The triple bottom line: Meeting ecological, economic and social goals with Individual Transferable Quotas

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Abstract

This paper deals with the sustainable management of a renewable resource based on individual and transferable quotas (ITQs) when agents differ in terms of harvesting costs or catchability. In a dynamic bio-economic model, we determine the conditions under which the manager of an ITQ system can achieve sustainability objectives which simultaneously account for stock renewal, economic efficiency and maintenance of fishing activity for the agents along time. We use the viability approach and more specifically the viability kernel to handle such a feasibility problem. We show that the capacity for the manager to set viable management strategies based on fixing Total Allowable Catch (TAC) limits simultaneously depends on the degree of heterogeneity of users in the fishery, the current value of the stock and its dynamic features. To quantify this, we also compute the maximal number of active (viable) agents for a given set of agents and a given stock. It is shown how this number decreases with heterogeneity of involved agents while it increases with the stock. A numerical example illustrates the whole results.

Keywords: Renewable resource; Sustainability; TAC; ITQs; Viability kernel.
JEL: Q01, Q28, O13, C61

1 Introduction

Numerous stocks of renewable resources are under extreme pressure worldwide. Nowhere is this more obvious than in marine fisheries (Garcia & Grainger, 2005). A key reason for this is the common pool status of marine fish stocks, which in the absence of dedicated access regulations, leads to the existence of incentives for fishing firms to invest

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in fishing capacity beyond levels which would be efficient at the collective level (Gordon, 1954). This often results in increased pressure on regulating agencies to accept higher exploitation rates of fish stocks, sometimes beyond sustainable levels. This has led major to the recognition that access regulations are an indispensable complement to the usual conservation regulations for guiding resources use towards more sustainable paths that respect ecological, economic and social goals (FAO, 2008).

Total Allowable Catch (TAC) limitations have been used extensively as conservation measures in fisheries management, as a way to keep annual harvest of fish resources to levels ensuring the long term sustainability of fish stocks and fisheries. These approaches have however proved insufficient to ensure the economic health of fisheries, since with no prior allocation of catch possibilities between fishers, race for fish conditions led to encourage short-term economic views, driving fishers to continually increase their fishing capacity and leading to economic inefficiency at the scale of fisheries (Kompas *et al*, 2004). Restricting access to fisheries and allocating shares of the TAC as secure harvesting privileges to fishers has been proposed as a way of solving this problem (Grafton *et al*, 2006; Branch, 2008). Assigning harvest rights is expected to create an incentive for fishers to minimize the cost and effort associated with catching their TAC share while at the same time choosing fishing strategies that maximize their revenue (Grafton *et al*, 2006). With costs and fishing abilities varying among fishers, the addition of transferability of individual quotas (ITQs) allows fishers to choose between continuing to fish, or transferring (by sale or lease) their quota holdings to other, more efficient, fishers. ITQs thus offer a decentralized method of allocating catch possibilities within fisheries which should promote efficient resource use (Clark, 1990). Reviews of the experience with ITQs in fisheries have shown that they are increasingly being used, and that there adoption was associated with improved status of fish stocks and levels of catches.

In contexts where excess capacity in the fishery exists, an expected effect of introducing ITQs is that fishing capacity should decrease as catch privileges are transferred to the more efficient fishers (Kompas & Che, 2005). Although an expected (and to some extent sought for) impact, it has turned out to be one of the key points of debate on the opportunity and effectiveness of ITQ approaches to access regulation in fisheries (Pinkerton & Edwards, 2009). Indeed, an immediate consequence of allowing individual quotas to be transferred in contexts where excess capacity existed was a rapid reduction in the nominal fishing capacity, as measured by, e.g. the number of registered vessels and fishermen in a fishery[1], but also of the number of active fishers and firms. The resulting concentration of fishing privileges in the hands of smaller groups, and reduced size of fishing activities in coastal areas have been considered as an important social consequence of management schemes in which ITQs have been adopted (Copes, 1986). This social dimension has indeed become one of the first and foremost debated dimensions of moving to tradeable catch privileges in fisheries. In some cases, these expected social impacts are considered important enough that they will outweigh the expected ecological and economic benefits of the regulations, leading to the feasibility of their implantation being questioned. The EU consultation on

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[1]In a number of cases, however, this was shown to merely reflect the eradication of idle capacity and fishing licences.

rights-based fisheries management in the new common fisheries policy illustrates this point.

