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Using Taxes to Deter Illegal Fishing in ITQ systems

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Using Taxes to Deter Illegal Fishing in ITQ systems

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Abstract: We study the effects of different tax schemes when used in fishery management in combination with an Individual Transferable Quota (ITQ) system. We focus on the effects of taxes on equilibrium quota prices and violations under the assumption that enforcement to induce compliance is imperfect and costly. The use of taxes is motivated by the regulator's need to recover costs for enforcement activities. We propose the use of a tax on the price of the processed products based on its impact on violations and information needs. We also show that this tax has a double pay-off on enforcement because it reduces the demand for illegal fishing and increases revenue for enforcement activities without producing a deadweight loss in the quota market. We present an application of our model to the case of the red shrimp fishery in Chile. In our simulation example, a tax of 7% on the price of fish exports could sufficiently reduce harvest demand and generate enough funding to completely eliminate quota violations, which in the absence of taxes could be more than 100% of the TAC. At the same time, this tax could increase the equilibrium quota price by 19%.

Keywords: *Taxes, enforcement, illegal fishing, individual transferable quotas.*

JEL Classification: L51, Q22, Q28.

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1. Introduction

The use of Individual Transferable Quota (ITQ) systems in fisheries is among the most important innovations helping fisheries recover around the world. Costello et al. (2008) present convincing evidence supporting that most fisheries using catch share systems have been able to stop the tendency of fishery collapse, improve stock biomass, and provide fishermen enough incentives to obtain a sustainable harvest. Nevertheless, most of the cases in their study occurred in developed countries where institutions are strong and property rights can be correctly enforced.

Several developing countries, including Chile, Perú, and Namibia, are now using ITQ systems with the hope of preventing fishery collapse. In Chile, this system has been in place since 1991 in four small fisheries, and it was temporarily extended to the most important industrial fisheries of the country in 2001. In 2012, a new fishery law amendment was approved, and ITQs were permanently introduced as the main regulatory regime. Perú has also used an individual quota system since 2009 in its anchovy and hake fisheries. Nevertheless, the evidence in these countries does not seem to be as positive as Costello et al. (2008) suggest. In fact, three of the four fisheries being managed with ITQs in Chile since 1991 were closed after years of implementation because they were unable to recover under the new regulatory system.[1] Additionally, between 2001 and 2012, none of the fisheries regulated with individual quotas in Chile showed signs of stock

[1] The Chilean sea bass fishery harvest was reduced from 6,000 tons in 1993 to 1,000 tons in 2003. Since then, the fishery has slowly increased harvest. Biomass has continuously declined, from over 50,000 in 1990 to lesss than 10,000 in 2012 (SUBPESCA, 2010). The red shrimp fishery was closed for commercial activity in 2001 after 9 years of increasing harvest until 2011 (SUBPESCA, 2011). The yellow prawn fishery was closed between 2001 and 2005 (SUBPESCA, 2011a). The orange roughy fishery was closed in 2007 and has not been open to commercial activity since (SUBPESCA, 2011b).

recovery, and the most important stocks experienced a decline. Chávez et al. (2008) proposed that one of the reasons ITQs have not worked as expected in Chile is the existence of illegal fishing.

One of the key elements for a proper functioning of an ITQ system is that the individual quotas can be correctly enforced. A rather common characteristic of most developing countries is the lack of proper institutions to provide enforcement that induces adequate levels of compliance.[2] In some cases, fishery managers are not well aware of the importance of enforcement activities for the operation and development of quota markets, and thus, ITQ systems are implemented with a lack of funding for the required enforcement activities. This has been the case, for example, in early experiences with ITQs in Chile and Peru [Chávez, et al. (2008), Paredes (2010), Paredes (2013)].

Recently, some developing countries have been considering the use of a tax system to help fund enforcement and research activities in fisheries. In Perú, for example, a tax is applied to the anchovy fishery, which is set at 0.25% of the international fish meal price per ton of harvest [De la Puente et al., (2011)]. During its discussion of the recent amendment to the fishery law in Chile, the government proposed a 4.2% tax on the value of quota holdings, arguing it would help fund enforcement and research activities. Chilean fishing firms opposed this and proposed using a tax on profits instead. The final law approved in 2012 includes a tax on quota holdings with some restrictions.

In this paper, we study the impacts different tax systems could have on the functioning of the quota market under illegal fishing. Moreover, we consider how a tax could help increase the enforcement level and reduce quota violations. We found that different tax systems will have different impacts on the quota market. We explore three types of tax schemes. First, we consider a

[2] Of course, another important requirement is that the TAC can be determined correctly. We do not deal with the TAC setting process in this paper, but acknowledge that it is a critical element in the regulatory design and implementation.

tax on quota holdings. This system has two effects: it reduces the demand for harvest, hence reducing the fishing pressure on the stock, but it also has the negative effect of inducing quota violations to avoid paying the tax and therefore reducing the impact the tax could have on the quota market. Second, we consider a tax on profits. This system does not affect the incentives of quota violations directly but only indirectly through an effect on the equilibrium quota. In fact, a tax over profits reduces the demand for harvest and the equilibrium quota price, reducing violations. The negative side of this tax system is that it requires collecting information on firm costs, which is usually unobserved by the fishery regulator. Therefore, information issues arise, affecting the feasibility and potential effects of the tax on quota violations and having a limited impact on enforcement. Finally, we study a tax on the price of the final processed product, which is the tax system that appears to be the most advantageous. It is easier to compute and to apply, has information benefits, and has the largest effect on quota violation reductions.

