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Abbreviations and acronyms

EEZ	Exclusive Economic Zone
FAO	Food and Agriculture Organization of the United Nations
FOB	Freight On Board
IDB	Inter-American Development Bank
IFOP	Chile's Institute of Fisheries Research
IIFET	The International Institute of Fisheries Economics & Trade
IMARES	Institute for Marine Resources & Ecosystem Studies
IQ	Individual Quotas
ITQ	Individual Transferrable Quotas
LE	Limited Entry
MRAG	Marine Resources Assessment Group
NOAA	National Oceanic and Atmospheric Administration
OFA	Operational Fishing Association
RBM	Rights Based Management
Sernapesca	Chilean National Fisheries Service (Servicio Nacional de Pesca y Acuicultura)
TAC	Total Allowable Catch
USD	United States Dollar
WB	World Bank

Abstract[*]

The debate in commercial fishery management has evolved from whether well-defined rights are necessary for sustainability to measuring the impacts of different rights-based system designs. Most assessments are on developed world fisheries. Using a unique collection of datasets, we develop counterfactuals to evaluate the impacts of the Chilean Jack Mackerel catch share program. We investigate vessel and trip characteristics, as well as trip costs and revenues, before and after the implementation of the program. We find an increase in higher value products and associated revenue, as well as consolidation of catch on larger vessels, vessels taking longer trips, and catching more per trip. Overall, we estimate that the program led to a measureable increase in fishing profits, mainly due to movement toward higher value products. A back-of-the-envelope calculation results in an implied annual quota rental rate on the order of ~15-19% of ex-vessel prices.

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Key words. Catch shares, Chile, Individual Transferrable Quotas (ITQs), Jack Mackerel

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1. Introduction

Over the past 25 years, the debate in commercial fishery management has evolved from discussing whether well-defined fishing rights are necessary for economic and ecological sustainability to measuring the impacts of different rights-based system designs (see, e.g., Kroetz, Sanchirico and Lew (2015)). Most of these performance assessments have been done on developed world fisheries (Jardine and Sanchirico 2012), which is a reflection of where most of the early adopters of rights-based systems are found (e.g., Iceland, New Zealand, Canada), and the locations where the data are rich enough to measure impacts (see, e.g., Grafton, Squires et al. 2000, Shotton 2001, Newell, Sanchirico and Kerr (2005), Newell, Papps and Sanchirico (2007), Chu (2009), and MRAG (2009)).

Over the last 10-15 years, developing world fisheries have also been implementing and tailoring rights-based measures to their socioeconomic conditions (e.g., Peruvian Anchovy and several Chilean industrial fisheries) but there is very little assessment of their performance. Now, international and national government agencies are calling for exactly these types of evaluations to occur (see e.g. Brinson and Thunberg (2013) and Arnason, Kelleher and Willmann (2008)). Furthermore, there are efforts underway to define a set of standardized indicators to evaluate the economic performance of fisheries (Brinson and Thunberg 2013) in order to be able to compare evaluations across fisheries. Indicators include, for example, economic profit, per-vessel and per-permit holder measures of profit, and aggregate fishery statistics including the number of active vessels, stock, and season length.

In this paper, we evaluate the impacts of the Chilean Jack Mackerel Individual Transferrable Quota (ITQ) program in the Central-South macro region. Given the many potential dimensions over which change can occur in response to policy implementation (Smith 2012), we explore changes in inputs and outputs and estimate changes in economic efficiency. We measure potential revenue-side changes related to product quality changes that can lead to an increase in the per-unit price of the final product (see e.g. Wilen (2005) and Smith (2012)), as well as cost-side changes. Relative to earlier work in this fishery (specifically Gómez-Lobo, Peña-Torres and Barría (2011)), we use more detailed data (including a longer time series), we disaggregate the margins of change (revenue and cost-side), and use detailed production data to examine shifts in products produced (e.g. canned versus fishmeal) over time. We proceed by calculating economic returns following the start of the ITQ program, and then developing an estimate of counterfactual profits in the absence of an ITQ program.

Following implementation of the ITQ program, we observe an increase in higher value products and associated revenue. There is also a change in fishing patterns as catch becomes concentrated on larger vessels, taking longer trips, and catching more per trip. Overall, we estimate that the program led to a measureable increase in variable fishing profits, on the order of 22-35% of ex-vessel revenue. We also calculate a back-of-envelope estimate of the implied annual quota rental rate in the second year of the program equal to ~15-19% of ex-vessel prices.

