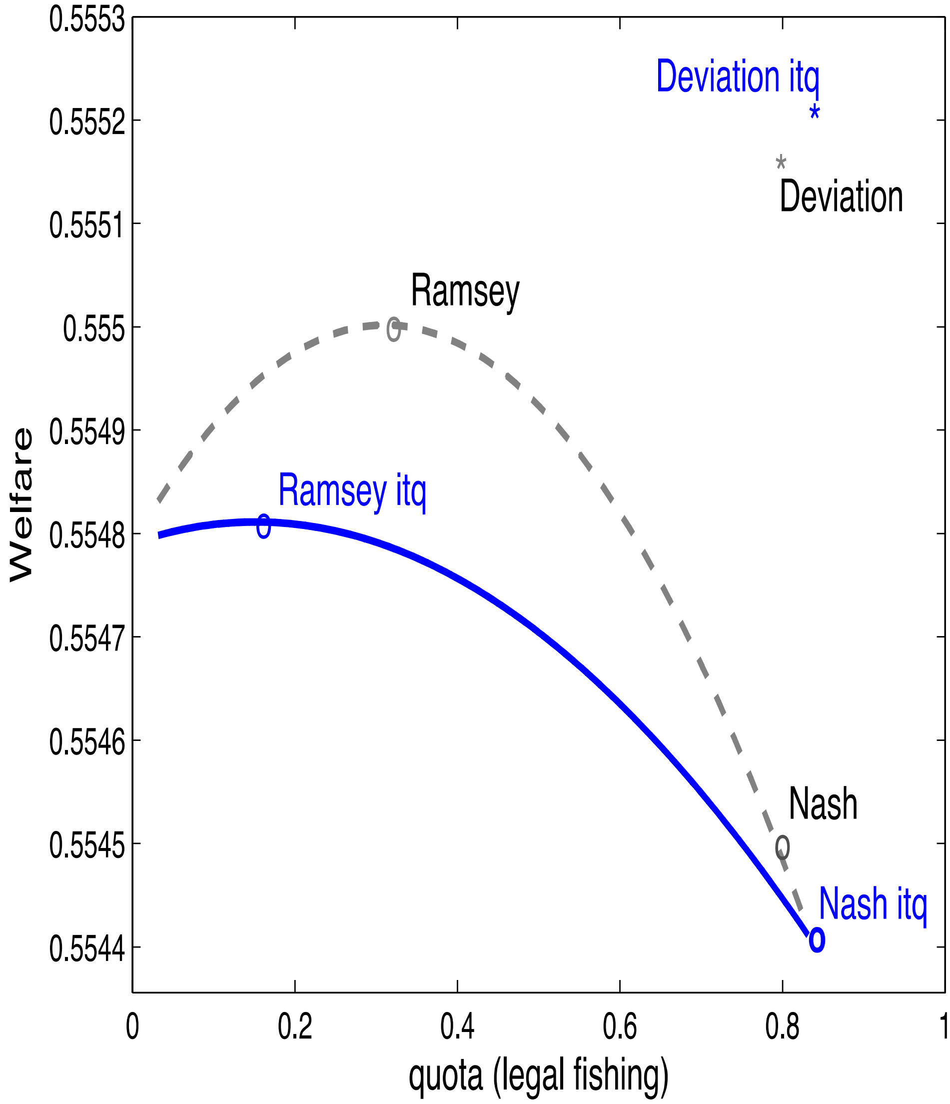

Figure 3. Welfare outcomes with and without ITQs. Numerical example with α = .18, γ = .0008, θ = .5, c = 1.5, β = 1.2, ψ = 6.0000e -005, and λ = 0.0150. Solid line depicts the welfare outcomes associates to the set of competitive equilibrium, $C = C_{itq}$. Ramsey outcomes are marked with circles. Nash equilibrium is marked with bold circles. Deviation from Ramsey outcome, the "time consistency" problem is marked with an asterisk.

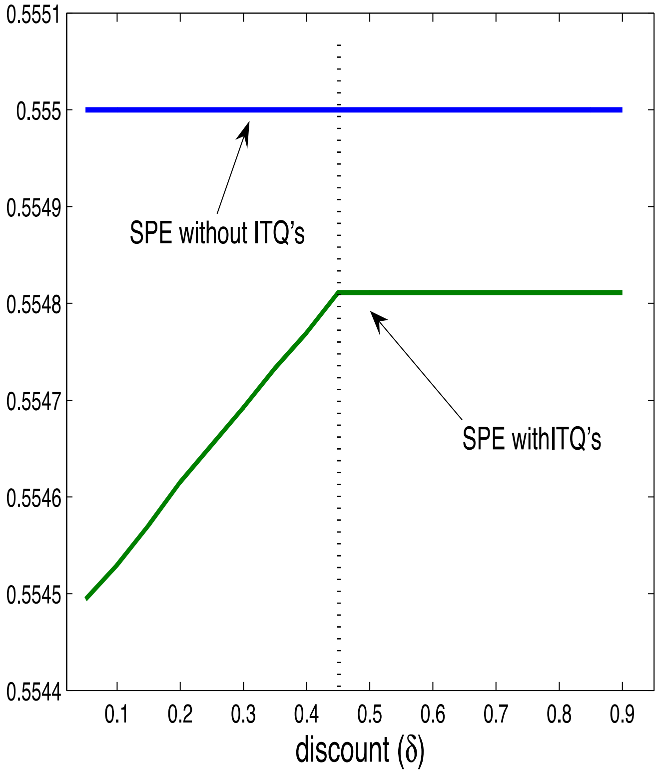

Figure 4. The best SPE with and without ITQ's obtained by applying the numerical dynamic programming methods for different discount values. Numerical example with $\alpha = .18$, $\gamma = .0008$, $\theta = .5$, $c = 1.5$, $\beta = 1.2$, $\psi = 6.0000e$ -005, and $\lambda = 0.0150$.