We propose using a tax on the price of the processed product to generate the required revenue to increase the funding for monitoring and other enforcement activities and achieve perfect compliance. Given that the quota supply in the quota market is completely inelastic, the proposed tax does not create efficiency welfare losses, and it is paid completely by the quota owner, creating a wealth transfer between the quota owners and the government. If constraints on the tax amount exist, for example, because the regulator is limited by fishermens' profits, political or social pressure, the proposed tax will not be able to achieve the best situation but rather the second-best situation with a lower level of violations in the quota market.

We provide a numerical example of the effects of the tax systems on the quota market under illegal fishing in the case of the red shrimp fishery in Chile [see Chávez et al. (2008)]. Our results suggest that a 7% tax applied over the tax of the processed exported product could sufficiently reduce harvest demand and generate enough funding to completely eliminate quota violations, which in the absence of taxes could be more than 100% of the TAC. At the same time, this tax could increase the equilibrium quota price by 19%.

The costs associated with monitoring and enforcement activities to deter illegal behavior as well as other costs related to the implementation and operation of fishery regulations can be significant [see, for example, Arnason, Hannesson, and Schrank (2000); Wallis and Flaaten (2000)]. The existing literature has suggested that there are both equity and efficiency factors that make fishers pay for these costs. From the equity perspective, fishers should pay for the management of an ITQ fishery because fishing activities produce private profits and it is not obvious that the government should help to increase those profits [Tietenberg (2003); Schrank, Arnason, and Hannesson (2003)]. From the efficiency perspective, fishers should bear the cost of managing the fishery because paying for the services they receive creates the proper incentives to care about the quality of the services being provided [Arnason, Hannesson, and Schrank (2000)]. The possibility of deadweight losses associated with the need of taxation to fund administration activities involved in the management of fisheries has also been suggested to support the call for cost recovery policies. More recently, Chávez and Stranlund (2013) have suggested that, except for a very special case, it would be efficient to make the fishers to pay for the administrative costs of an ITQ fishery. According to their work, introducing cost recovery is efficiency enhancing because it may reduce incentives to violate the quota, thus reducing monitoring and enforcement costs. Moreover, making the fishers pay for administrative costs can affect the size of the operating fleet, inducing a reduction in the number of active fishers (less fishers to be controlled) and consequently reducing administrative costs.

The remainder of the paper is organized as follows. In the second section we build on Chávez and Salgado (2005) to present the basic conceptual model to analyze the functioning of the quota market under non-compliance. We incorporate in the model the three tax systems and study the effects they have on a firm's individual behavior and on the quota market equilibrium. We then discuss how to set the proper tax to deter illegal fishing in quota markets. The third section of the paper presents an example of a numerical simulation with the potential effects from different tax systems on the quota market of the red shrimp fishery in Chile. The final section offers our conclusions.

2. The Model

This section presents a conceptual model of an individual fisherman operating in an ITQ system under illegal fishing. We lay out the basic elements of the model and briefly describe its analytical solution. The model serves as a basis for the numerical simulations.

2.1. A basic model of an individual fisherman under an ITQ system

To analyze the individual fisherman's behavior, a regulated individual fisherman is considered. The analysis is based on a static model of a risk-neutral fisherman operating in a perfectly competitive ITQ system. The model closely follows Chavez and Salgado (2005) and Chavez et al. (2008).

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

We consider that the fisherman sells his harvest to a competitive processing industry that transforms the fish into a final product at a rate λ.[3] The processed product is sold in a final market at a price p. To simplify the analysis, we assume that there is no processing cost and that there are constant returns to scale in the processing sector.[4] Under these assumptions, the price the fisherman receives is λp. We assume that the transformation parameter, the first transaction price, and the individual harvest are not observed for the regulator, who can only observe the amount of final products being sold, $\lambda h(e, B)$, and the final price p due to a higher formality of the processing sector, which is under control of the tax system.[5]

A violation of individual quota holdings occurs whenever a fisher's harvest level exceeds the number of quotas held; that is, $v = [h(e, B) - q] \geq 0$. We assume that a system is in place to track the number of quotas a fisherman holds. There is a probability θ that the fisherman will be inspected and a penalty will be applied. From previous literature on the enforcement of fishery

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[3] This can also be interpreted as the existence of a processing sector vertically integrated with the fleet. Another possible interpretation is the case of a competitive intermediary who faces a cost of distributing the product of (1-λ) of the price.

[4] This assumption simplifies the analysis by avoiding the discussion on the rent generated by the industry and by implying that the price of the first transaction reflects the industry rent. This assumption has no effect on the core results of our model.

[5] This is the case in most developing countries, where the harvesting activity has a higher informality than the fishing processing industry. Moreover, an important fraction of the production of the industry is usually directed to international markets with nearly perfect monitoring of sales and prices. An example of this situation is reported in Paredes (2010), who finds an unusual increase in the efficiency of the Peruvian fish meal processing industry immediately after the introduction of ITQs. He suggest that this is due to an increase in unreported harvest but correctly reported fish meal exports.

management programs, if a violation is detected, a penalty $f(h(e,B)-q)$ is imposed [see for example, Sutinen and Andersen (1985)]. We assume that the penalty is zero for a zero quota violation ($f(0) = 0$) but that the marginal penalty for a zero quota violation is greater than zero ($f'(0) > 0$). For a positive quota violation, the penalty function is strictly increasing and convex. We assume that the structure of the penalty function is given for the regulator and that it is established by law, so the regulator cannot affect it. The only enforcement variable available is the enforcement effort he uses, which affects the probability of detection of illegal activity.

