

August, 2002

Individual Transferable Quota Markets Under Illegal Fishing

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Abstract: The presence of violations and the need for enforcement of tradable property rights systems in fisheries has not receiving much attention in the literature. The theoretical promise of property rights-based fisheries is to achieve a given total allowable catch with a maximum social benefit. One of the assumption for that result is that the system is in perfect compliance. The incidents of noncompliance, however, may affect the performance of transferable property rights-based fisheries in unexplored ways. In this paper, we construct and analyze a positive model of fisherman behavior that operates under a perfectly competitive individual transferable quota system, when recognizing the opportunities for violations of quota holdings, given incomplete enforcement. Considering an ill enforced transferable property rights-based fishery we are able to obtain a number of implications for the performance of the quota market and the economic efficiency of the regulatory system.

1. Introduction

The use of individual quota as a regulatory instrument in fisheries is one of the most important innovations for the management of natural resources. Currently there are more than 60 property rights based fishery programs in about 15 countries, which pursue to achieve efficiency gains by the creation and allocation of property rights in those fisheries. The imposition of a restriction in the aggregate catching level in a fishery, or the use of command and control type of regulations are not able to eliminate the common property characteristics inherent in the exploitation of fishing resources. It is that characteristic which might end causing the negative economic effects such as over investment, excess of fishing capacity, seasonality of landings, and the alike; reducing the social benefits from the fishery. In that context, it is possible that total allowable catch be achieved maximizing the social benefit through regulatory policies based on the use of property rights.

The fundamental idea that a transferable property right system (also named as individual transferable quota [ITQ] system) would offer a regulator the opportunity to optimally organize the fishing activity was primarily proposed by Moloney and Pearse

(1979). In their contribution, they were able to show that a competitive transferable harvest right system in fisheries would guarantee an equilibrium distribution of fishing rights among fisherman that maximizes aggregate net revenue. The harvest of a given total allowable catch will be attained in a socially efficient manner. Furthermore, they also show that the efficiency result is independent of the initial allocation of rights, having it impacts only on the distribution of rents from the fishery. The presumption of a well behaved market for fishing rights as well as the efficiency result obtained by these authors assumed that a fisherman “is prohibited from catching in excess of his holding rights”[pp. 366]. The incidents of noncompliance, however, may affect the performance of transferable property rights-based fisheries in unexplored ways.

In this paper, we construct and analyze a positive model of fisherman behavior that operates under a perfectly competitive individual transferable quota system, when recognizing the opportunities for violations of quota holdings, given fixed enforcement strategies that are insufficient to induce perfect compliance. We do so by combining and extending recent work that explores the impacts of non-compliance in the context of markets for pollution rights and literature that explores from an economic perspective the illegal behavior and the need for enforcement of fisheries regulation. [See for example, Stranlund and Dhanda (1999), Charles et. al. (1999), Malik (1990), Sutinen and Andersen (1985)]. Considering a positive choice model of a risk-neutral individual fisherman in the context of an incomplete enforced transferable property rights-based fishery, we are able to obtain a number of implications for the performance of the quota market and the economic efficiency of a transferable property right system for fisheries.

The lay out of the paper is as follow. In section 2, we extend previous models that allow for non-compliance in the context of transferable emissions to consider fisherman

behavior. We specifically allow here for the possibility of a fisherman choosing levels of fishing effort that induce harvesting levels that exceed quota holdings. We assume the presence of a fixed enforcement strategy from an enforcement authority which is insufficient to guarantee full compliance.

Considering the structure of the positive behavioral model from section 2, we proceed in section 3 to analyze individual fisherman's choices. Specifically, we examine choices of fishing effort, quota demand, and quota violation. We show that the extent of an individual violation is a choice that depends on the economic conditions (price) in the market for landed fish, the enforcement pressure from the regulator authority, as well as the total allowable catch level, and the biological conditions in the fishery.

In section 4 we examine the implications of the presence of quota violation on the performance of the quota market. We show that the presence of violations will affect the equilibrium quota price in a very specific manner: the equilibrium level of quota price will be lower than the equilibrium price in an otherwise perfect compliance system. We also explore in this section how regulatory tools as enforcement strategies and total allowable catch, the economic conditions as those prevailing in the market for landed fish, as well as the biological conditions in the fishery, affect equilibrium choices through their effect on the quota market. We show that increasing monitoring effort (audit probability) while increasing the equilibrium price of the quota, might have an ambiguous effect on the extent of the quota violations. Furthermore, an increase in total allowable catch reduces quota price and the extent of violations in the fishery, and at the same time, increases aggregate harvest in the fishery. Perhaps surprisingly, we are also able to show that a fishing season characterized by an increase in the biomass, will increase both, quota price

and the extent of the violations. The same result hold in the case of an increase in the price of landed fish.

In section 5 we re-examine the efficiency property of an ITQ regime when fisherman are non-compliant. In principle, we argue that the presence of non-compliance add two aspects on the analysis of efficiency of a transferable rights based system in the context of a fishery. First, the possibility of non-compliance requires enforcement actions which are costly to the society. Second, the presence of non-compliance involve a tension between an increase in current social benefits and eventual future losses. On one hand, fishing in excess of the total allowable catch it is beneficial to the society because it increases total surplus in a given compliance period. On the other hand, fishing above catch limit implies a social cost because if the aggregate quota was needed in the first place, harvesting in excess of it presumably has a negative impact on the biomass into the future, affecting the sustainability of the fishery.