There have been several approaches to modeling ITQs in fisheries, ranging from analytical approaches based on simplified models of a fishery (Clark, 2006) and Linear Programming approaches (Lanfersieck & Squires, 1992), through models that use numerical simulation (Dupont, 2000; Guyader, 2002; Guyader & Thebaud, 2001; Little *et al*, 2009). Despite the fact that social considerations may have a strong influence on the possibility for policy makers to adopt ITQs as access regulation measures, these have only rarely been explicitly included as an objective or a constraint in the traditional bio-economic modeling approaches. Guyader & Thebaud (2001) considered the impact of social factors regarding distributional issues in determining participation of fishing firms in a fishery and the associated quota market. However, little work has been done on the interaction between the social objectives and the economic and biological objectives which a policy maker may pursue in an ITQ setting.

The aim of this paper is specifically to address the tradeoffs between the conservation, economic efficiency and social objectives in an ITQ managed system. To deal with this question, we develop a dynamic bio-economic model based on weak invariance method (Clarke *et al*, 1995) or viable control method (Aubin, 1991). This method focuses on inter-temporal feasible paths, and aims at identifying the conditions that allow desirable objectives or constraints to be fulfilled over time, considering both present and future states (Baumgartner & Quaas, 2009; Bene *et al*, 2001). The method does not strive to identify optimal paths. It is well known that optimal control modeling for the sustainable management of renewable resource can be criticized because it may imply what some have called dictatorship of the future over the present (Heal, 1998) and favor exhaustion of a resource stock as shown by Clark (1990). The viability approach offers an another way to deal with the sustainability by ensuring minimum levels of key state variables in a fishery at each period in time, assigning an equal weight to every period. As emphasized in DeLara & Doyen (2008), viability is closely related to the maximin (Rawlsian) approach with respect to intergenerational equity. Viability may also allow for the satisfaction of economic, social and biological constraints and is, in this respect, a multi-criteria approach. It has been applied to renewable resources management and especially to fisheries (see, e.g. Bene *et al* (2001)), but also to broader (eco)-system dynamics (Cury *et al*, 2005). Relationships between sustainable management objectives and reference points as adopted in the ICES precautionary approach are discussed in **?**. Here the viability framework allows us to exhibit the conditions under which a manager can achieve economic, social and biological objectives in a fishery managed under ITQs, considering both present and future states of the renewable resource system.

The paper is structured as follows. Section 2 is devoted to the description of the dynamic bio-economic model together with the profitability and social constraints. Section 3 provides the results related to the maximum number of viable active users with respect to the level of the resource. The last section concludes.

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2 The bio-economic model

2.1 The resource dynamics

A renewable resource is described by its state (e.g. biomass or density) $x(t) \in \mathbf{R}$ at time t. When the amount removed or caught $Q(t)$ is at the beginning of each time step, the dynamics of the exploited resource $x(.)$ is given by the escapement function:

$$x(t + 1) = f(x(t) - Q(t)). \tag{1}$$

where the dynamics of f is supposed to be continuous, increasing and zero at the origin. Since the amount caught cannot exceed the resource stock, a scarcity constraint holds:

$$0 \leq Q(t) \leq x(t). \tag{2}$$

2.2 The ITQ market:

At the beginning of each period t, a regulator allocates a total allowable catch (TAC) among the n agents. The supply of quota is $Q(t) = \sum_{i=1}^{n} Q_i^-(t)$ where $Q_i^-(t)$ is the initial amount of quota given to agent i and $Q_i(t)$ the amount of quota held by agent i after trade. We assume that quotas can freely be traded on a lease market and that inter-temporal trade of quotas is not allowed[2]. The demand for quota is derived as the sum of the optimal amount of harvest of the n agents, $H^*(t) = \sum_{i=1}^{n} H_i^*(t)$. The quota market clearing condition is given by $Q(t) = H^*(t)$. Agents are assumed to be price takers in the output market. The quota price is denoted by $m(t)$ and the price of the resource by p. The quota demand of an agent is obtained by maximizing its profits with respect to its effort $E_i(t)$ under the constraint that its amount of harvest $H_i(t)$ is equal to its quota demand $Q_i(t)$:

$$\Pi_i(E_i(t), x(t)) = pH_i(t) - C_i(E_i(t)) - m(t)(H_i(t) - Q_i^-(t)) \tag{3}$$