2.2. Individual fisher behavior

As is standard in the literature, we assume that an enforcement authority is committed to a strategy and communicates this strategy to all fishermen. We assume that each fisherman chooses a positive fishing effort and quota holdings and never over-complies.[6] Each fisher chooses a fishing effort e (and, consequently, a level of harvest h) and a quota demand q to solve (1), taking the enforcement strategy as given.

$$\max_{e,q}\ p\lambda h(e,B) - c(e,B) - w(q-q_0) - \theta f(h(e,B)-q) \qquad (1)$$

$$s.t. \qquad h(e,B-q) \geq 0$$

As presented in Chávez and Salgado (2005), considering that enforcement is insufficient to induce perfect compliance, the optimal choices of a noncompliant fisherman on fishing effort, quota demand, and quota violation are given by:[7]

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[6] Under our model's assumptions about individual risk neutrality along and that the quota can be traded in the market, it is never optimal for an individual fisherman to overcomply. We acknowledge that under a different set of assumptions, such as individual risk aversion or the presence of a multispecies fishery, fishermen might have an incentive to hold the quota and not use it by the end of the season and, consequently, overcomply.

[7] Designing an enforcement strategy that induces full compliance requires that each fisher face an expected marginal penalty for a violation that exceeds the equilibrium quota price, that is,

$$w = p\lambda - c_e(e,B)/h_e(e^*,B) \qquad (2)$$

$$w = \theta f'(h(e^*,B) - q^*) \qquad (3)$$

$$v^* \equiv h(e^*,B) - q^* \qquad (4)$$

Equation (2) characterizes the optimal choice of fishing effort. This is the standard result for individual fishing effort in a competitive ITQ fishery: a fisher chooses his/her effort to equate the marginal cost of using the quota (*w*) to the marginal benefit of fishing, which is the difference between the landed fish price and the marginal cost of fishing. This condition implicitly suggests that the choice of effort depends on the level of relevant prices (quota and landed fish) and on the level of the stock abundance. Given an optimal choice of fishing effort, equation (3) defines the optimal level of quota demand and implicitly defines quota violations in equation (4). The condition in equation (3) indicates that quota violations are chosen so that the quota price is equal to the expected marginal penalty. This balances the marginal benefit of quota violation with its marginal expected costs.

2.3. Imperfect enforcement, fishing taxes and regulator's budget constraint

We assume that the regulator has a budget constraint that may make full compliance unfeasible. Therefore, in the absence of appropriate funding, we will expect to have positive quota violations. From now on, we allow the regulator to increase the enforcement effort by collecting a tax from the regulated fishermen. We assess three tax options. First, a tax on the price of the fish (τ_1).

$\theta f'(0) \geq w$. If the fisherman is compliant, it follows in the context of this model that $h(e(p,w,B),B) = q(p,w,B)$. However, if the fisherman is in violation, his demand for quota will depend not only on the net price of harvested fish but also on the enforcement effort from the regulator [see Chávez and Salgado (2005)].

Second, a tax on the value of quota holdings or quota transactions (τ_2).[8] Third, a tax on firm profits (τ_3).

The problem of an individual fishermen under these three taxes types is the following:

$$\max_{e,q} \; [(1-\tau_1)p\lambda h(e,B) - c(e,B)](1-\tau_3) - (1+\tau_2)wq - wq_0 - \theta f(h(e,B)-q) \quad (5)$$

$$s.t. \qquad h(e,B) - q \geq 0$$

The optimal solution for the fisher is given by,

$$w = \frac{1-\tau_3}{1+\tau_2}[(1-\tau_1)p\lambda - c_e(e^*)h_e(e^*,B)] \quad (6)$$

$$(1+\tau_2)w = \theta f'(h(e^*,B)-q^*) \quad (7)$$

$$v^* \equiv h(e^*,B) - q^* \quad (8)$$

In equation (6), we observe that $\tau_1, \tau_2,$ and τ_3 reduce the demand for effort (and harvest), which is, as explained before, given by the right hand side of equation (6). Note that τ_2 and τ_3 affect the slope of the quota demand function and that τ_1 only affects its position. Additionally, τ_2 affects the optimal level of non-compliance in equation (7), increasing the incentive for quota violations, which is now given by $(1+\tau_2)w$.[9] The three taxes also affect the violation decision through the aggregate effect on the equilibrium quota price (w), which will be analyzed later. Equation (8) defines the equilibrium individual quota violation level as the difference between the harvest level and the number of permits being held by the fishermen.

[8] The first-order condition and individual incentives for both cases are identical.

[9] This implies that a lower quota price is required to create a similar incentive for quota violations compared to the other two tax systems.

The solution to the fisher problem determines the individual choice of effort level and quota demand, which in turn determines the level of quota violations. Specifically, assuming that enforcement is insufficient to guarantee perfect compliance with catch quotas, the analysis of the individual fisherman's behavior suggests the following results [for a formal proof of these results, see Chávez and Salgado (2005)].