Examining a problem that take enforcement as given, we show that in the presence of non-compliance it is optimal for the society that fisherman equals marginal revenue to marginal social cost (marginal damage from exceeding the total allowable catch plus marginal cost of harvest). This implies that as long as the quota price differ from marginal damage of aggregate harvest that exceed the total allowable catch , the presence of violations will result in a choice of fishing effort that is inefficient. This inefficiency implies that total catch will be greater or lower than the optimal harvest. However, because fisherman equals their marginal benefits, the distribution of the fishing effort to attain this total catch will be efficient. We conclude then, that an individual transferable quota system in the presence of violations might result in an inefficient total catch, but an efficient distribution of fishing effort between fishermen. Conclusions and implications

from our work for the enforcement of property rights based fisheries are offered in section 6.

2. Fisherman Behavior

To analyze the individual fisherman compliance behavior, a regulated individual fisherman is considered. The analysis is based on a static model of a risk-neutral fisherman that operates under an perfectly competitive individual transferable quota system (ITQ). The model is an extension of the work of Stranlund and Dhanda (1999) and Stranlund and Chávez (2000) to design enforcement strategies in the context of a market-based environmental policy.

The fisher's benefits are given by the difference between total revenue and total costs from fishing activity. Harvest level, $h(e, B)$, is a function of fishing effort, e , and biomass B , the latter assumed constant during the compliance period of analysis. The harvest level is strictly increasing and concave in fishing effort e ; that is $h_e > 0$ y $h_{ee} < 0$. Cost of harvesting, $c(e, B)$, are strictly increasing and convex in the fishing effort e . Let q_0 be the number of fishing quotas allocated to the individual fisherman, and q the number of fishing quota that fisher hold after transactions. Possession of a quota confers the legal right to harvest one unit of fish, for example, a ton.¹ We assume that total allowable catch Q is fixed, and that quotas trade at a competitive price w , while landed fish trade at a competitive price p . Finally, there are n fishermen participating in the fishery.

A violation of the individual quota holdings occur whenever fisher's harvest level exceeds the number of quota it holds; that is $[h(e, B) - q]$. We assume that a system is in place to perfectly track the number of quotas that a fisherman holds.

¹ Because the static nature of the model, we do not consider the possibility of quota banking or borrowing.

In addition , we assume that the regulatory authority conduct random audits; that is the fisherman is audited with probability θ . To simplify the analysis, we assume that an audit uncover the presence and extent of a quota violation, if it does exists.

From previous literature on enforcing environmental policies and natural resource management programs, if a violation is detected, a penalty $f(h(e, B) - q)$ is imposed [see for example, Sutinen and Andersen (1985), Malik (1990), Keeler (1993), Stranlund and Dhanda (1999)]. We assume that the penalty is zero for zero quota violation [$f(0) = 0$], but that the marginal penalty for zero quota violation is greater than zero [$f'(0) > 0$]. For positive quota violation, the penalty function is strictly increasing and convex.

As is standard in the literature, we assume that an enforcement authority commits itself to a strategy and communicate this strategy to all fishermen. We assume that each fisherman chooses positive fishing effort and quota holdings and never overcomplies. A fisherman chooses its fishing effort e (and consequently its level of harvest h) and its quota demand q to solve [1], taking the enforcement strategy as given.

$$\begin{aligned} \max_{e,q} \quad & ph(e,B) - c(e, B) - w(q - q_0) - \theta f(h(e, B) - q) & [1] \\ \text{s.t.} \quad & h(e, B) - q \geq 0. \end{aligned}$$

The Lagrange equation for [1] is $L = ph(e,B) - c(e, B) - w(q - q_0) - \theta f(h(e, B) - q) + \mu (h(e, B) - q)$, and the Kuhn-Tucker conditions are:

$$L_e = ph_e(e,B) - c_e(e, B) - \theta f'(h(e, B) - q)h_e(e,B) + \mu h_e(e,B) = 0 \quad [2-a]$$

$$L_q = -w + \theta f'(h(e, B) - q) - \mu = 0 \quad [2-b]$$

$$L_\mu = (h(e, B) - q) \geq 0, \mu \geq 0, \mu \times (h(e, B) - q) = 0. \quad [2-c]$$

Equations [2 a-c] are necessary and sufficient to determine the fisherman's optimal choices of fishing effort, and the demand of quota.²

3. Fisherman's Choices and Equilibrium Price of Fishing Quotas

Assume a given enforcement strategy that is not sufficient to guarantee perfect compliance, and consider the positive behavioral model structure described before. In this section we analyze fisherman's choices regarding fishing effort, quota demand, and the extent of quota violation.

3.1 Fisherman's Choices: fishing effort, and demand of quota

To begin, we consider a fisherman's choice of fishing effort. In our context, we found that, perhaps surprisingly, the fishing effort choice is independent of the regulator's enforcement strategy.

Result 1: *Given an optimal choice of quota demand (q) and regardless of its compliance status, a fisherman chooses its fishing effort(e) so that*

$$(p-w) h_e(e,B) - c_e(e, B) = 0. \quad [3]$$

Proof of Result 1: Suppose that the fisherman is non-compliant so that $h(e, B) - q > 0$.

Then [2-c] require $\mu = 0$. Thus, [2-a] becomes $ph_e(e,B) - c_e(e, B) - \theta f'(h(e, B) - q)h_e(e,B) = 0$, and [2-b] becomes $-w + \theta f'(h(e, B) - q) = 0$. Taking together, [2-a] and [2-b] then imply $(p-w) h_e(e,B) - c_e(e, B) = 0$. Now suppose that the fisherman is under compliance.

