ITQ Markets with Administrative Costs: An Application to the Industrial Common Sardine and Anchovy Fishery in Chile

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Abstract. Using numerical simulations of the mixed common sardine and anchovy fishery of central-southern Chile, we study the effects of the distribution of administrative costs between the government and the fishing industry in an individual transferable quota system. Consistent with recent theoretical results, we find that the level and distribution of the administrative costs between the public and private sector affects the period-by-period equilibrium quota price and number of active vessels. In addition, the distribution of administrative costs affects the optimal total allowable catch and the steady state biomass. In general, our results demonstrate two effects on the social value of the fishery when the industry bears all administrative costs. On one hand, the social value of the fishery increases, because there are fewer vessels operating and because of the deadweight costs of public funds. On the other hand, when the industry pays all administrative costs, the optimal quota policy changes which affects the fishery value during the transition to the steady state equilibrium. Taken together, our results suggest that having the industry bear all administrative costs might not be efficient.

Key Words: individual transferable quotas, administrative costs, quota market.

1. Introduction

Markets for individual transferable fishing quotas (ITQs) allow the achievement of a total allowable catch (TAC) with the maximum social benefit. ITQs involve setting a maximum cap on catches to comply with a biological target, and the creation of individual transferable rights consistent with the cap. Conceptually, ITQ systems can prevent over-exploitation of a fishery and create incentives for fishermen to manage their fleets and related fishing effort efficiently.¹

The operation of an ITQ system involves several administrative costs associated with implementing and managing the regulation, including the formulation of regulatory requirements, monitoring and sanctions to deter illegal fishing, and research to support management efforts. These activities can generate significant costs (Arnason et.al. (2000), Wallis and Flaaten (2000)). Despite the potential relevance of the administrative costs of an ITQ

¹There are currently hundreds of fishery regulations that use some system based in the use of individual catch quotas (Arnason (2002)). In Latin America, ITQs are being used in Chile and Peru. These systems are also being used in some African countries, including South Africa, Morocco, and Namibia (see, for example, Chávez et. al. (2008), EDF (2015), Paredes (2013), and Peña-Torres et. al. (2011)).
system, there has been very little research on the welfare effects of these costs, how they affect the design of an ITQ system, and the optimal distribution of these costs between the government and the fishing industry.

In fact, Chávez and Stranlund (2013) appear to be the first to provide a rigorous economic model of an ITQ fishery to address these issues. They model four influences on administrative costs that ultimately determine the optimal distribution of these costs. The quota price may have a direct positive influence on administrative costs because fishers have a greater incentive to violate their quota with a higher price, requiring greater enforcement effort to maintain compliance. There may also be a direct positive effect of individual harvests if landings require costly certification. There could be a fleet size effect as well if more vessels require greater enforcement or other administrative effort. Finally, the level of administrative costs may depend on the distribution of these costs because of the deadweight cost of raising public revenue.

In the absence of all of these effects the quota market equilibrium, aggregate administrative costs, and the value of the fishery is unaffected by the distribution of administrative costs. However, the deadweight costs of public funds, the fleet size effect, and the quota price effect all suggest shifting the burden of administrative costs to the industry. It is only the harvest effect that can lead to having the public bear a portion of administrative costs. Chávez and Stranlund conclude that, except in special cases, an efficient design of an ITQ system should make the regulated fishing industry pay the administrative costs.² In this paper we

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² Other work on fisheries management suggests that there is an equity reason for distributing administrative costs to fishers. This is that administration of an ITQ system mainly benefits fishers, and it might be unfair to require the public to pay for what is largely a private benefit (Tietenberg (2003), Schrank et al. (2003)). Arnason et al. (2000) suggest another reason why shifting the burden of administrative costs to fishers can promote efficiency. They argue that doing so will give fishers a powerful incentive to make sure the administrative services are provided efficiently. We do not deal with these additional possibilities in this paper.
extend this analysis to consider a fishery’s transition to the steady state and we find that these transitional net benefits might change this conclusion.

Chávez and Stranlund (2013) also show that the presence and distribution of administrative costs affects the steady-state allowable catch, biomass, and quota market equilibrium, but that these effects are indeterminate because the presence and distribution of administrative costs generate ambiguous stock effects on the total costs of fishing (the total costs of administrative and fishing effort) and on the shadow price of the resource stock. These ambiguities suggest that the market effects of the distribution of administrative costs and their optimal distribution are empirical matters that must be settled on a case-by-case basis.

In this paper we conduct such an empirical analysis. Specifically, we use data from the mixed common sardine and anchovy fishery of central-southern Chile to calibrate a dynamic ITQ model with administrative costs. We evaluate how the optimal total allowable catch and equilibrium in the quota market for a period change with changes in the distribution of administrative costs and the current biomass. We then estimate the optimal steady state biomass, total allowable catch, number of vessels, and the quota price, as well as the paths of these variables to the steady state. Finally, we calculate the value of the fishery as a function of the initial biomass and the distribution of administrative costs. Our results suggest that the distribution of administrative costs can have non-monotonic effects on the paths of the optimal quota and market equilibria, much of which show up in differences in the transitions to the steady state. Ultimately, there are important non-monotonic effects of the distribution of administrative costs on the value of the fishery.