- Individual choice of fishing effort *e*: A fisherman will chose a level of fishing effort such that the quota price equals the marginal net benefits per unit of harvest (equations (2) and (6)). This condition suggests that the individual fishing effort is a function of the price of the extracted resource (p), the transformation parameter (λ), the quota price (w), the resource abundance level (B), and the amount of the tax being used (τ), that is, $e^{*} = e(\lambda p, w, B, \tau)$.[10] Given strict convexity of the harvesting and cost functions, fishing effort increases in p and λ, decreases in w, increases in B, and decreases in the tax level. It is interesting to note that the effort e does not directly depend on the parameters associated with enforcement but only indirectly through the effect that enforcement has on the equilibrium quota price w.
- Individual choice of quota demand: Assuming an optimal fishing effort choice, any non-compliant fisherman will demand quota up to the point at which the marginal benefit of non-compliance (given by the quota price whose use is avoided) equals the marginal cost of non-compliance (given by the expected marginal penalty): $w = \theta f'(h(e(\lambda p, w, B, \tau), B) - q^{*})$. Consequently, the quota demand by a non-compliant agent is a function of relevant prices w and p, monitoring effort θ, the landing tax τ, and the level of fish abundance B; that is, $q^{*} = q_{nc}(w, p, \theta, \tau, B)$, where this choice decreases in w and τ and increases in θ, p, λ and B.

[10] We use τ in its general form here to refer to any of the three taxes being analyzed.

- Individual equilibrium level of quota violation: The optimal choice of effort and quota levels determines the extent of the violation v*. At the equilibrium, this level is such that $w = \theta f'(v^*)$. The equilibrium level of individual quota violation is an increasing function of quota price w and a decreasing function of the inspection probability θ, which we denote as $v = v(w, \theta, \tau)$.

Based on the analysis of individual fisher's behavior, the quota market functioning in the situation of non-compliance can be studied. The existing analysis suggests several results that are interesting for the numerical simulation: (i) quota demand in the presence of quota non-compliance (q_{nc}) is lower than under perfect compliance (q_c), that is, $q_{nc} < q_c$. (ii) The equilibrium quota price in the presence of quota non-compliance is lower than under perfect compliance, that is, $w_{nc} < w_c$. These results follow directly from the fact that, given the TAC, the aggregate quota demand under noncompliance is lower than under perfect compliance. (iii) An increase in the total allowable catch (Q) diminishes the equilibrium quota price, increases the catch, increases the quota demand, and diminishes the magnitude of equilibrium quota non-compliance. This is so because the increase in the TAC put downward pressure on the quota price given that at the original level of the price there is an excess of quota supply. The reduction in quota price increases the quota demand and, given the enforcement parameters, should reduce the extent of quota violations. (iv) An increase in the abundance level (B) increases the equilibrium quota price and increases the magnitude of quota non-compliance. This is so because an increase in the stock of fish abundance reduces the cost of fishing, increasing the optimal fishing effort, putting upward pressure on quota demand, and consequently increasing the equilibrium quota price for a given TAC. Because the equilibrium price of the quota represents the marginal benefit of violating the quota, given the monitoring effort and the marginal penalty, this should increase the extent of the quota violation. Finally, (v) an increase in the tax level reduces the level of violation because it reduces the equilibrium quota price.[11] As we will see later, the tax can also reduce violation if it helps increase the monitoring effort to induce quota compliance.

In Figure 1, we present aggregate quota demand (H_d), aggregate quota supply (Q), aggregate level of violations ($V(w)$) and the equilibrium quota price (w). We show the effects of the three tax systems on the equilibrium of the quota market. Figure 1.a shows the equilibrium quota market under non-compliance, as in Chávez and Salgado (2005). If the regulator is able to achieve full compliance of the TAC, the equilibrium quota price will be w_c^*, which is higher than the equilibrium quota price if non-compliance exists (w_{nc}^*). Figure 1.b shows the equilibrium of the quota market when τ_1 is in place and its revenue is used to fund enforcement to achieve perfect compliance. Under this scenario, the tax extracts some of the rents of the quota owner, reducing the demand for harvest and creating a downward pressure on the quota price compared with the situation under full compliance. On the other hand, the probability of detection increases, reducing the incentives for quota violations and creating upward pressure on the equilibrium quota price compared to the original non-compliance situation. The final effect is an increase on the quota price that is lower than the full-compliance and no tax quota price due to the rent extraction of the tax. The full rent of the fishing operation can now be separated into three parts: the fishing surplus (FS), the tax revenue to cover enforcement costs (TR) and the rent for the quota owner (RQO). Figures (1.c) and (1.d) show a similar analysis for τ_2 and τ_3, respectively. The main difference of τ_2 is that it affects the aggregated level of illegal fishing; therefore, to achieve perfect compliance, higher enforcement effort and tax revenue are required. In the case of τ_3, the revenue required is similar to τ_1, with the only difference being that it affects the slope of the

[11] Propositions and formal proofs of all of these results for a model of an ITQ system under illegal fishing withouth taxes are presented in Chávez and Salgado (2005).

harvest demand function.[12] Note that in all these figures we can observe the two effects of taxes on the quota market. First, we observe the impact of taxes on quota demand, which reduces the violation level and the equilibrium price in the quota market. Second, when tax revenue is used to increase the enforcement effort, the marginal expected penalty is increased, creating an additional incentive for reducing the level of quota violations.

Insert Figure 1 about here

2.4. Using a tax to induce compliance in the quota market

We have argued that revenue generated by taxes can be used to increase the enforcement effort, which will have an impact on the probability of detection, consequently reducing the expected level of violations. We have presented three types of taxes that could help achieve the goal of improving quota compliance. We have shown that the three tax systems presented can also help induce greater compliance because it reduces the equilibrium quota price, which represents the incentive at the margin to violate quota holdings. Nevertheless, the application of a tax on quota holding will reduce the impact of the increased enforcement because it also creates incentives for illegal activity.