² We notice here that if the fishery is being regulated under a non-transferable individual quota system, the fisherman problem becomes $\max ph(e,B) - c(e, B) - \theta f(h(e, B) - q_0)$ s.t. $h(e,B) - q_0 \geq 0$. Which is the problem in [1] considering $w = 0$ and $q = q_0$. In such a case the only choice variable is fishing effort. It is possible to show that in this situation the optimal level of fishing effort become a function of the price of harvested fish, the enforcement effort, and the biomass; that is, $e(p, B, q_0, \theta)$. Under usual assumptions, it is easy to show that in such a case, e is increasing in p, B and q_0 , and decreasing in θ . This result suggest that under a non-transferable individual quota regime, the enforcement strategy chosen by the regulator affect the marginal benefit from illegal activity. As we show later, under an individual transferable quota system, the regulator enforcement effort affect the choice of fishing effort only indirectly through the level of quota price.

In this case its objective function reduces to $ph(e,B) - c(e, B) - w(h(e,B) - q_0)$, the maximization of which requires $(p-w) h_e(e,B) - c_e(e, B) = 0$. QED.

Thus the fisherman's choice of fishing effort is a function of the net price of a harvested unit of quota $(p - w)$, and the biomass B ; that is $e((p - w), B)$. It is also easy to show that fishing effort is increasing in $(p - w)$. In fact, strict convexity of harvest and costs functions guarantee that result. In addition, it is also easy to show that increase in biomass is likely to increase the optimum level of fishing effort, which requires beyond the properties discussed above, that $h_{eB} > 0$ y $c_{eB} < 0$.³

Two important implications stem from the result that a fisherman's choice of fishing effort is $e((p - w), B)$. First, perhaps surprisingly, under an ITQ system, the fisherman's choice of fishing effort is independent of a regulator's enforcement strategy. However, as we will show later, the equilibrium-distribution of fishing effort will depend on the enforcement strategy because the enforcement strategy will affect the equilibrium quota price. Second, since all fishermen's face the same quota and price of landed fish, in an equilibrium, fishermen's marginal net benefit are all equal. This is the standard condition for maximizing social benefit, so that, even under non-compliance the distribution of effort between fishermen is optimum.

Given our analysis on the optimal choice of fishing effort, we are ready to study the demand for fishing quota for a fisherman operating under an ITQ system. Because Result 1 implies that $e((p - w), B)$, then, if the fisherman is compliant, follows that $h(e((p - w), B), B) = q((p - w), B)$. However, if the fisherman is in violation, its demand of quota will depend

³ These additional requirements imply that an increase in biomass has to increase the marginal productivity and to reduce the marginal cost of effort. Furthermore, although mentioned before, this analysis requires that the level of the price for landed fishing do not depend on B .

not only on the net price of harvested fish, but also on the enforcement effort from the regulator. This is implied by the following result.

Result 2: *Given an optimal choice of fishing effort, a non-compliant fisherman will demand quota so that*

$$-w + \theta f'(h(e((p-w), B), B) - q) = 0. \quad [4]$$

Proof of Result 2: To obtain this note from [2-b] and [2-c] that $h(e((p-w), B), B) - q > 0$ implies $\mu = 0$ and $L_q = -w + \theta f'(h(e, B) - q) = 0$. Substituting the fisherman's fishing effort choice yields $-w + \theta f'(h(e((p-w), B), B) - q) = 0$. QED.

The marginal condition in Result 2 suggests that a non-compliant fisherman's quota demand is a function of the quota price, landed fish net price, monitoring effort, and biomass; that is, $q(w, p-w, \theta, B)$. The impact of exogenous variables on quota demand is formally established in our next result.

Result 3: *Given an optimal choice of quota demand $q(w, p-w, \theta, B)$; the following comparative static result hold:*

	w	p	θ	B
q	-	+	+	+

Proof of Result 3: See Appendix.

The comparative static in Result 3 suggest the following. First, as it is expected, an increase in quota price will reduce the demand of quota. Second, an exogenous increase in the net price of landed fish will end increasing the quota demand. Third, exogenous

changes in both, monitoring effort, and biomass, will induce a change in quota demand in the same direction.

3.2 Quota violation

Having analyzed a fisherman choice of fishing effort (and harvest), and quota demand, we turn our attention to the determinants of the extent of quota violation for a non-compliant fisherman. We do so in our next result.

Result 4: A non-compliant fisherman, chooses the extent of the violation so that

$$w = \theta f' (h(e((p - w), B), B) - q(w, \theta, p - w, B)). \quad [5]$$

Proof of Result 4: From Result 2 note that the demand of quota for a non-compliant fisherman is implicitly defined as $q(w, \theta, p - w, B)$. Replacing this in equation [4] yields $w = \theta f' (h(e((p - w), B), B) - q(w, \theta, p - w, B))$. QED.

Result 4 suggest that a non-compliant fisherman, will harvest in excess of quota holdings up to the point where the marginal benefit from violating is equal to the expected cost of violation, which in turn is given by the probability of being audited, and the marginal penalty at the level of violation. Furthermore, Result 4 implicitly define the extent of quota violation, $v = h(\bullet) - q(\bullet)$, as $v(w, p, \theta, B)$.⁴

Result 4 suggest that under an ITQ regime, with perfect competitive quota market, and assuming penalties uniformly applied, the extent of the violation is independent from the individual fisherman characteristics. This implies that all fisherman will choose to

⁴ In contrast, under an individual non-transferable quota regime, it is possible to show that a non-compliant fisherman chooses the extent of its violation so that $p - c_e(e(p, B, \theta), B) / h_e(e(p, B, \theta), B) = \theta f' (h(e(p, B, \theta), B) - q_0)$.

exceed its quota holdings in the exactly the same magnitude. In contrast, under an individual non-transferable quota system the optimal extent of the violation will differ among fishermen. The expected difference on violation extent will depend on the differences in the marginal net benefits from the fishing activity, as well as on the differences on the level of the quota allocated among them.⁵

Considering the effects of the exogenous variables on fishing effort, and quota demand, then, it is possible to show that the extent of quota violation v is an increasing function of the price of quota, and decreasing in enforcement effort. Perhaps surprisingly, while fishing effort and quota demand depend both on the price of landed fish and biomass; we obtain that the extent of quota violation does not. We formalize these in our next result.