The structure of the paper is as follows. First, we provide a review of the literature evaluating ITQ fisheries, a background on the Jack Mackerel fishery and the ITQ program, and a summary of the data we use for the analysis. We then describe the methods we use to evaluate the impact of the management change. Finally, we provide results, including summary statistics showing margins of change, and concluding thoughts and areas for future study.

2. Background

2.1. Literature review on ITQ fisheries

Past work provides evidence of significant changes from ITQ program implementation; changes that depend on the nature and strength of the fishing rights (Arnason 2012). The four dimensions of any property right are exclusivity, durability, security, and transferability. In an individual fishing quota program that does not permit trading, the gains accrue from dimensions other than transferability which are sufficient to better define rights of a common pool resource. [2] Some evidence of benefits associated with ownership include a reduced incentive to race for fish that can result in longer seasons, lower costs, and greater capacity utilization (see e.g. Herrmann (1996), Knapp (1997), Townsend (2005) and Sylvia, Mann and Pugmire (2008)). In turn, longer seasons allow a slower pace of fishing, improving the ability to optimize onboard processing facilities, which results in an increased product recovery rate per pound of fish caught (see e.g. Pollock Conservation Cooperative and High Seas Catchers' Cooperative (2007) and Sylvia, Mann and Pugmire (2008).

Additionally, a secure and exclusive right, along with longer seasons, has been shown to change incentives from maximizing the quantity of fish caught to maximizing the value of the catch. This can shift the product mix to a higher composition of more valuable products, such as fresh rather than frozen fish (see e.g. Boyd and Dewees (1992), Arnason (1993), Casey, Dewees et al. (1995), Herrmann (1996), and Pollock Conservation Cooperative and High Seas Catchers' Cooperative (2007)). This can also result in a change in the type of the fishing methods (e.g. gear), timing, and location of fishing, thus improving the quality and value of the fish caught (see e.g. Boyd and Dewees (1992), Casey, Dewees et al. (1995), Dupont, Grafton et al. (2002), Knudson (2003), Wilen (2005), Branch (2006), and Agar, Stephen et al. (2014)). Changes in the intensive margin may also occur to decrease the cost of fishing, such as type of the fishing methods (gear), timing, and location of fishing.

Additional benefits can occur when ownership rights are transferable. For example, transferability can result in consolidation of quota on the most profitable vessels. Specifically, quota will be transferred from the least profitable vessels (i.e. those for whom the difference between revenue and cost is lowest) to more profitable vessels. There is empirical evidence showing vessels that have higher costs of fishing will exit (see e.g. Weninger (1998), Kompas and Che (2005), and Solís, del Corral et al. (2014)).The number of vessels and fishing capacity are two relatively simple indicators that can change as quota is transferred from less efficient to more efficient vessels. Changes in these indicators have been documented in many fisheries post-ITQ implementation (see e.g. Wang (1995), Sanchirico and Newell (2003), Townsend

[2] In other words, these benefits can accrue to resource users with sufficient exclusivity, durability (even if only in the short term such as a year or season), and security. In particular, individual quotas (IQs) address the rule of capture incentives found in regulated open-access fisheries. That is, the allocation of shares of the total allowable catch (TAC) reduces the incentives to race for fish, as participants have greater certainty over their catch levels. Under an ITQ program, with the additional flexibility to buy and sell shares, participants are able to adjust the scale of their operations.

(2005), Dupont, Fox et al. (2005), Brandt and McEvoy (2006), Hamon, Thébaud et al. (2009), Agar, Stephen et al. (2014).

Researchers have also investigated the overall economic benefits of the programs as measured by quota prices (see e.g. Arnason (1993), Newell, Sanchirico et al. (2005), Wilen (2005), Newell, Papps et al. (2007), and Agar et al. (2014)). For example, Newell, Sanchirico and Kerr (2005) found that the value of fishing quota in New Zealand increased over time for fisheries with greater degrees of freedom to change their fishing operations post-ITQ implementation (such as inshore and shellfish fisheries relative to specialized deep-water fisheries).

2.2. Jack Mackerel fishery background

The evolution of industrial fisheries in Chile has followed a similar path to many large scale industrial fisheries around the world with respect to capacity expansion, overfished stocks, and the tightening of regulations in response to both (see Table 1 for summary). Until the mid-1980s, industrial fisheries in Chile operated under regulated access conditions, with the imposition of mesh size requirements and fishing permits, which implied an annual payment that varied with the vessel's capacity (gross weight). However, there were no output restrictions in place and vessels competed to catch fish. By 1986 the fleet was composed of purse-seine vessels and primarily targeted jack mackerel but also caught sardine and anchovies. All three small pelagic species were used to produce fishmeal, which was then used as feed in the aquaculture and agriculture sectors both within Chile and for export.