The harvest function and the quadratic cost function are given by

$$H_i(t) = q_i E_i(t) x(t) \tag{4}$$

$$C_i(E_i) = c_{0,i} + c_{1,i} E_i + \frac{c_{2,i}}{2} E_i^2 \tag{5}$$

where q_i is the catchability constant and $c_{0,i}$, $c_{1,i}$ and $c_{2,i}$ the cost parameters. Assuming for a while that the optimal effort of agent i is positive, it is solution of

$$E_i^*(t) \in \arg \max \Pi_i(E_i, x(t))$$

We obtain the individual effort of agent i

$$E_i^*(t) = \frac{1}{c_{2,i}} \left((p - m(t)) q_i x(t) - c_{1,i} \right) \tag{6}$$

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[2]The question of the original allocation of ITQs is beyond the scope of the paper.

and its amount of harvest $H_i^*(t)$. The demand of quota is the sum of harvest across all agents

$$H^*(t) = \sum_{i=1}^{n} H_i^*(t) = x(t) \left[(p - m(t)) \, x(t) \sum_{i=1}^{n} \frac{q_i^2}{c_{2,i}} - \sum_{i=1}^{n} \frac{c_{1,i} q_i}{c_{2,i}} \right]$$

Setting

$$\alpha = \sum_{i=1}^{n} \frac{q_i^2}{c_{2,i}}; \beta = \sum_{i=1}^{n} \frac{c_{1,i} q_i}{c_{2,i}}$$

we obtain

$$H^* = x(t) \left[(p - m(t)) \, x(t) \alpha - \beta \right] \tag{7}$$

From the quota market clearing condition, the equilibrium quota price is

$$m^*(Q(t), x(t)) = p - \frac{\frac{Q(t)}{x(t)} + \beta}{x(t)\alpha} \tag{8}$$

If a positive quota demand exists, then a unique quota price $m^*(Q(t), x(t))$ should exist such that $m^*(Q(t), x(t)) \in [0, p[$. When the quota price $m(t)$ is greater than the product price p, the demand of quota will be null. The positivity condition on $m^*(Q(t), x(t))$ implies a state-control constraint

$$x(t)(px(t)\alpha - \beta) \geq Q(t) \tag{9}$$

From the scarcity constraint (2), we deduce the stock constraint

$$x(t) \geq \frac{\beta}{p\alpha}.$$

2.3 Social constraint:

The model so far shows the conditions which are needed to maximize the economic return of the fishery. For the purposes of managing for the triple bottom line, management must also consider social and biological constraints. As shown by Bene *et al* (2001), the existence of an economic viability constraint in a fishery leads to the identification of a stock viability constraint, as a minimum stock size is required to maintain sustainable levels of catches and rent above their viable level. In an ITQ system, where the initial situation is one of excess capacity, one may observe a reduction in the number of participants leading to social disruption beyond acceptable levels. To account for this, a social constraint may thus be introduced on the management decisions. An extreme approach to this is that the policy ensures that all n agents initially present remain active in the fishery. This will allow the levels of economic impacts associated to the fishery (in terms e.g. of employment on board vessels and land-based activity, and the induced upstream and downstream effects) to be maintained over time. Formally, we introduce a participation constraint representing the fact that ideally, when adopting

a management approach, a policy maker would like to be able to keep all the fishers active:

$$E_i^*(t) > 0, \quad \forall i = 1, .., n, \ \forall t = 0, 1, \ldots, T \tag{10}$$