Result 5: *Given an optimal choice of quota violation $v(w, p, \theta, B)$; the following comparative static result hold:*

	w	p	θ	B
v	+	0	-	0

Proof of Result 5: See Appendix.

⁵ We notice that a fisherman facing two alternatives property rights-based regulatory regimes, with and without transferability, will violate its quota holdings up to the point where the marginal benefit of the violation equals its expected marginal penalty. However, a comparison of the related compliance decisions, reveal fundamental differences between them. First, while in both cases the expected cost of a violation is fully determined by the expected marginal penalty, under an ITQ system the marginal benefit of non-compliance is given by the quota price. That price represent the avoided cost when a fisherman chooses not to demand enough quota to cover its harvest. It is important to notice that in a perfect competitive quota system, the quota price is the same for all fishermen. In contrast, under an individual non-transferable quota system, the marginal benefit of a violation is given by the difference between the price of landed fish and the marginal cost of fishing, which it is likely to differ among fishermen. Second, while under an ITQ system the extent of the violation does not depend on the initial allocation of quota, under an individual non-transferable quota system, the extent of the violation is decreasing in the allocated quota.

4. Non-Compliance and Quota Market

In this section we turn our attention to study the effect of non-compliant fisherman on the equilibrium quota price. Then, considering equilibrium price of a non-compliant quota market, we explore the equilibrium choices of fisherman in the fishery: effort, quota demand, and extent of violation and proceed to the analysis of the impact that regulator's enforcement policy, biological conditions in the fishery, and the conditions of the market for landed fish have on the performance of the quota market.

4.1 Quota violations and the equilibrium quota price

The implications of the presence of violations for the performance of a pollution permits market in the context of market-based environmental policies have been explored before in the literature [see for example Malik (1990)]. We explore here the implications of an ill enforced transferable property rights-based fishery for the equilibrium price of the quota market. Our primary purpose is to show that, in our context, the presence of noncompliance will alter the equilibrium price of quota in a very specific manner.

Assume two alternative enforcement strategies, θ^c and θ^{nc} . We assume that the strategy θ^c allow the regulator to achieve perfect compliance; while under the strategy θ^{nc} every fisherman is non-compliant. From Result 5, it must be true that $\theta^c > \theta^{nc}$. Furthermore, assume that all other variables remain constant, except the enforcement strategy. Using Result 3, we conclude that in such a situation quota demand under compliance is greater than quota demand under non-compliance; that is $h^c(e^c) = q^c > q^{nc}$.⁶

⁶ We notice that in a situation where all fishermen face the same quota price w , and same marginal expected penalties, our analysis suggests that they will choose the same compliance status, and if in violation, the same extent of it. Therefore, under these conditions, the comparison above is valid for every fisherman.

Then, the equilibrium quota price in a compliant market (w^c) and the equilibrium quota price in a non-compliant market (w^{nc}) are implicitly defined by the following equations,

$$\sum_{i=1}^n h_i^c(e_i^c(w)) = Q \quad [6]$$

$$\sum_{i=1}^n q_i^{nc}(w) = Q \quad [7]$$

We are now ready to establishing that the presence of non-compliance alter the equilibrium quota price in a very specific manner. The following result hold,

Result 6: *The equilibrium quota price in the presence of quota violations will be lower than the equilibrium quota price of an otherwise compliant ITQ system.*

Proof of Result 6: Consider the market clearing condition for a compliant quota market and a non-compliant quota market given by equations [6] and [7], respectively. From the fact that $h^c(e^c) > q^{nc}$, and because $h^c(e^c(w))$ is strictly decreasing in w , it follows that in equilibrium $w^{nc} < w^c$ QED.

In addition, by definition, aggregate harvest must be higher for an ITQ fishery in which fisherman are non-compliant; that is, the following relationship must hold,

$$\sum_{i=1}^n h_i^{nc}(e_i^{nc}(w^{nc})) > \sum_{i=1}^n q_i^{nc}(w^{nc}) = Q \quad [8]$$

4.2 Equilibrium choices and market effects in the presence of quota violations

In a market-based system, firms' choices and characteristics are linked together by a market. In an unpublished working paper, Stranlund (1998) has examined some of the linkages among firms in a market-based system for pollution control and their implications

for enforcement. In our context, first, the presence of non-compliant fisherman might have impact on the fishing effort and harvest level of other members of the regulated community though the effect that quota violations have on the equilibrium price of quota. Second, because quota demand also depend on the enforcement strategy, equilibrium price of quota also depend on the regulatory policy, and therefore, the enforcement design will also affect fishing effort choices and harvest result though its impact on violation decision and equilibrium quota price. In principle, an increase in monitoring effort or sanctions will induce fishermen to reduce their violations by purchasing more quota and fishing less. The first effect is expected to puts upward pressure on the equilibrium permit price. Third, fluctuation in price of landed fish and biomass might also influence fishing effort choices and harvest result though the effects on equilibrium price of quota.