The paper is organized as follows. In section 2, we sketch the conceptual framework of Chávez and Stranlund (2013), which forms the basis for our simulation exercise. In section 3 we
describe the common sardine and anchovy fishery in central-southern Chile and present details of the model calibration. Section 4 contains our simulation results and we conclude in section 5.

2. Conceptual model of individual transferable quotas with administrative costs

In this section we briefly present the structure of the conceptual model of Chávez and Stranlund (2013), and review some of its main implications.

2.1 Model elements

Consider an ITQ fishery with \( n \) endogenous fishers. An individual fisher’s harvest in a period is \( q \), which sells at a competitive price \( p \). The current biomass of the fishery is \( B \). A fisher’s harvest cost function is \( c(q, B) + \lambda \), which is increasing and convex in harvest, decreasing in the stock of the resource, and the marginal cost of harvest decreases with the biomass so that \( c_{qB} < 0 \). \( \lambda \) denotes a fixed cost. To simplify their model Chávez and Stranlund assume that the variable part of the cost function is the same for all fishers, but costs vary according to fixed costs. In our numerical simulation we relax the assumption of identical variable cost functions.

Fishers operate under a competitive ITQ program. The total allowable catch in a period (TAC) is achieved with \( Q \) quota, which trade at price \( w \). Ownership of a quota confers the legal right to harvest a unit of the resource in a single period, and we assume that fishers do not violate their quota. A fisher receives an initial allocation of quota \( q^0 \); it holds \( q \) quota and harvests that amount after trading is completed.
Administrative costs associated with each active fisher is the function $m(w, q)$. This function is non-decreasing in the quota price, reflecting the possibility that a higher price can lead to a greater incentive to violate and, consequently, a greater need to allocate resources to deter illegal fishing. The administrative cost function may also be increasing with greater harvests, because greater harvests may be associated with higher costs of certifying their legality. Administrative costs are strictly positive for all active fishers even if they are independent of quota price and individual level of harvest because there are likely to be costs that vary with the number of fishers. The model does not include administrative costs that are independent of the number of fishers. This is a simplifying assumption that does not affect the results as long as these costs are not so high that any ITQ program is inefficient. Since the government and fishers may share administrative costs (or administrative services which can be modeled as cost sharing), let $\alpha$ be the fraction of administrative costs borne by the government: $1 - \alpha$ is the portion borne by fishers. This cost-sharing arrangement is the same for all fishers. Finally, since public financing requires revenue raised with distortionary taxes, let the marginal cost of public funds devoted to fishery administration be $\mu \geq 1$. Combining all the components of administrative costs to specify an aggregate administrative cost function produces

$$M = (1 - \alpha + \alpha \mu) nm(w, q).$$

3 The theoretical model assumes that all administrative costs are associated with individual fishers that operate under the ITQ program. However, this does not mean that individual fishers will actually bear the costs associated with them or that all management costs are attributable to individual fishers. The assumption does allow us, for modelling purposes, to describe total administrative costs as an aggregation of these costs over fishers. Moreover, the implementation of any distribution of administrative costs can be accomplished by distributing responsibilities for the necessary services between the fishers and regulators, and possibly with auxiliary fees and subsidies.

4 This does not mean that the government is less efficient in providing management services than the fishing industry, but that to fund administrative activities the government must raise funds using distortionary taxes, consequently one dollar of government expenditure costs more than one dollar. The marginal cost of public funds is equal to one plus the marginal excess burden of taxation, where the latter is the efficiency loss of a higher tax per dollar of increased revenue.
Of aggregate administrative costs, \((1 - \alpha)nm(w, q)\) is borne by the fishing industry, while \(\alpha\mu nm(w, q)\) is borne by the government. Note that there are potentially four direct effects that impact aggregate administrative costs; a quota price effect, an individual harvest effect, the effect of the deadweight cost of public funds, and a fleet size effect. Be aware that these are only direct effects, as each parameter can also have indirect effects that work through the quota market. For example, the distribution parameter \(\alpha\) can have indirect effects on equilibrium individual harvests, the quota price, and the active fleet size. We now turn to specifying these equilibrium interactions.

### 2.2 Fisher’s choices, quota market equilibrium, and optimal policy

Begin with the profit maximizing choices of an individual fisher, who every period solves the following optimization problem:

\[
\max_q \pi = pq - c(q, B) - \lambda - w(q - q^0) - (1 - \alpha)m(w, q). \tag{2}
\]

The solution to this problem is the fisher’s optimal harvest for a period, \(q(\alpha, w, B, p)\), which is also its demand for quota. It is straightforward to show that a fisher’s quota demand is increasing in the government’s share of administrative costs, the biomass, and the price of landed fish, but it is decreasing in the quota price.