Substituting the value of m^* given by (8) in the optimal effort E_i^* given by (6) leads

$$\frac{\frac{Q(t)}{x(t)} + \beta}{\alpha} > \max_i \frac{c_{1,i}}{q_i} = \lambda \tag{11}$$

This participation constraint for all users implies a condition on the ratio $c_{1,i}/q_i$ for the less efficient user. If we denote by

$$F_{\text{par}} = \alpha\lambda - \beta \geq 0 \tag{12}$$

the stock mortality rate associated to participation requirements, the previous constraint (11) reads

$$Q(t) > F_{\text{par}}x(t). \tag{13}$$

Bringing together equations (9) and (13) gives the following inequality

$$F_{\text{par}} < \frac{Q(t)}{x(t)} \leq \alpha p x(t) - \beta$$

From the previous condition, we derive a critical stock threshold denoted by x_{lim} as

$$x(t) > \frac{F_{\text{par}} + \beta}{\alpha p} = \frac{\lambda}{p} = x_{\text{lim}} \tag{14}$$

Note that such stock constraint also reads

$$x(t) > \sup_i \frac{c_{1,i}}{pq_i} = \sup_i x_i^{\text{oa}}$$

where x_i^{oa} is the stock size at bionomic equilibrium with open access for the less efficient user i (Clark, 1990). Hence maintaining all fishers active in a fishery will require that the stock be maintained at a level that is higher than the level at which the least efficient fisher would stop fishing.

3   Results

Based on the above model of the fishery and set of constraints, we consider the case in which a policy maker must decide on a set of TAC policies which ensure that the fishery will respect these constraints. We use the concept of viability kernel to characterize the sustainability of the system. This kernel is the set of initial stock sizes for which an acceptable regime of quotas exists and satisfies the constraints put forward in the previous section. Viable quotas are derived from the viability kernel whenever it is not empty.

3.1   Viability kernel.

The dynamics $x(t+1) = f(x(t) - Q(t))$ has to be combined with

- The stock constraint (14) namely $x(t) \geq x_{\text{lim}}$,

- The social or participation constraint (13) or $Q(t) > F_{\text{par}}x(t)$,

- The economic constraint (9) namely $Q(t) \leq (p\alpha x(t) - \beta)x(t)$.

According to the values of F_{par} and the associated x_{lim}, several cases can be distinguished. We also need to introduce the notation $\sigma(x)$ for the sustainable (steady[3]) yield function as

$$h = \sigma(x) = x - f^{-1}(x).$$

It is convenient to also introduce the "sustainable" (again steady) mortality rate F_{lim} related to stock level x_{lim}

$$F_{\text{lim}} = \frac{\sigma(x_{\text{lim}})}{x_{\text{lim}}}.$$

It gives the following proposition for the viability kernel.

Proposition 1 *Assume f is continuously increasing and $\sigma(x)/x$ is decreasing. We obtain*

- *If $F_{\text{lim}} < F_{\text{par}}$ then no viability occurs* $\text{Viab} = \emptyset$.

- *If $F_{\text{par}} < F_{\text{lim}}$ then the viability kernel is nonempty and defined by*

$$\text{Viab} =]x_{\text{lim}}, \infty[.$$

The case of no viability is related to the social or participative objective. The mortality rate required to ensure a positive effort for the less efficient user is too high with respect to the sustainable mortality rate associated to the stock constraint. The favorable case consists in an efficient trading which allows for the participation of the whole users is possible despite their heterogeneity.

3.2   Viable quotas.

We derive the following proposition for the viable quotas which depend on the structure of costs, catchability of the agents together with population dynamics.