Table 1: Timeline of key fishing regulations for Jack Mackerel fishery.

	Fishing Year	Fishing Gear Regulations	Fishing Effort and Catch Regulations	Access Regulations
Pre-ITQ period	**Before 1986**		No regulations.	Vessel permits/licenses were required and limited.
	1986		Placed cap on industrial fleet's aggregate hold capacity in regions I to IV and VIII at the 1986 levels. No TAC.	Established a hold capacity cap for the fleet that in essence limited entry to the fishery in regions I to IV and VIII. Permits tied to vessel and hold capacity.
	1991		Aggregate hold capacity includes regions V up to IX. No TAC. Creation of artisanal fishing zone prohibiting industrial operations within 5 nm of the coast.	Regions X, XI, and XII remained outside the aggregate hold capacity restriction.
Research period	**1998**	Minimum catch size instituted via mesh size in purse-seine nets	Research fishing trips, de facto TAC	Fishery closed unless Gov't permitted the vessel to fish.
	1999		Seasonal and area TAC	
	2000		Hold capacity enforced in region X, No TAC, VMS required for industrial fleet.	All areas now subject to hold capacity regulations.
	Jan. 2001		No TAC for this month.	Permits applied.
Post-ITQ period	**Feb. 2001**		Seasonal and area based TACs. Industrial vessels banned within 5 nm of coast.	Individual quotas tied to vessels catch history and capacity. Duration of program was 2 years. Quotas are operationally transferable within a firm or via an inter-firm association.
	2003-2013			Quotas allocated for 10 years. Increase in fishing license fees.
	Post 2013		 Eastern-South Pacific Jack Mackerel RFMO and binding multi-country TACs	Individual quotas, fully transferable and 20 year duration, 15% of the TAC is auctioned giving 20 year right to share of the TAC

In 1986, following an expansion of fishing capacity and observed stock depletion in the Northern regions of Chile, the government began to actively manage the industrial fleets catching the small pelagic species (Peña-Torres 1997, Peña-Torres and Basch 2000). The government instituted a cap on the fleet's aggregate storage capacity for five of Chile's twelve fishing regions; the fishing regions correspond to Chile's administrative regions (see Figure 1, Regions I-IV and Region VIII). A new vessel could enter the fishery, but only if it purchased or retired a number of permits such that the total capacity of permits of the vessels exiting was equal to or greater to the capacity of the entering vessel.[3] Permit transactions could occur across or within fishing firms, where firms often own multiple fishing vessels.

[3] When this transaction required multiple vessels, the system operated similar to permit-stacking regimes that have been used in other fisheries around the world (e.g., the West Coast Sablefish tiered permit staking program (Kroetz and Sanchirico 2009)).

Figure 1: Map of administrative regions.[4] *

*Note: The Central-South fishery consists of regions V-XII.

In 1991, the Government passed a number of fishery management reforms in the Chilean Fisheries and Aquaculture Law (Castilla 2010), including the creation of an artisanal fishing zone extending 5 nautical miles (nm) for regions I to X where industrial vessels could not fish for small pelagics. The new law also extended the hull capacity limits to cover regions V through IX, which includes most of the Central-Southern portion of the fishery (latitude ~32^0S to 42^0S).[5]

Despite restrictions on aggregate capacity, from 1985-1995 the storage capacity of the fleet increased significantly through both vessel entry and an increase in vessel capacity. At the same time as capacity was growing, the fish stocks were declining (see Figure 2). In response, the Government closed the fishery at the end of December 1997.

The government opened the fishery for the 1998 season but only for a series of 'experimental' fishing expeditions called 'research fishing' trips. This "research period" lasted for three fishing years (1998, 1999, and 2000). During the research period the only way a vessel