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[12] We have implicitly assumed that the TAC is correctly set, which implies that at this level the marginal social cost of harvesting the fish, including the dynamic users' cost of the stock, equals its marginal private benefit, given by the harvest demand. Therefore, exceeding the TAC by quota violation creates a welfare loss. Therefore, a tax that eliminates quota violations is a welfare improving intervention. Additionally, given that the supply of permits is perfectly inelastic, these taxes do not create deadweight losses in the quota market.

In this section, we explore how to set the proper level of tax to reduce the violation levels, and even induce perfect compliance, when possible. Because of the undesired side effect of a tax on quota holdings, and considering the information problems associated with a tax on profits, we explore how to set the level of the fishing tax assuming that the regulator uses a tax on the price of the final product, τ_1. From now on, we denote this tax only by τ.

We start our analysis by describing the regulator's budget constraint related to enforcement activities. Enforcement costs include both the regulator's monitoring and sanctioning costs.[13]

Because the marginal incentive to violate the quota is determined by the quota price and the marginal sanction, there is no reason to apply a different monitoring effort across fishers. Therefore, we are assuming that monitoring is uniformly applied to all fishermen ($s_i = s$, with $i = 1,2, \dots n$). This implies that, in equilibrium, all fishermen have the same marginal incentives for quota violations and, therefore, $v_i = v$. This further implies that the aggregated level of violations is given by $V = nv$. Under this set of conditions, the budget constraint faced by the fishery's manager is given by:

$$M_0 + \tau\lambda pQ + n\theta(s)f(v) \geq cns + \beta n\theta(s)f(v) \quad (9)$$

where M_0 is an exogenous budget level to fund enforcement activities. The second and third terms on the left hand side are the revenue generated from the tax and from the collections of sanctions, respectively. The terms on the right hand side are expected monitoring costs and

[13] The analysis of sanctioning costs (including litigation) is not common in the analysis of the enforcement of environmental policies; however, it is more common in the general literature on optimal enforcement of the law. In the enforcement of environmental regulation literature, Stranlund (2007) has considered the costly collection of sanctions in the context of transferable emission permits systems. Also, Stranlund et al. (2009) assume that imposing sanctions in the context of emissions taxes is costly, and they study the impact of those costs on the proper design of tax policies. Sanctioning costs have also been considered in the context of the enforcement of emission standards (see, for example, Malik (1993) and, more recently, Arguedas (2008) and Caffera and Chávez (2011)).

expected sanctioning costs, where c is the cost per unit of the monitoring effort, which we assume to be constant across fishers, s is the monitoring effort applied to each fisher that determines the probability of detection θ, β is the cost of imposing sanctions conditional on the detection of quota violators, and v is the equilibrium quota violation at the quota market equilibrium level.

Equation (9) implicitly defines the maximum monitoring effort that can be applied by the regulator given the budget constraint and other exogenous variables as $s(\tau, p, c, \beta, v)$. Therefore, the equilibrium in the quota market will be given by the following equations:

$$w = \theta(s)f'(v) \quad (10)$$

$$Q = \sum_i [h_i(w, \tau, p) - v] \quad (11)$$

$$s = s(\tau, p, c, \beta, v) \quad (12)$$

These three equations determine the equilibrium in the quota market for a given tax level. Equation (10) defines the optimal level of violation for each individual, which is uniform among them, while equation (11) defines the equilibrium quota price that equals the supply and demand of permits. Equation (12) presents the maximum enforcement effort allowed by the regulator budget constraint, as previously defined in equation (9). Note that the tax will have two effects on the equilibrium level of violations. On the one hand, a tax will increase the regulator budget, which will allow her to increase the enforcement effort and the probability of detection, reducing quota violations. Additionally, increasing the enforcement will create a multiplier effect: more violations will be detected, which will increase penalties and revenue from collected sanctions, allowing an additional increase in enforcement effort. On the other hand, the increase in the probability of detection will tend to generate less violations, which will counteract the previous effect. Given that these are second- and third-order effects, we expect the first-order effect to dominate, and therefore, the increase in taxes will allow an increase in the level of enforcement effort and reduce violations.[14]

Using equations (10)-(12), we are ready to characterize the taxes that could induce perfect compliance or, if taxes are constrained for social or political reasons, the level of compliance a given tax could achieve.

If the regulator is able to freely choose the tax level to fund the monitoring effort to induce perfect compliance in a least-cost manner, not using an excessive enforcement effort, the following relations should hold

$$w = \theta(s) f'(0) \tag{13}$$

$$Q = \sum_i h_i(w, \tau, p) \tag{14}$$

$$s = \frac{M_0 + \tau\lambda p Q}{nc} \tag{15}$$

Equations (13), (14) and (15) characterize the tax level, the enforcement effort and the quota price that will generate equilibrium under perfect compliance in the quota market, respectively.

Note that if the regulator is restricted in the maximum amount of taxes she can apply and is not allowed to impose the level of tax that induces perfect compliance, the equilibrium in the quota market will still have quota violations, which will decrease as both, the tax level and the enforcement effort, increase. We will now analyze this case.

Imagine a regulator who is in charge of implementing an ITQ system while facing a constraint in the tax level she can apply and that she wants to minimize violations.[15] There are several

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[14] It is straightforward to show that if the cost of collecting sanctions (per dollar of sanction) is greater than or equal to one ($\beta \geq 1$), lower violations will increase the regulator budget, and therefore, higher taxes will always increase enforcement efforts.