Substituting a firm’s quota demand function into its profit function gives its maximum profit for a period, \(\pi(\alpha, w, B, p)\), should it decide to operate. It could, instead, sell its allocation of quota and not fish for the period. This occurs if \(\pi(\alpha, w, B, p) < wq^0\). Firms with \(\pi(\alpha, w, B, p) \geq wq^0\) will operate in a period. Chávez and Stranlund show how this condition determines the number of active fishers in a period, \(n(\alpha, w, B, p)\). The fleet size in a period is non-decreasing as the government takes on a larger share of administrative costs because fishing
is more profitable. Likewise, since a higher biomass and higher price of landed fish make fishing more profitable, the fleet size is increasing in these variables. However, the fleet size is decreasing in the quota price because a higher quota price makes fishing less profitable. 5

Of course, the quota price is endogenous in a period. Aggregate demand for quota in a period is \( Q^D(\alpha, w, B, p) = n(\alpha, w, B, p)q(\alpha, w, B, p) \). Given \( Q \) quota are supplied to the market in a period, the equilibrium quota price is determined by \( Q^D(\alpha, w, B, p) = Q \), resulting in the quota price \( \hat{w}(\alpha, Q, B, p) \). The equilibrium fleet size is \( \hat{n}(\alpha, Q, B, p) = n(\alpha, \hat{w}, B, p) \) and the harvests of a firm are \( \hat{q}(\alpha, Q, B, p) = q(\alpha, \hat{w}, B, p) \). Finally, using [1], equilibrium administrative costs are:

\[
\hat{M}(\alpha, Q, B, p) = (1 - \alpha + \alpha\mu)\hat{n}m(\hat{w}, \hat{q}).
\]  

While the quota price is non-increasing in the government’s share of administrative costs, the effects of \( \alpha \) on the equilibrium fleet size, harvests per fisher, and aggregate administrative costs are generally indeterminate. In addition, the effects of the total allowable catch and the resource stock in a period on administrative costs are indeterminate.

With a full specification of the equilibrium consequences of the policy choices—the distribution of administrative costs and the total allowable catch—it is possible to choose the policy elements optimally. These choices will maximize the present value of the net social benefit of fishing over an infinite horizon, subject to equilibrium in the quota market in each period and the stock dynamics. Formally, the regulatory problem is to choose \( \alpha \) and a time path of \( Q \) to solve the following:

\[
\max_{(\alpha, Q)} \int_0^\infty \left[ \int_0^Q p(z)dz - \hat{n}c(\hat{q}, B) - F(\hat{n}) - \hat{M}(\alpha, Q, B, p) \right] e^{-rt} dt
\]

subject to \( \alpha \in [0,1], \dot{B} = G(B) - Q. \)  

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5 For formal proofs of these results and others presented in this section, see Chávez and Stranlund (2013).
In this problem, \( r \) is the constant discount rate, \( p(Q) \) is the stationary inverse demand curve for fish and \( F(\hat{n}) \) is aggregate fixed harvest costs, which are increasing in \( n \). \( G(B) \) is the stationary growth function and \( \dot{B} = G(B) - Q \) is the state equation for the problem.

With this model Chávez and Stranlund (2013) derive several results about the optimal distribution of administrative costs. (1) If the administrative costs do not depend directly on individual harvests, the distribution of administrative costs does not affect the size of the active fleet, and public funds are not more expensive than private funds, then the distribution of administrative costs does not have any effect on the value of a fishery regulated under ITQ. (2) In most cases where the distribution of administrative costs has efficiency effects, it is optimal that fishermen cover all administrative costs. In fact, it is only the direct harvest effect on administrative costs that can lead to having the government bear a portion of administrative costs, but it is not at all sufficient. (3) The presence of administrative costs and their optimal distribution affect the steady state total allowable catch, the resource stock, and the shadow price of the resource, but these effects are generally indeterminate. It is clear, that much in this model must be determined for real settings on a case-by-case basis. That is the main purpose of this paper.

3. Application to the industrial common sardine and anchovy fishery in central-southern Chile

3.1 The industrial common sardine and anchovy fishery in central-southern Chile

Common sardine (\textit{Strangomera bentincki}) and anchovy (\textit{Engraulis ringens}) are small pelagic resources that make up a significant mixed fishery in central-southern Chile. These
species inhabit areas close to the coast where biological productivity is high. These species support a significant industry of fishmeal and fish oil, which process harvests from an artisanal trawl fleet of medium scale (boats from 15 to 18 meters in length) and an industrial trawl fleet (vessels larger than 18 meters in length). In 2012, landings of both species were about 1.7 million tons, which represented approximately 89% of the raw material for the manufacture of 400 thousand tons of fishmeal.