Supporting online material for

Credible enforcement policies: The role of ITQs in marine social-ecological systems

José María Da Rocha, Sebastián Villasante*, Rafael Trelles González

*To whom correspondence should be addressed
E-mail: sebastian.villasante@usc.es

Credible enforcement policies: The role of ITQs in marine social-ecological systems

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Methods and Data

In the following we present detailed information for the f.o.c in relation to the different solutions used in our model.

Appendix A

Proof. Lemma 1

Proof. Note that fishermen's problem can be written as

$$\max_{q,v}(v+q)-\frac{c}{2}\frac{(v+q)^{2}}{A}-\theta f(v)+T$$

The f.o.c. is

$$\frac{\partial\pi}{\partial v}=1-c\frac{(v+q)}{A}-\theta f'^{(v)}=0$$

where $A=(v+q)^{-\beta}$. ■

Proof. Proposition 1

Proof. From the f.o.c. of equation (3), it is known that

$$\left[\frac{\partial\pi(h)}{\partial h}-\theta f'(g(\bar{q})-\bar{q})\right]\frac{dg(\bar{q})}{\partial\bar{q}}+\theta f'(g(\bar{q})-\bar{q})-\psi=0$$

therefore, $\frac{\partial\pi(h)}{\partial h}<0$. ■

Proof Lemma 2

Proof. From the f.o.c. of equation (4), taking into account that $1 - c(\upsilon + \bar{q})^{1+\beta} - \theta f'(\upsilon) = 0$, it holds that

$$1 - c(h)^{1+\beta} - (\psi/\lambda) = 0,$$

and

$$\alpha \upsilon = \frac{\psi}{\lambda} - \gamma \qquad \blacksquare$$

Proof Lemma 3

Proof. Note that fishermen's problem can be written as

$$\max_{q,\upsilon}(\upsilon + q) - \frac{c}{2}\frac{(\upsilon + q)^2}{A} - \theta f(\upsilon) - \omega q + T$$

The f.o.c's are

$$\frac{\partial \pi}{\partial q} = 1 + c\frac{(\upsilon + q)}{A} - \theta f'(\upsilon) = 0$$

$$\frac{\partial \pi}{\partial q} = 1 + c\frac{(\upsilon + q)}{A} - \omega = 0$$

Therefore, the competitive allocation is independent of the existence of ITQ's. ■

Proof. Proposition 2

Proof. Note that

$$\max_{\bar{q}} \pi(h) - \lambda[\theta f(h - \bar{q}) + \omega(h - \bar{q})\bar{q}] - \psi\bar{q}$$

is equivalent to

$$\max_{\bar{q}} - \lambda\theta\, [f(h - \bar{q}) + f'(h - \bar{q})\bar{q}] - \psi\bar{q} \qquad \blacksquare$$

Therefore, given that the penalty function, $f(v)$, is strictly increasing and convex, its follows that the objective function is not concave. In particular, the enforcement agency's best response function $\theta = G(h)$ is obtained by solving

$$\max_{v[0,h]} \frac{\lambda\theta\alpha}{2}\ v^2 +\ (\psi - \lambda\theta\alpha h)v$$

Therefore, $\bar{q} = G(h)$ that is $v = 0$, which is the solution if $\psi < \frac{\lambda\theta\alpha}{2}\ h$. ■

Proof Lemma 4

Proof. Note that

$$r(h^N, \bar{q}^N) \geq r_{itq}(h^N, \bar{q}^N) = r_{itq}\left(h^N_{itq}, \bar{q}^N_{itq}\right) + \gamma\theta\bar{q}^N_{itq}$$ ■

Proof Proposition 3

Proof. Note that

$$\Delta r_{itq} \quad = \ \lambda\theta\left[f\left(v^R_{itq}\right) + \omega\left(v^R_{itq}\right)\bar{q}^R_{itq}\right] - \psi q^R_{itq}\ -$$

$$\lambda\theta\left[f\left(v^N_{itq}\right) + \omega\left(v^N_{itq}\right)\bar{q}^N_{itq}\right] - \psi q^N_{itq}$$

$$= \ \left[\lambda\theta\alpha\left(\frac{v^R_{itq}}{2} + 1\right) - \psi\right] v^R_{itq},$$

and

$$\Delta r = \lambda\theta[f(v^R) - f(v^N)] - \psi\ (q^R - q^N)$$

We also show that

$$\frac{\Delta r}{\pi(h^R) - \pi(h^N)} < \frac{\Delta r_{itq}}{\pi\left(h^R_{itq}\right) - \pi\left(h^N_{itq}\right)} \tag{7}$$

Given that $\frac{\partial\pi}{\partial v} = \theta\lambda f'(v)$, equation (7) is equivalent to

$$\frac{f'(v^R)}{\theta f(v^R) - \psi} \leq \frac{\alpha \dfrac{v^R_{itq} + \alpha - \psi}{2}}{\gamma\theta}$$

then if ψ goes to zero,

$$1 \leq \frac{\alpha \frac{v_{itq+\alpha}^{R}}{2}}{\gamma\theta}$$

if $\gamma\theta < \alpha$. ■