Proposition 2 *Assume f is continuously increasing and $\sigma(x)/x$ is decreasing. Assume that $F_{\text{par}} < F_{\text{lim}}$. Then, for any stock x within the viability kernel* $\text{Viab} =]x_{\text{lim}}, \infty[$, *viable TAC controls lie in the interval (non empty)*

$$Q(x) \in]F_{\text{par}}x, F_{\text{PA}}(x)x[$$

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[3]In the sense that $f(x - \sigma(x)) = x$.

where precautionary mortality rate $F_{\text{PA}}(x)$ is defined by

$$F_{\text{PA}}(x) = \min\left(\alpha px - \beta, 1 - \frac{f^{-1}(x_{\text{lim}})}{x}\right)$$

It turns out that several quota policies may exist, that allow distinct strategies and trade-offs between the biological aims of stock conservation and the economic aims of rent maximisation, while also respecting the social constraint. The set of quota policies can be rewritten as

$$Q(x) = \left(\omega F_{\text{par}} x + (1 - \omega)F_{\text{PA}}(x)\right) x$$

with $0 < \omega < 1$. Low value of ω refers to an ecological and conservation viewpoint since it favors the resource. High value of ω promotes catches and rent. Mix-strategies can also be implemented.

3.3 Number of active agents

When the viability kernel is empty namely $F_{\text{par}} > F_{\text{lim}}$, the policy maker knows that it will not be feasible to respect the social or participating constraint for all agents and maintain the less efficient users active in the fishery, given the stock level x and the heterogeneity amongst users. His problem can be re-cast in terms of the maximal number of viable users denoted by $n^*(x)$ that the system could allow to remain active. This maximal number of viable agents is defined as follows

$$n^*(x) = \max\left(a \in \{0, \dots, n\} \mid x \in \text{Viab}(a)\right)$$

where $\text{Viab}(a)$ means the viability kernel associated with $a \leq n$ agents supposed to be ranked according to

$$\frac{c_{1,1}}{q_1} \leq \frac{c_{1,2}}{q_2} \leq \dots \leq \frac{c_{1,n}}{q_n}$$

Through Proposition 1, we can characterize such maximal number of active player through the adaptation of critical thresholds $F_{\text{par}}(a)$, $x_{\text{lim}}(a)$ and $F_{\text{lim}}(a)$. They need to be defined as follows

$$\begin{cases} F_{\text{par}}(a) = \alpha(a)\lambda(a) - \beta(a) \\ x_{\text{lim}}(a) = \frac{\lambda(a)}{p} \\ F_{\text{lim}}(a) = \frac{\sigma(x_{\text{lim}}(a))}{x_{\text{lim}}(a)} \end{cases}$$

with

$$\alpha(a) = \sum_{i=1}^{a} \frac{q_i^2}{c_{2,i}}, \ \ \beta(a) = \sum_{i=1}^{a} \frac{c_{1,i}q_i}{c_{2,i}}, \ \ \lambda(a) = \max_{i=1,..,a} \frac{c_{1,i}}{q_i}$$

We deduce the following proposition.

Proposition 3 *Assume f is continuously increasing and and $\sigma(x)/x$ is decreasing. Then*

$$n^*(x) = \max\left(a \leq n \mid x_{\mathsf{lim}}(a) < x \text{ and } F_{\mathrm{par}}(a) \leq F_{\mathsf{lim}}(a)\right)$$

Whenever $n^*(x)$ is strictly positive, it is then feasible to ensure a positive effort for the $n^*(x)$ users through the quota policies defined in Proposition 2. The set of quota policies is expanded as

$$Q^*(x) = \left(\omega F_{\mathrm{par}}(n^*(x))x + (1 - \omega)F_{\mathrm{PA}}^*(x)\right)x$$

where upper viable or precautionary quota $F_{\mathrm{PA}}^*(x)$ correspond to:

$$F_{\mathrm{PA}}^*(x) = \min\left(\alpha(n^*(x))px - \beta(n^*(x)), 1 - \frac{f^{-1}(x_{\mathsf{lim}}(n^*(x)))}{x}\right)$$

We can show how the number of active agents depends positively on resource stock and negatively on heterogeneity of agents.

4 Conclusion

This paper addresses the problem of the sustainable management of a renewable resource based on individual and transferable quotas (ITQs) when agents differ in terms of harvesting efficiency. Through a quota policy, we have been able to determine the conditions under which a manager can achieve both ecological, economic and social objectives along time. In a dynamic bio-economic model, we have identify a maximal number of agents, viable resource states and possible TAC policies to sustain a constraint of positive effort for all the users.

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