We explore the interconnections above. We start considering the equilibrium choices of a fisherman; and move on to analyze of the impact of regulators enforcement policy, market conditions for landed or processed fish, and the biological conditions of the fishery might have on the equilibrium of the system.

Let assume that enforcement is insufficient to induce full fishermen compliance. Further assume that each fisherman faces an enforcement strategy given by θ_i , which is assumed to be fixed. Consider that total allowable catch (TAC) is given by Q , the equilibrium price of quota is given by $w^{nc}(p, \theta, Q, B)$, where θ is a vector that contains the fixed enforcement strategy faced by each fisherman, θ_i . According to [8], the equilibrium quota price satisfies:

$$\sum_{i=1}^n q_i (w^{nc}(p, \bar{\theta}, Q, B), \theta_i, p - w^{nc}(p, \bar{\theta}, Q, B), B) = Q \quad [9]$$

The equilibrium price of the quota define the equilibrium choices of the fisherman (fishing effort, quota holding and violation of quota) given by:

$$e^{nc}(p, \bar{\theta}, Q, B) = e(p - w^{nc}(p, \bar{\theta}, Q, B), B) \quad [10-a]$$

$$h^{nc}(p, \bar{\theta}, Q, B) = h(e^{nc}(p, \bar{\theta}, Q, B), B) \quad [10-b]$$

$$q^{nc}(p, \bar{\theta}, Q, B) = q(w^{nc}(p, \bar{\theta}, Q, B), \theta_i, p - w^{nc}(p, \bar{\theta}, Q, B), B) \quad [10-c]$$

$$v(p, \bar{\theta}, Q, B) = h(e^{nc}(p, \bar{\theta}, Q, B), B) - q^{nc}(p, \bar{\theta}, Q, B)^7. \quad [10-d]$$

The exogenous variables affecting the equilibrium price and choices includes the price of landed fish; p , which we assume given by the fish market; the enforcement strategy, represented by the vector θ , which is chosen by the enforcement authority; total allowable catch (TAC), Q , which is assumed to be chosen by the regulatory authority; and the level of biomass, B , which is given by the biology of the fish and eventually other environmental variables.⁸

We are now ready to explore the impacts of the changes in the exogenous variables on the equilibrium price, and choices, when considering the quota market effects in the presence of violations. To that purpose we proceed first, by deriving the impacts of changes in the landed fish market conditions on the equilibrium of the system. The following result hold.

⁷ The equilibrium quota violation can also be obtained from equation [5]. In effect, considering the equilibrium quota price, the condition $w^{nc}(p, \theta, Q, B) = \theta f'(v(p, \theta, Q, B))$ holds.

⁸ We are not analyzing here the dynamic problem involved; that is, biomass in the current compliance period it is probably given by biomass, TAC, and aggregate harvest level in the previous period.

Result 7: *An increase in the price of landed fish will increase equilibrium quota price and the extent of the equilibrium quota violation.*

Proof of Result 7: Substitute equilibrium quota price $w^{nc}(p, \theta, Q, B)$ in equation [9]. Then, differentiate it with respect to p , to obtain

$$\frac{dw}{dp} = - \frac{\sum_{i=1}^n \left(\frac{\partial q_i}{\partial p} \right)}{\sum_{i=1}^n \left(\frac{\partial q_i}{\partial w} \right)} > 0 \quad [11]$$

As for the effect of a change in the price of landed fish on the equilibrium quota violation, consider the condition for the quota violation extent at the equilibrium price of the quota;

$w^{nc}(p, \theta, Q, B) = \theta f'(v(p, \theta, Q, B))$, which implicitly defines $v = v(w(p, B, \theta, Q), \theta$.

Differentiate it with respect to p to obtain

$$dv / dp = dv/dw \times dw/dp > 0 \quad [12]$$

Result 7 suggests that the increase in the price of landed fish increase the equilibrium quota price under non-compliance and though it will also increase the extent of the equilibrium quota violation. The intuition for that result is straightforward. An increase in the price of landed fish will increase the marginal net benefit of quota violation, which in a competitive quota market, is given by the equilibrium quota price, given the enforcement strategy, it will increase the equilibrium level of quota violation. This result has clear implications for the design of enforcement strategies from a fishery authority: better conditions in the market in the industry for processing fish might end triggering more violations of the quota.

We explore now, the impact of the regulator enforcement strategy on the equilibrium choices. The following result holds,

Result 8: *An increase in enforcement effort increases the equilibrium quota price and have an ambiguous effect over the equilibrium aggregate level of quota violation.*

Proof of Result 8: Substitute the equilibrium quota price $w^{nc}(p, \theta, Q, B)$ in equation [9].

Differentiating the expression with respect to θ_i , we obtain

$$\frac{dw}{d\theta_i} = -\frac{\frac{\partial q_i}{\partial \theta_i}}{\sum_{i=1}^n \left(\frac{\partial q_i}{\partial w} \right)} > 0 \quad [13]$$

To see the effect of more enforcement pressure on the aggregated equilibrium quota violation we first have to note that

$$V = \sum_{j=1}^n v_j(w(p, B, \bar{\theta}, Q), \theta_j)$$

Without losing generality, suppose that the authority just change the enforcement effort over the firm 1; then we have:

$$\frac{dV}{d\theta_1} = \frac{dv_1(w(p, B, \bar{\theta}, Q), \theta_1)}{d\theta_1} + \sum_{j=2}^n \frac{dv_j(w(p, B, \bar{\theta}, Q), \theta_j)}{d\theta_1} \quad [14]$$

On one hand, differentiating $v_1(w(p, B, \theta, Q), \theta_1)$ with respect to θ_1 we obtain,

$$\frac{dv_1}{d\theta_1} = \frac{1}{\theta_1 f''(v)} \left(\frac{dw}{d\theta_1} - f'(v) \right)$$

The sign of which is ambiguous.