[15] The limit in taxation could be motivated by a participation constraint, as in Jensen and Vestergaard (2002). In their model, the regulator uses a participation constraint that requires fishermen to have non-negative profits. Our analysis is a more general version of this constraint

potential motivations for pursuing this goal. On the one hand, if the TAC is properly set, quota violations will imply that the level of harvest will be above the target, with potential consequences on stocks. On the other hand, avoiding violations could reduce the costs of imposing sanctions. In this scenario, the fishery's manager solves the following problem:

$$\min_{\tau,s} \quad V = nv \tag{16}$$

$$s.t. \quad M_0 + \tau\lambda pQ + n\theta(s)f(v) = cns + \beta n\theta(s)f(v) \tag{17}$$

$$v = v\Big(\theta(s), w\big(p, B, \tau, \theta(s)\big)\Big) \tag{18}$$

$$\tau \leq \bar{\tau} \tag{19}$$

$$0 \leq \theta(s) \leq 1 \tag{20}$$

We notice that because the incentives for violations are uniform among fishermen, the aggregate level of violation is given by $V = nv$. Where $v = v\Big(\theta(s), w\big(p, B, \tau, \theta(s)\big)\Big)$ is the optimal violation level of a fisherman at the equilibrium of the quota market, given the enforcement effort and the tax being used by the regulator. Moreover, for the regulator to be able to induce perfect compliance, it must hold that $\theta(s(\tau^*, \dots))f'(0) \geq w$, with $\tau^* \leq \bar{\tau}$, and $Q = \sum_i h_i(p, w^c)$, at the chosen level of tax, τ^*, and at the equilibrium quota price under perfect compliance, w^c. If this is not feasible and $\theta(s(\bar{\tau}, \dots))f' < w^c$, given that the equilibrium violation level is strictly decreasing in τ and that equations (17) and (19) imply an upper bound to the optimal enforcement level s^*, the optimal level of τ is $\bar{\tau}$. This implies further that if the

that can include other types of limitations to the tax amount beyond avoiding fishers abandoning the activity, such as the amount of taxes being applied to other industries or simply political realities that could make it unfeasible for the regulator to freely choose the level of tax.

regulator would like to have the lowest possible level of violations and cannot ensure perfect compliance, she should apply the maximum feasible tax, given by $\bar{\tau}$.

3. Application to the red shrimp fishery in Chile

In this section we present an application of our model to show the effects of the different tax systems on the quota market and violations. We use the Chilean red shrimp fishery case presented in Chávez et al. (2008).

The red shrimp fishery in central southern Chile began in the mid-20th century in response to the reorientation of fishing efforts from other overexploited fisheries. Declared catches for the 1982 to 1989 period fluctuated by approximately 6,800 tons. After closing the fishery in 1990 and 1991, it was reopened in 1992 with catches increasing from 4,000 tons in 1992 to nearly 12,000 tons in 1999. Following the moratorium in 1992, the fishery was declared to be in recovery, and interested parties were allowed to participate in the exploitation of this species. Participation was controlled by individual fishing rights to extract a percentage of the annual TAC determined by the fishing authority. These rights could be obtained through public auctions. This new administrative system placed the red shrimp fishery under new regulatory measures, which included the fixing of annual TAC quotas, the definition of an authorized fishing period, and the granting of individual transferable quotas, legally called *Permisos Extraordinarios de Pesca (PEP)*. This regulation measure was complemented with a minimum extraction size of 20 cm of length (head to thorax) and with a yearly reproductive moratorium between January 1st and March 31st. After several years of decreasing stocks, in 2001 the Undersecretary of Fisheries decreed a new extraction prohibition that continued until 2011, after two years of authorizing harvesting for research purposes.

We use the data available for the red shrimp fishery to perform our model simulations. Table 1 presents the parameter values for a Cobb-Douglas harvest function used to simulate the harvest and quota demand (for more details on this estimation, see Chávez et al. 2008, Table 3, page 574). These estimations are based on monthly landings reports by the eight vessels continuously operating in the fishery during the fishing seasons of 1997-2000. Estimations of the landings function were conducted for each vessel. The estimation includes, as explanatory variables, the effort measured by the number of monthly fishing trips, the abundance of the fish stocks, and two dummy variables to reflect monthly variability in the harvest levels. The number of observations fluctuate between 12 and 75 fishing trips/year per vessel, R^2 fluctuates between 58% and 90% and most of the parameters are statistically significant, including F-statistics that are significant for all the estimations. Additionally, Table 2 presents the parameters of the enforcement and sanction function used in the same study. In this table, θ_0 represents the probability of detection assumed to be covered by M_0 when $\tau_1 = \tau_2 = \tau_3 = 0$.

Insert Table 1 and Table 2 about here.

Table 3 presents the results of the equilibrium quota price and violations in the quota market under no taxes and different enforcement efforts and probabilities of detection. We observe that even with θ=1, perfect compliance cannot be obtained for this fishery. This is due to the low sanctions imposed by law, the high price, the market demand, and the high productivity of effort at the fishery.

Insert Table 3 about here.