Management of these fisheries involves an annual total allowable catch (TAC) that is distributed among the artisanal and industrial fleets. A biological stock evaluation is conducted to set this quota. The evaluation produces data for a scientific committee of independent experts who analyze the state of the stock and the fishery and establish precautionary quotas. These quotas are reviewed after the main annual recruitment takes place in March each year to set the final quota for the second half of the fishing season. These species exhibit high recruitment vulnerability (Cubillos et al. 2012, Morales-Bojórquez et al. 2003), which determines the annual evolution of the recruits and the adult stock. In addition, there exists a seasonal fluctuation of biomass with high values in the austral summer (January – February), a stationary pattern that is closely associated with the strength of recruitment (Cubillos and Arcos 2002).

The annual TAC is distributed between artisanal and industrial sectors. In the artisanal sector, the quota is distributed among legally constituted fishermen organizations that use their group quota according to their own internal arrangements. The industrial quota is distributed to each industrial owner. Individual quotas in this case are transferable. In 2012, the quota of both

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6There are at least three stocks of common sardine and anchovy in Chile: one anchovy stock is located along the northern coast of the country; another anchovy stock is located in the Coquimbo area (300 miles to the north of the capital city of Santiago), and a third mixed stock, which is the focus of our work, covers the coastline between the port cities of Valparaiso and Puerto Montt.
species in the central-southern area reached 1.12 million tons, 69% of which was distributed to artisanal sector and 31% to the industrial sector.

Administrative costs of the sardine and anchovy fishery are significant. Annually, at least two evaluations of spawning and recruitment biomass stock are conducted, and given the high seasonal variability of both species, some experts have recommended increasing the number of these evaluations and implementing a real-time monitoring system, which can have significant costs. Additionally, implementation of surveillance and control systems in both the industrial and artisanal sectors have significantly increased the costs of the National Fisheries and Aquaculture Service (SERNAPESCA), the agency responsible for monitoring and enforcing the quota system. Furthermore, the ITQ system for industrial fishers involves a landings certification protocol whose costs must be fully paid by the private sector. Finally, the industrial sector pays an annual vessel tax, which is intended to cover part of the administrative costs.

3.2 Functional specifications

We modify the model of Chávez and Stranlund (2013) slightly to apply it to the common sardine and anchovy fishery of central-southern Chile. We begin by estimating a Cobb-Douglas harvest function for each vessel, from which its quota demand function will be calculated (see Chávez et. al (2008)). The harvest function is:

$$q_{it} = q(e_{it}, B_t, SC_i) = A e^{\delta} B_t^\beta SC_i^\gamma,$$  \[5\]

where $q_{it}$ represents the level of harvest of vessel $i$ in year $t$; $e_{it}$ is the fishing effort of vessel $i$ in year $t$, measured in number of fishing trips; $B_t$ is the estimated biomass in year $t$; $SC_i$ denotes storage capacity of vessel $i$; and $A$, $\delta$, $\beta$, and $\gamma$ are parameters to be estimated. A significant difference of this application with the theoretical model of Chávez and Stranlund is that vessels
differ not only with respect to fixed harvesting costs, but also due to differences in their storage capacity. This leads to the result that vessels will have heterogeneous quota demands.

Administrative costs associated with each active vessel consist of the landing certification cost, which is set per unit of harvest, and a fixed component, which is total research costs divided equally among active fishers. Vessel $i$’s administrative costs in period $t$ are:

$$m(q_{it}) = c_v q_{it} + F/n.$$ \[6\]

In [6], $c_v$ is the price that the companies must pay per landed ton for private certification as established by the National Fisheries Service (SERNAPESCA). $F$ is the average annual budget for research spending between the years 2003 and 2012, which includes funding for basic research and transfers to the Institute of Fisheries Development and to the Fisheries Research Fund. We do not model a quota price effect on administrative costs, because of difficulties in estimating this effect. This omission biases the analysis toward finding that the government should bear a portion of administrative costs.

A vessel determines the number of fishing trips in a year, $e_{it}$, at price $c_e$, to maximize profit:

$$max_{e_{it}} \pi_{it} = p_t q_{it} - c_e e_{it} - \lambda_{it} - w_t (q_{it} - q_{it}^0) - (1 - \alpha)(c_v q_{it} + F/n)$$

subject to [5]. The solution to this problem is the optimal number of fishing trips for a vessel,

$$e_{it} = \left[ \delta \left( \frac{p_t - w_t - (1 - \alpha)c_v AB_t^\beta SC_i^\gamma}{c_e} \right) \right]^{1 - \delta},$$ \[7\]

which upon substitution into the harvest function [5] yields a vessel’s quota demand function,

$$q_{it} = \left[ \delta \left( \frac{p_t - w_t - (1 - \alpha)c_v}{c_e} \right)^\delta \right]^{1 - \delta} \left( AB_t^\beta SC_i^\gamma \right)^{1 - \delta}.$$ \[8\]
Equation [8] suggests that a vessel’s quota demand in a period is a function of the quota price in that period \( (w_t) \), the price of landed fish \( (p_t) \), the level of abundance of the resource \( (B_t) \), the vessel’s storage capacity \( (SC_t) \), the marginal cost of fishing effort \( (c_e) \), marginal administrative costs \( (c_p) \), and the proportion of administrative costs paid by the government \( (\alpha) \).