On the other hand, the effect of an increase in the enforcement effort over firm 1 in the violation of the other firms is given by:

$$\sum_{j=2}^n \frac{dv_j}{d\theta_1} = \sum_{j=2}^n \frac{1}{\theta_j f''(v)} \frac{dw}{d\theta_1} > 0$$

The sign of which is positive. So that the final effect in equation [14] is ambiguous. QED.

We first notice that Result 8 suggests that more enforcement pressure to one or all fisherman will end increasing the equilibrium quota price. As for the violation, and perhaps surprisingly, we found that increasing the enforcement effort to one or all fisherman have an ambiguous effect on the extent of the equilibrium violation; that is, the violation extent might increase or decrease with more enforcement. In effect, more enforcement pressure have a direct effect of increasing the demand of quota; thus, reducing the violation; however, because more enforcement increases the equilibrium quota price, by Result 6, it tend to increase the violation. The net effect is case specific. In the case in which enforcement does not increase for all fishermen, for those that enforcement remain fixed there is only an incentive to increase the extent of their violation. Further, this result suggest that if the regulator decide to increase the enforcement effort, it should be over all firms to reduce the possibility of increase the aggregated violations.

Interestingly, our result suggest that more enforcement pressure even over one violator fisherman produce upward pressure on equilibrium quota price; affecting all the choices from other regulated population. Depending upon specific situation the change in enforcement strategy may result not only increasing the quota price, but also increasing the aggregate level of violation.

Another variable under a regulator control is the total allowable catch (TAC). We now answer the question of how the TAC policy for a given compliance period affect the equilibrium fisherman choices and the equilibrium outcome of the quota market. We offer the following result,

Result 9: *An increase in the total allowable catch (Q) increases equilibrium quota price, increases equilibrium fishing effort and harvest, increases equilibrium quota demand, and reduce the extent of the equilibrium violation.*

Proof or Result 9: First, to see how changes in total allowable catch affect equilibrium quota price, as before substitute equilibrium quota price $w^{nc}(p, \theta, Q, B)$ in equation [9], differentiate with respect to Q to obtain,

$$\frac{dw}{dQ} = \frac{1}{\sum_{i=1}^n \left(\frac{\partial q_i}{\partial w} \right)} < 0 \quad [15]$$

Second, to derive the effect of a change in total allowable catch on the equilibrium fishing effort, equilibrium harvest, equilibrium quota demand, and equilibrium violation, differentiate [10-a], [10-b], [10-c] and [10-d] with respect to Q to obtain,

$$de^{nc} / dQ = e_w \times dw/dQ > 0 \quad [16-a]$$

$$dh^{nc} / dQ = h_e \times e_w \times dw/dQ > 0 \quad [16-b]$$

$$dq^{nc} / dQ = dq/dw \times dw/dQ > 0 \quad [16-c]$$

$$dv / dQ = dv/dw \times dw/dQ < 0 \quad [16-d]$$

An increase in the TAC reduce the equilibrium level of quota price; thus, increasing the equilibrium level effort and quota demand. Furthermore, because violations are increasing in equilibrium quota price, a reduction in it induced by greater level of TAC will end reducing the level of harvest that exceed the quota holdings. Of course, the result suggests that “bad seasons” (in terms of low TAC with the same Biomass) will induce illegal behavior. This is because low TAC will generate high quota price, that will generate an increase in the incentive to violate the quota holding. The result have policy implications for the design of enforcement strategies in a fishery regulated with transferable property rights.

Finally, we also study the impact of biological conditions on the equilibrium choice variables and quota market results in a property rights regulated fishery under non-compliance. That leads us to our next result,

Result 10: *Suppose that biomass in the fishery increases. Then, it will increase the equilibrium price of the quota and the extent of the violation.*

Proof of Result 10: To see how changes in biomass (B) affect the equilibrium quota price we proceed as before. Substitute equilibrium quota price $w^{nc}(p, \theta, Q, B)$ in equation [9], differentiate with respect to B to obtain,

$$\frac{dw}{dB} = - \frac{\sum_{i=1}^n \left(\frac{\partial q_i}{\partial B} \right)}{\sum_{i=1}^n \left(\frac{\partial q_i}{\partial w} \right)} > 0 \quad [17]$$

Next, considering $v(w(p, B, \theta, Q), \theta)$. Differentiate it with respect to B to obtain

$$dv^* / dB = dv/dw dw/dB > 0 . \text{ QED} \quad [18]$$

Result 10 suggests that an increase in the level of biomass increases the level of quota violation. This is so because a greater level of biomass, increases the demand of quota under non-compliance, and consequently increasing the equilibrium quota price. This effects generates an increase in the choice of the extent of the violation of quota holding. The result may look against the intuition that “bad season” in terms of resource availability may influence a high level of violations. However, we should remember that the optimum violation is given only by the relation between the marginal expected penalty and the equilibrium level of quota price.

Interestingly, our result suggest that the increase in biomass if not considered in the definition of the TAC, say by increasing it, will generate incentives to induce more violation in the fishery.

5. Efficiency in Quota Markets in the Presence of Non-Compliance⁹

The idea that an ITQ system would offer a regulator the opportunity to optimally organize the fishing activity by using transferable property rights was primarily pursued by Moloney and Pearse (1979). Enforcement problems and illegal activity aside, they were able to show that transferable harvest rights in fishery would guarantee an equilibrium distribution rights among fisherman that will maximize aggregate net revenue. In this section we re-examine the efficiency property of an ITQ regime when fisherman may be non-compliant.