The results from applying different tax schemes are presented in Table 4. In the first two rows, we assume that no taxes are applied, and for comparative purposes, we show the cases of $\theta_0 = 0.1$ and $\theta_0 = 1$. We observe the effect of a change in the probability of detection in firms' profits, before and after taxes, and the equilibrium quota price. As presented before, increasing the probability of detection reduces quota violations and firms' profits and increase the equilibrium quota price. In the following cases, we keep $\theta_0 = 0.1$ and increase the enforcement effort funded by taxes. In the third, fourth and fifth cases, we present the tax level that induces perfect compliance, if possible. Both a tax on export price (τ_1) and a tax on profits (τ_3) can achieve perfect compliance. Nevertheless, due to a lower reduction in harvest demand, the tax on profits requires slightly higher tax revenue and a higher probability of detection to induce perfect compliance. This also implies a higher quota price. On the other hand, the tax on quota holdings (τ_2) cannot achieve perfect compliance, even when generating enough funds to create perfect monitoring ($\theta_1 = 1$). This is due to the effects of creating a minimum reduction in quota demand and an increase in the incentives for quota violations. It also implies a lower equilibrium quota price. We also compare the three tax systems by using a similar tax revenue. This is presented in the last three rows of Table 4. We computed the taxes that create a revenue of US$100.000 in the market equilibrium in the three cases. We observe that at equal revenue, and therefore equal monitoring effort, the first tax system creates a lower level of quota violations. This came at the cost of a slightly lower profit and quota price compared to the tax on profits. Again, the second tax system creates a 29% higher violation level even with the same enforcement effort.

Insert Table 4 about here.

4. Conclusions

We have presented a model to analyze the effects different tax systems that could provide funding for enforcement activities will have on the equilibrium quota price and violations of quota holdings. We have at least three reasons to prefer a tax on the price of the final product. First, compared to a tax on quota holdings, the tax on the price of the final processed product does not induce more quota violations, as is the case when a tax must be paid when the quota is used. Second, compared to a tax on profits, it has lower information requirement because it does not require information on costs of fishing, which is private, costly and difficult to obtain. Third, the tax over the price of the processed product also has an advantage over a *lump-sum* tax, such as the one proposed by Johnson (1995), because it reduces quota demand and quota price, reducing the incentives for quota violations.

While our conceptual and numerical analysis suggests that a well-designed ITQ system with a tax to fund enforcement activities should consider taxing fishermen revenue instead of profits or quota holdings, this approach may encounter practical and political difficulties. On the one hand, resource extraction industries may tend to favor taxes on profits over taxes on revenue or quota holdings. On the other hand, equity considerations might also play an important role as part of the practical implementation of an ITQ system with taxes on revenue. Fishery managers, motivated perhaps by distributional considerations, could wish to impose most of the burden of a tax on revenue in a way that reduces the potential negative impact on some fishermen in hopes of reducing the risk of forcing some of them out of the fishery, with the consequent job losses and deterioration of livelihoods in coastal communities.

While the precise structure of the tax we propose is beyond the scope of this paper, it is desirable to obtain preliminary information to attempt to compute estimates of the profit margin after the tax is set in order to demonstrate that it will not threaten the industry viability. However, even in a case where a regulator is unable to obtain precise measures of the relevant profit margin and where some fishermen are forced out of the activity because of the policy, those affected fishermen may be able to sell their quota allocation because of the ITQ system. This could serve as a way to facilitate the adjustment to a more efficient level of operation in the industry. How to set an appropriate tax system on revenue under an ITQ regime is an issue that deserves further analysis and compels future research.

Finally, while the analysis of this paper focuses on the effects of different taxes to generate revenue for improving monitoring activities to deter quota violations, others policy options are also possible. For example, the design of proper enforcement should also consider the possibility of influencing the level and structure of the penalty in the case of detection of violations, and perhaps also the procedures for imposing those penalties. Although the effects of manipulating the penalty are beyond the scope of this paper, it is possible to argue that our results are robust and may even improve, in terms of compliance levels, when, along with additional funding for monitoring activities, there is a better design of penalties.

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Table 1: Harvest function parameters per vessel

Vessel	1	2	3	4	5	6	7	8
A	5.687*	2.536*	2.796*	0.681*	7.533*	3.159	6.239**	10.58*
α	0.833*	0.922*	0.520*	0.623*	0.840*	0.757*	0.795*	0.53*
β	0.005	0.105	0.374*	0.414*	0.010	0.187	0.022	0.431*
d_1		0.017	0.058	0.081	-0.052	0.034	-0.111	-0.296*
d_2		0.004	-0.133**	0.015	-0.095	-0.039	-0.302	0.004
Trips/year	18	12	75	70	60	60	30	16
Harvest/trip	8.3	14.4	16.4	16.4	15.5	15.4	10.1	10.7
Adjusted R^2	0.58	0.89	0.90	0.87	0.66	0.79	0.89	0.80
F-statistics	5.860	12.420	64.778	47.917	11.900	21.000	37.047	12.107
p-value	0.040	0.010	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

Harvest function is $H = Ae^{\alpha}SC^{\beta}$, where e is fishing trips and SC is the storage capacity of the vessel. d_1 and d_2 are fishing season dummies. Based on Chávez et al. (2008), page 574. Marks indicate statistically significant levels at 5% (*) and 10% (**).