As in section 2, we use the individual quota demand functions to calculate the equilibrium quota price for a period. This price will be a function of all the parameters above, plus the total allowable catch for the period \( Q_t \). We are particularly interested in the distribution of administrative costs and the resource stock. For our purposes here, we denote the equilibrium quota price in a period as \( \hat{w}_t \). Plugging this value into [7] and [8] gives us vessel-specific fishing trips \( \hat{e}_{it} \) and harvests \( \hat{q}_{it} \). Insisting that firms are active only if they are profitable gives us the equilibrium composition of the active fleet in a period. We denote the set of active vessels in a period as \( I_t \) and the number of vessels as \( n_t \).

With our simulation of equilibrium in the quota market, we simulate optimal paths of total allowable catches. These paths will maximize the present value of fishing, given alternative distributions of administrative costs and initial stocks of the resource. The discrete dynamic optimization problem is to choose a time path of \( Q_t \) to maximize:

\[
\sum_{t=0}^{\infty} \frac{1}{(1 + r)^t} \left[ p_t Q_t - \sum_{i \in I_t} (c_e \hat{e}_{it} - \lambda_{it}) - \left(1 - \alpha + \alpha \mu\right) \sum_{i \in I_t} (c_p \hat{q}_{it} + F/n_t) \right],
\]

subject to \( B_{t+1} = B_t + G(B_t) - Q_t \) and \( B_0 = \) a constant. \[9\]

In equation [9], \( B_{t+1} = B_t + G(B_t) - Q_t \) is the state equation and \( r \) is a constant discount rate. To describe the biological growth function in [9], we use historical data from the fishery to estimate the following function:

\[
G(B_t) = \theta B_t (1 - B_t/K),
\] \[10\]
where $\theta$ is the intrinsic growth rate, and $K$ is the level of carrying capacity. While the policy problem is over an infinite horizon, in practical terms this is simulated in finite time sufficient to reach the steady state equilibrium.

Note that in our simulation model the distribution of administrative costs is exogenous, while it is chosen optimally in the theoretical model outlined in the previous section. In our simulations we prefer to analyze alternative distributions to provide a more detailed analysis of the effects of this parameter. We analyze three cases: when the public sector covers all these costs ($\alpha = 1$); when administrative costs are distributed between the public and private sectors ($\alpha = 0.5$), and when all administrative costs are covered by the industry ($\alpha = 0$). \footnote{Notice that because of the presence of the marginal cost of public funds devoted to fishery administration, $\alpha = 0.5$ does not mean that total administrative costs are divided in equal parts. With $\mu = 1.12$ and $\alpha = 0.5$, the industry’s share of total administrative costs is approximately 47%, while the government’s share is about 53%.

\footnote{Notice that because of the presence of the marginal cost of public funds devoted to fishery administration, $\alpha = 0.5$ does not mean that total administrative costs are divided in equal parts. With $\mu = 1.12$ and $\alpha = 0.5$, the industry’s share of total administrative costs is approximately 47%, while the government’s share is about 53%.

3.3 Estimation of harvest function, calibration and other procedures

The results of the estimation of the harvest function are shown in Table 1. To estimate this function daily data from official landing reports from the National Fisheries Service are used, which are summed on an annual basis for each of the vessels that operated between 2002 and 2012. This gives a total of 383 observations corresponding to 36 vessels. The results show an annual catch-fishing day elasticity of 0.831, which implies the existence of decreasing returns to fishing effort, which leads to quota demand functions with negative slope. Additionally, an annual catch-biomass elasticity of 0.522 is observed showing a significant effect of biomass on the landings of the industrial fleet. Finally, vessel storage capacity also has a positive and
significant effect on annual harvests, showing an annual catch-storage capacity elasticity of 0.339. All parameters are individually statistically significant.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Coefficient</th>
<th>$p &gt; t$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\ln(e)$</td>
<td>0.831</td>
<td>0.000</td>
</tr>
<tr>
<td>$\ln(B)$</td>
<td>0.522</td>
<td>0.000</td>
</tr>
<tr>
<td>$\ln(SC)$</td>
<td>0.339</td>
<td>0.000</td>
</tr>
<tr>
<td>$\exp(A)$</td>
<td>-4.404</td>
<td>0.004</td>
</tr>
</tbody>
</table>

Source: Authors’ calculation based on estimations using data from the National Fisheries Service (SERNAPESCA).