In principle, the presence of non-compliance add two aspects on the analysis of efficiency of a transferable rights based system in a fishery. First, the possibility of non-compliance requires enforcement actions which are costly to the society. Enforcement will typically require the design of monitoring strategies to detect quota violations and imposition of penalties if a violation is detected. The implementation of both of them will clearly demand resources from society. Second, the presence of non-compliance; that is, aggregate harvest that exceed the total allowable catch might also involve other effects related to additional net surplus to the fishery. On one hand, fishing in excess of the TAC is beneficial to the society because fish has value and it may increase fisherman profits. On the other hand, fishing above the TAC limit implies a social cost because harvest in excess

⁹ The analysis of this section follows closely that of Malik (1990) in the context of a transferable emissions permit system.

of the TAC has a negative impact on the biomass into the future, negatively affecting the sustainability of the fishery, otherwise it would not be necessary to impose the TAC in the first place. We notice here that if the TAC is optimal, the presence of non-compliance reduce social surplus. If it was not optimally chosen, there is one case where non-compliance increase social welfare; that is when TAC is chosen to be lower than the optimal level of catch. This imply than may be optimal to the society establish low level of TAC and permit illegal behavior.

In the analysis that follows, we assume that the TAC has been optimally chosen. The objective function is given by,

$$\max V = \sum_{i=1}^n (ph_i(e_i, B) - c_i(e_i, B)) - D\left(\sum_{i=1}^n h_i(e_i, B) - Q\right) - m \sum_{i=1}^n \theta_i \quad [19]$$

Where, $D(\bullet)$ is the social damage from fishing over the TAC; we assume this function increasing and convex in the level of aggregate harvest that exceed the TAC. The expected enforcement costs are given by $m \sum \theta_i$ are composed of audit cost; it is assumed that each audit cost m to implement.

The analysis of the efficiency implications for an ITQ system from the presence of non-compliance that consider explicitly the need for enforcement requires first, to derive an efficient enforcement design. Because that analysis is out of the scope of this paper; we would proceed to re-examine the efficiency property of an ITQ regime in the presence of non-compliance by assuming the presence of a given enforcement strategy in the fishery that is insufficient to guarantee full compliance. Then, because under our assumptions enforcement cost are a constant, we focus on the bounded social problem of maximizing a social objective function given by the difference between aggregate net revenue from the

fishery and the damage as an increasing function of the aggregate harvest that exceed the TAC, we write [19] as,

$$\max_{q_{0i}} V = \sum_{i=1}^n (ph_i(e_i(q_{0i}), B) - c_i(e_i(q_{0i}), B)) - D(\sum_{i=1}^n h_i(e_i(q_{0i}), B) - Q) \quad [20]$$

A social optimal allocation of quota from the regulator in the presence of non-compliance requires,

$$\left[(p - D')h_{e_i} - c_{e_i} \right] \frac{\partial e_i}{\partial q_{0i}} = 0 \quad \forall \quad i = 1, \dots, n \quad [21]$$

Equation [21] suggests that in the presence of non-compliance it is optimal for the society that each fisherman chooses fishing effort such that they equals marginal revenue to marginal social costs (marginal damage plus marginal cost of harvesting). This result combined with Result 1, implies that as long as the equilibrium quota price differ from marginal damage of harvesting in excess of total allowable catch, the presence of violations will result in total effort that is inefficient. This inefficiency cause that total catch will be greater or lower than the optimal harvest¹⁰. However, because fisherman equals their marginal benefits, the distribution of the fishing effort to attain this total catch will be efficient. We conclude then, that an individual transferable quota system in the presence of violations might result in an inefficient total catch, but an efficient distribution of fishing effort between fishermen.

We shall remind here that Result 1 suggested that under an ITQ system all fishermen, regardless its compliance status, have the same marginal benefits in its optimum

¹⁰ The social planner problem away of enforcement consist of choosing a distribution of fishing quotas such that it maximizes the social net revenue, which is given by the difference between the value of aggregate

effort choice. This condition implies that the distribution of fishing effort among fishermen will be efficient still in the presence of illegal behavior. This in turn implies that the quota market assure that the harvest is attained with the maximum private benefits. The problem is that under violations total harvest is greater than the defined total allowable catch, and this might involve dynamic efficiency losses.¹¹

6. Conclusions

In this paper we constructed and analyzed a positive choice model of a fisherman regulated under a individual transferable quota system with opportunities for violations of quota holdings. We study individual choices of fishing effort, quota demand, and the extent of the violation. Furthermore, we explored the equilibrium quota market in the presence of non-compliant fishermen, and we compare it with a perfect compliance situation. Considering equilibrium choices of fishermen, we then move to study how these choices interact with several exogenous variables of the model; i.e. economic conditions in the market for landed fish, regulator and enforcement authority controls like total allowable catch, and enforcement effort, and biological conditions in the fishery.

We obtain several implications from our work. First, we have been able to show that, for our context, the presence of non-compliance will affect the equilibrium quota price in a very specific way: it will reduce the equilibrium quota price compared to a situation of full compliance. Second, we show that equilibrium choices of fishing effort (harvest),

harvest and aggregate costs of attaining that harvest. The solution of that problem requires that marginal net revenue be equal among fishermen [see Moloney and Pearse (1979)].