Table 2: Market and enforcement parameters used in the simulation

Parameter	Value (US$)
λp (harvest price per ton)	879
c_E (cost per unit of effort)	1048
$f'(0)$, marginal sanction for v=0.	500
Δ, $f''(v)$, change on marginal sanction	70
β, sanctioning cost	200
Q (TAC in tons.)	2500

Table 3: Equilibrium in quota market under different enforcement and no taxes

θ_0	*w*	*V*	*V/TAC*
0.1	379.9	4523.8	181.0%
0.2	428.2	2250.3	90.0%
0.3	453.1	1385.5	55.4%
0.4	468.9	922.1	36.9%
0.5	480.1	631.2	25.2%
0.6	488.5	430.8	17.2%
0.7	495.0	284.1	11.4%
0.8	500.3	171.9	6.9%
0.9	504.6	83.2	3.3%
1	508.2	11.3	0.5%

Table 4: Equilibrium in quota market under different tax schemes

Tax type	Probab. of detection (θ_1)	Profits Before Taxes	Tax Revenue	Profits After Taxes	Quota Value	Quota Violation (Tons)	Quota Price
$\tau_1 = \tau_2 = \tau_3 = 0$	10.00%	3,591,480	0	3,591,480	949,648	4,524	380
$\tau_1 = \tau_2 = \tau_3 = 0$	100.00%	1,469,197	0	1,469,197	1,270,610	11	508
τ_1=6.59%	90.27%	1,463,152	144,815	1,318,337	1,127,252	-	451
τ_2=14.65%	99.99%	1,469,232	162,358	1,306,874	1,108,244	11	443
τ_3=10.1%	91.91%	1,463,152	147,778	1,315,374	1,143,588	-	457
τ_1=4.55%	65.43%	1,605,865	100,008	1,505,857	1,139,216	269	456
τ_2=8.85%	65.43%	1,645,940	100,006	1,545,934	1,130,526	346	452
τ_3=6.19%	65.43%	1,615,286	100,001	1,515,285	1,160,570	287	464

In all cases, a TAC=2500 tons is considered. All values are in US$ on an annual basis.

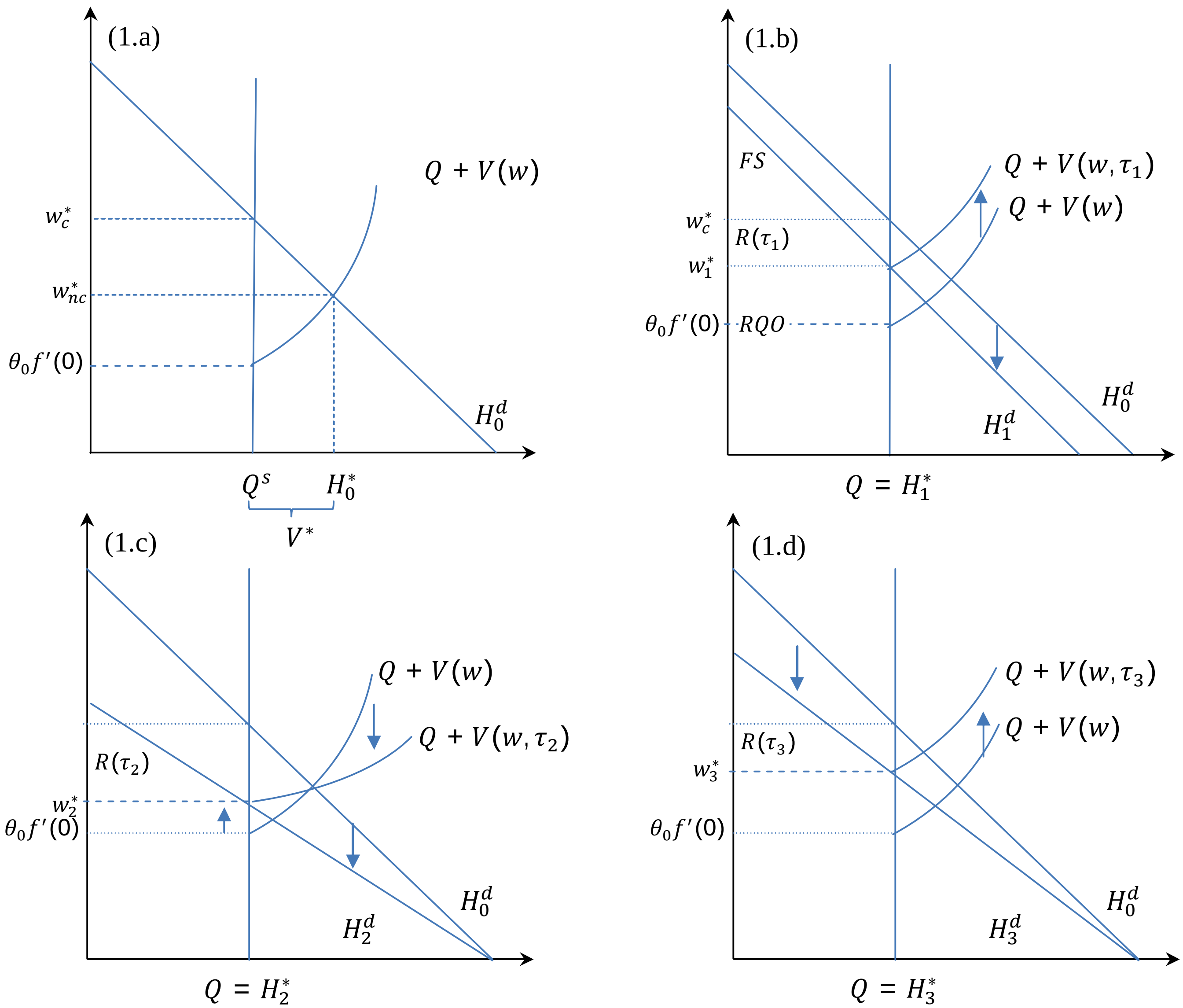

Figure 1: Equilibrium in the quota market under different tax systems.