To perform simulations of the quota market, initially data from the year 2012 is taken as the base scenario, where biomass was 4 million tons and the sale price of common sardine and anchovy was $140 per ton. To estimate harvest costs, data from the First Fishing and Aquaculture Census from 2009 is used. A cost per fishing day ($c_v$) and a fixed cost per vessel ($\lambda_i$) are estimated. To obtain the fixed cost per vessel, a linear regression is estimated with the data from the Census that associates the fixed cost with the level of total catch. Then, this estimated fixed cost is associated with the storage capacity of each vessel in the sample using the harvest function. Administrative costs are divided into a variable cost ($c_v \hat{q}_{it}$), with per unit certification costs ($c_v$), and a fixed cost ($F$) which is the total amount currently being spent by the government in research and administration of the fishery. Finally, we use the marginal cost of public funds $\mu = 1.12$, recently estimated for the Chilean economy (Rodríguez (2012)). A summary of this data is shown in Table 2.
Table 2: Parameters used in the simulation

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fish sale price ($p$)</td>
<td>$140/ ton.</td>
</tr>
<tr>
<td>Cost per fishing day ($c_e$)</td>
<td>$5,348.78/ trip.</td>
</tr>
<tr>
<td>Annual fixed costs ($\lambda_i$)</td>
<td>$38.6$ Thousand - $105.6$ Thousand (Depending on the Storage Capacity)</td>
</tr>
<tr>
<td>Biomass ($B$)</td>
<td>2 Million Tons</td>
</tr>
<tr>
<td>Intrinsic growth rate ($\theta$)</td>
<td>0.3570256</td>
</tr>
<tr>
<td>Carrying capacity ($K$)</td>
<td>4,300,606.5 ton.</td>
</tr>
<tr>
<td>Fleet size ($n$)</td>
<td>36 vessels</td>
</tr>
<tr>
<td>Marginal administrative cost ($c_v$)</td>
<td>$1.6/ton</td>
</tr>
<tr>
<td>Fixed administrative cost ($F$)</td>
<td>$1.08$ Million</td>
</tr>
<tr>
<td>Marginal cost of public funds ($\mu$)</td>
<td>1.12</td>
</tr>
<tr>
<td>Discount rate ($r$)</td>
<td>0.05</td>
</tr>
</tbody>
</table>

Source: Based on description in text.

4. Results

This section presents the results of the numerical simulations to study the effects of the distribution of administrative costs on the optimal management of the common sardine and anchovy industrial fishery in central-southern Chile. To simulate the optimal quota, given fundamental discontinuities due to discrete changes in the number of operating vessels, we choose to follow a simple optimization procedure. First, we approximate the optimal policy by a linear function with a minimum biomass size, below which a moratorium is established. Secondly, starting with a biomass of 0.5 million tons, we look for the parameters of the linear policy function that maximize the net discounted value of the fishery over an infinite horizon, given a starting biomass. For this, we consider a long period of time, long-enough to reach a steady state, and use the infinite annuity of the steady state value from that period on. To predict the behavior of the quota market, taken as given a certain distribution of administrative costs.

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8 All monetary values are expressed in US$ using an exchange rate of CH$500/US$.
(according to the parameter $\alpha$), we conduct a forward simulation of the stock and we compute in each period the equilibrium in the quota market, including the number of active vessels, the associated administrative costs, and the fishing costs. Then, we use a numerical procedure to estimate the value of the parameters of the policy function that maximize the value of the fishery over this period of time. One interesting characteristic of this procedure is that it considers not only the value in the steady state of the fishery, but also the values that can be obtained along the approach path to the steady state. We found this procedure to provide more stable and consistent results over a number of alternative procedures that we tried, including the policy function and value function iteration procedures.

Table 4 shows the optimal TAC at different levels of the biomass and the corresponding number of active vessels and quota price at the equilibrium of the quota market. We repeat this analysis for three levels of the distribution of administrative costs; $\alpha = 0$, where fishing companies pays all the administrative costs, $\alpha = 0.5$ where fishing companies and the government share the administrative costs, and $\alpha = 1$ where all the administrative costs are paid by the government.

The results show that the distribution of administrative costs affects the optimal quota of the fishery. Given the distribution of administrative costs, we observe that the optimal quota, the number of active vessels, and the quota price are all increasing in the biomass. However, the effects of changes in the administrative cost share are not as straightforward. While the number of vessels is non-increasing, and is usually strictly decreasing as the industry takes on more of the administrative cost burden, the optimal TAC and quota price change non-monotonically with the administrative cost share. For example, given a biomass equal to 2.5 million tons, the optimal TAC is lowest when the government bears all the fishing costs and highest when administrative
costs are shared. Moreover, when the biomass is equal to 4 million tons, the TAC increases as
alpha is reduced, but when the biomass is 1.5 million tons the TAC decreases as alpha is
reduced. Similar non-monotonicity occurs with the quota price. For example, when the biomass
is 1.5 million tons, the equilibrium quota price is highest at $85.6 per ton when the industry bears
all administrative costs, but is lowest at $82.6 per ton when \( \alpha = 0.5 \).