¹¹ We notice here that under a non-transferable individual quota regime with perfect compliance there is an efficiency losses because there is differences in the marginal benefits of firms. Furthermore, in this case the presence of violations may generate that some firms equals its marginal benefits to marginal penalty and each one. Interestingly, under such a regime, this may imply that illegal catch has positive effects over distributional efficiency. Again, the problem is originated because total catch exceed the TAC.

quota demand, and the extent of a quota violation depends not only on economic conditions in the fishery, but also on the regulator control, and biological conditions. Like it is expected, an increase in the price of landed fish is likely to trigger an increase in the extent of quota holding violations; however, our results also suggests that more enforcement pressure is likely to be ineffective, especially when it focus on some agents, rather than in all fishermen. As we have seen, an enforcement authority that seeks to increase compliance in this regulatory system must be aware that enforcement effort will be distorted by the effect that they produce on the equilibrium quota price.

In addition, we also found that while a good fishing season associated by greater level of biomass might end increasing violations because it put upward pressure on quota price through the increase in quota demand. That effect might be mitigated by increasing the total allowable catch. In some way this result might be useful because in the context of information problems, a regulator facing an unexpected increase in biomass may want to increase total allowable catch within the fishing season, period when it is probably more likely to be better informed.

As an additional contribution of this work, we move ahead in the analysis and explored the efficiency implications of incomplete enforcement for a tradable property rights-based system in a fishery. Considering a fixed enforcement, and taking explicit account on the potential damages from non-compliance, we conclude that to ensure social efficiency, the equilibrium quota price in the fishery must equal the marginal damage from an aggregate harvest level that exceed the total allowable catch. If it is not the case, then the choice of fishing effort will be inefficient. However, and perhaps, surprisingly, in this context the distribution of fishing effort among fisherman will be efficient in the sense that it will involve the lowest cost way to attain that harvest level.

Our work can be extended in a number of ways. Let us to mention a few of them. One of the major concerns in the literature about the implementation of individual transferable quota system has to do with the possibility of concentration of quota and the exercise of market-power. We feel that re-examining our results in the context of market-power it will be worth to pursue. In addition, our result on the potential inefficiencies of a property rights based fishery in the presence of non-compliance depend on our assumptions about the damage function and the choice of total allowable catch. Explore the implications of changes on them is another road of research. Finally, it will also be nice to complement the conceptual analysis with empirical work; to explore this result from an empirical perspective might shed lights on specific issues.

The use of transferable property rights to regulate fisheries have been going from the academic agenda to the practice of policymakers who are responsible for the regulation and management of fisheries. The promise of maximizing social benefit from a fishery being regulated with property rights might not be obtained in the case of violations. Exploring these and other issues might contribute to a better design of these programs.

Appendix

1. Prof of Result 3:

The optimal level of quota demand under non-compliance, q^{nc} , is given by:

$$-w + \theta f'(h(e((p-w), B), B) - q) = 0 \quad [A-1]$$

This equation implicitly defines $q^{nc} = q(w, \theta, p, B)$. Totally differentiating [A-1] we obtain

$$-dw + f'(\cdot) d\theta + \theta f''(\cdot) [h_e e_p dp + (h_e e_B + h_B) dB - h_e e_p dw - dq] = 0 \quad [A-2]$$

a. Setting $dw = d\theta = 0$, we have

$$dq^{nc}/dp = h_e e_p > 0 \quad [A-3]$$

b. Set $dp = dw = d\theta = 0$, we have

$$dq^{nc}/dB = h_e e_B + h_B > 0 \quad [A-4]$$

c. Set $dp = dB = d\theta = 0$, we have

$$dq^{nc}/dw = - [1/\theta f''(v) + h_e e_p] < 0 \quad [A-5]$$

d. Set $dp = dB = dw = 0$, we have

$$dq^{nc}/d\theta = f'(v)/\theta f''(v) > 0 \quad [A-6]$$

From [A-3], [A-4], [A-5] and [A-6] we have that given an optimal choice of quota demand $q(w, p - w, \theta, B)$; the following comparative static result hold:

	w	p	θ	B
q	-	+	+	+

QED.

2. Proof of Result 5:

The level of optimum violation, v , is given by

$$v(p-w, w, \theta, B) = h(e(p-w, B), B) - q^{nc}(w, \theta, p-w, B) \quad [A-7]$$

Taking derivative with respect to p from [A-7], we have

$$dv/dp = h_e e_p - dq^{nc}/dp$$

From [A-3] we know that $dq^{nc}/dp = h_e e_p$, so that

$$dv/dp = 0 \quad [A-8]$$

Taking derivative with respect to B from [A-7], we have

$$dv/dB = h_e e_B + h_B - dq^{nc}/dB$$

From [A-4] we have $dq^{nc}/dB = h_e e_B + h_B$, so that

$$dv/dB = 0 \quad [A-9]$$

Taking derivative with respect to w from [A-7] we have

$$dv/dw = -h_e e_p - dq^{nc}/dw$$

From [A-5], we have $dq^{nc}/dw = - [1/\theta f''(v) + h_e e_p]$, so that

$$dv/dw = 1/\theta f''(v) > 0 \quad [A-10]$$

Taking derivative with respect to θ from [A-7], we have

$$dv/d\theta = -dq^{nc}/d\theta$$

From [A-6], we have $dq^{nc}/d\theta = f'(v)/\theta f''(v)$, so that

$$dv/d\theta = -f'(v)/\theta f''(v) < 0 \quad [A-11]$$

From [A-8], [A-9], [A-10] and [A-11] we have that an optimal choice of quota violation $v(w, p, \theta, B)$; the following comparative static result hold:

	w	p	θ	B
v	+	0	-	0

QED.

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