Table 4: Optimal TAC with administrative costs

<table>
<thead>
<tr>
<th>Biomass</th>
<th>TAC</th>
<th>n</th>
<th>w</th>
</tr>
</thead>
<tbody>
<tr>
<td>500,000</td>
<td>0</td>
<td>0</td>
<td>-</td>
</tr>
<tr>
<td>1,000,000</td>
<td>0</td>
<td>0</td>
<td>-</td>
</tr>
<tr>
<td>1,500,000</td>
<td>0</td>
<td>0</td>
<td>4</td>
</tr>
<tr>
<td>2,000,000</td>
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<td>0</td>
<td>22</td>
</tr>
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<td>2,500,000</td>
<td>0</td>
<td>4</td>
<td>28</td>
</tr>
<tr>
<td>3,000,000</td>
<td>0</td>
<td>22</td>
<td>32</td>
</tr>
<tr>
<td>3,500,000</td>
<td>0</td>
<td>28</td>
<td>33</td>
</tr>
<tr>
<td>4,000,000</td>
<td>0</td>
<td>32</td>
<td>33</td>
</tr>
</tbody>
</table>

\( \alpha = 0 \)

(Industry pays 100% of fishing administrative costs)

<table>
<thead>
<tr>
<th>Biomass</th>
<th>TAC</th>
<th>n</th>
<th>w</th>
</tr>
</thead>
<tbody>
<tr>
<td>500,000</td>
<td>0</td>
<td>0</td>
<td>-</td>
</tr>
<tr>
<td>1,000,000</td>
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<td>0</td>
<td>-</td>
</tr>
<tr>
<td>1,500,000</td>
<td>0</td>
<td>0</td>
<td>4</td>
</tr>
<tr>
<td>2,000,000</td>
<td>0</td>
<td>0</td>
<td>22</td>
</tr>
<tr>
<td>2,500,000</td>
<td>0</td>
<td>4</td>
<td>28</td>
</tr>
<tr>
<td>3,000,000</td>
<td>0</td>
<td>22</td>
<td>32</td>
</tr>
<tr>
<td>3,500,000</td>
<td>0</td>
<td>28</td>
<td>33</td>
</tr>
<tr>
<td>4,000,000</td>
<td>0</td>
<td>32</td>
<td>33</td>
</tr>
</tbody>
</table>

\( \alpha = 0.5 \)

(Industry pays 50% of fishing administrative costs)

Changes in the quota price as the administrative cost burden changes are due to induced
changes in the TAC and the number of active vessels. The quota price increases with the number
of vessels, but it decreases with a higher TAC. The reduction in the number of active vessels as
the industry bears a greater burden of administrative costs puts downward pressure on the quota
price. However, it is clear that that the non-monotonic effects of the cost share on the optimal
TAC produces non-monotonic effects on the quota price. We will examine the complex

Source: Authors’ calculation.
relationship between the administrative cost share and the optimal TAC more closely in a moment.

Table 5 shows how the distribution of administrative costs affects the steady state values of the biomass, the optimal TAC, the number of operating vessels, and the quota price. The results suggest that under the different distributions of administrative costs, the optimum is close to the maximum sustainable yield, and consequently, there are only small differences in the equilibrium harvest level as well as in the biomass level. Nevertheless, we observe similar effects to those in Table 4: the steady state number of vessels decreases as the industry takes on more of the administrative costs, but the effects of this burden on the steady state TAC and quota price are non-monotonic.

<table>
<thead>
<tr>
<th>Table 5: Optimal steady state equilibrium</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \alpha = 0 )</td>
</tr>
<tr>
<td>( n )</td>
</tr>
<tr>
<td>( w )</td>
</tr>
<tr>
<td>Biomass</td>
</tr>
<tr>
<td>TAC</td>
</tr>
</tbody>
</table>

Source: Authors’ calculation.

To further explore the non-monotonic relationship between the administrative cost share and the optimal TAC we show in Figure 1 the optimal TAC as a function of the biomass for the three different scenarios under consideration (\( \alpha = 0, \alpha = 0.5, \) and \( \alpha = 1 \)). The intersections of these functions with the growth function provide the steady-state TACs and biomass levels for different values of \( \alpha \), which are given in Table 5. We observe that as the government pays a higher share of the management cost (\( \alpha \) moves from 0 to 1), the slope of the optimal TAC functions falls and the level of biomass at which the fishery is closed is also reduced. This
implies that the fishery is open earlier but with smaller increases in the TAC as the stock grows. These effects make the relationship between the TAC and $\alpha$ non-monotonic. At lower values of the biomass, the TAC is higher when the government pays the administrative costs, but for higher levels of the biomass the TAC is higher when the industry shares the burden of administrative costs.

Figure 1: Optimal TAC, growth and steady state under different scenarios.

While the steady state TAC and biomass are not very different from each other, the complicated impacts of the administrative cost share on the relationship between the optimal TAC and the biomass below the steady state suggests that the administrative cost share impacts the approach paths to the steady state. In fact, that is what we observe in Figures 2, 3, 4 and 5, which show how the distribution of administrative costs affects the time paths of the optimal quota, the biomass, the number of active vessels, and the equilibrium quota price starting with an
initial biomass of 0.5 million tons. In Figure 2, we observe the small differences in the quota in the steady state, but important differences in the way $\alpha$ affects the approach of the TAC to the steady state. Similarly, we observe the small differences in the steady state biomass (Figure 3), but important impacts on how the biomass grows to the steady state. These, in turn, affect how the market evolves in terms of the number of active vessels (Figure 4) and the quota price (Figure 5). It is important to emphasize that the value of the fishery depends on both the transition to the steady state as well as its value in the steady state. We observe in this case study that the different administrative cost sharing rules have significant impacts on transition paths without affecting the steady state in important ways.

Figure 2: Optimal paths of the TAC depending on the distribution of administrative costs
Figure 3: Optimal paths of the stock depending on the distribution of administrative costs

Figure 4: Number of active vessels depending on the distribution of administrative costs
Figure 5: Evolution of the equilibrium quota price depending on the distribution of administrative costs

In Table 6 we present the net present value of the fishery in terms of the starting value of the biomass and the distribution of administrative costs. While it is clear that the value of the fishery is increasing in the initial biomass, again the impacts of the distribution of administrative costs are non-monotonic. Differences in approaches to the steady state of the TAC and the biomass, differences in the number of active vessels, and differences due to the deadweight costs of public funds produce relatively complicated impacts of the distribution of administrative costs on the present value of the fishery. Significantly, note that except for a low initial biomass, it is optimal for the government to bear at least part of the burden of administrative costs.
Table 6: Net Present Value of the Fishery

<table>
<thead>
<tr>
<th>Initial biomass (Million tons)</th>
<th>Fishery value (Million US$)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$\alpha = 0$</td>
</tr>
<tr>
<td>0.5</td>
<td>449.6</td>
</tr>
<tr>
<td>1</td>
<td>511.3</td>
</tr>
<tr>
<td>1.5</td>
<td>564.6</td>
</tr>
<tr>
<td>2</td>
<td>614.3</td>
</tr>
<tr>
<td>2.5</td>
<td>657.9</td>
</tr>
<tr>
<td>3.0</td>
<td>695.7</td>
</tr>
<tr>
<td>3.5</td>
<td>731.6</td>
</tr>
<tr>
<td>4.0</td>
<td>762.3</td>
</tr>
</tbody>
</table>

Source: Authors’ calculation.

5. Conclusions

Theory and numerical evidence suggests that the presence and distribution of administrative costs can have important impacts on the performance of an individual transferable quota system. Our numerical simulations reveal significant and non-monotonic effects on the optimal paths of transferable quotas, biomass, quota price, size of the active fishing fleet, and the value of the fishery. While the effects of the distribution of administrative costs are complicated in our case study, we have found that it is likely optimal for the industry and government to share the administrative costs in our case study.

Recall that Chavez and Stranlund (2013) reached the opposite conclusion with their theoretical model. They identified four potential drivers of administrative costs that can affect the optimal distribution of these costs—the quota price, the fleet size, the deadweight costs of public funds, and the level of individual harvests—and they concluded that it is only the direct harvest effect that can lead to having the government take on a portion of administrative costs.

Administrative costs in our simulation exercise do not include direct quota price and fleet size effects, but the individual harvest effect, which is generated by the costly certification of
landings, is very important. This harvest effect, and the absence of direct price and fleet size effects, is probably what drives the conclusion that administrative costs should be shared in our application. In addition, we have noted the importance of considering how the distribution of administrative costs affects transitions to the steady state that is missing in the work of Chavez and Stranlund (2013).

A possible extension of this work is to consider the possibility of making fishers face discriminatory payments of administrative costs. The use of a discriminatory cost recovery policy could be motivated by social considerations and the alternative cost of using government funds, especially in developing countries. We suggest that the inclusion of more heterogeneity in the fraction of the administrative costs that each fisher must pay could significantly change the results. For example, if vessels pay these costs in a way that is proportional to their harvest, this will change their marginal benefits, affecting the equilibrium in the quota market. On the other hand, making them pay a fixed cost annually might not affect the equilibrium quota market directly, but instead might have an important impact in the number of active vessels, which will have an indirect impact on the quota market.

Acknowledgments

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