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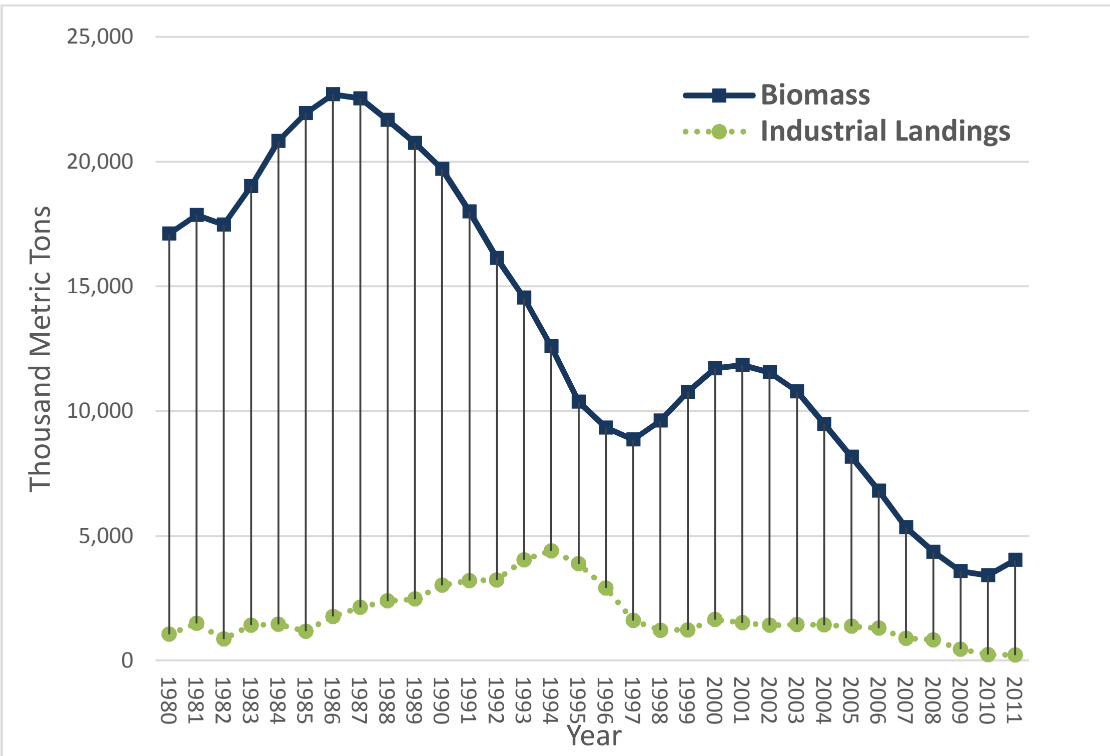
[4] Sernapesca. 2015. Sitios Regionales. Last accessed October 6, 2015. Available: http://www.sernapesca.cl/index.php?option=com_content&task=view&id=413&Itemid=293

[5] In 2000, capacity constraints were also extended to the southernmost region X in the jack mackerel fishery.

could fish for jack mackerel was to participate in a 'research fishing' trip organized and regulated by the authorities. During a research fishing trip, a participant boat was restricted to fishing a pre-determined stretch of sea and had to report existing schools of fish to the authorities. By limiting the number of trips, a (de facto) total allowable catch (TAC) was established during this period.

Figure 2: Estimated jack mackerel biomass and total Chilean landings over time. For the period of our analysis, 1996-2005, the Central-South landings comprise the vast majority of landings (74% or greater).*



*Source: IFOP (2013).

During the research period, however, there remained several incentives not to reduce capacity. First, a company maximized its chances of participating in an experimental expedition by paying the licensing fees for as many qualified vessels as possible, as the probability of a firm participating in an expedition in the research period was proportional to the number of qualified boats a company had. Second, many of those vessels could also be used in the anchovy and sardine fishery. Third, given the uncertainty as to the future regulation of the fishery, and given the possibility that the fishery would be reopened in the future, there was an option value associated with maintaining a larger licensed and operational fleet. For a more detailed description of the research period see Gomez-Lobo, Peña-Torres and Barria (2011).

2.3. The ITQ program

In this section we provide a brief overview of the ITQ program. For more information see the original 2001 Chilean Law N^0 19.731, and the amendments passed in December 2002 (Law N^0 19.849) and February 2013 (Law N^0 20.657), as well as discussion in Gomez-Lobo, Peña-Torres and Barría (2011).

In February 2001, the quota system was initiated,[6] granting owners of licensed industrial sector ships in the Central-South macro region a right to a certain percentage of each year's annual TAC. In the Jack Mackerel fishery quotas were allocated using a formula that gave 50% weight to the share of the total caught by each vessel from 1997 to 2000 and a 50% weight to the vessel's hold capacity relative to the total storage capacity in the fishery. Quotas were initially granted for a 2-year period, and then in December 2002 the rights were extended for 10 more years and incorporated the Northern Jack Mackerel fishery as well.

Quota trading was prohibited across species and between the industrial and artisanal fleets. However, the program did permit several means of transferring the yearly jack mackerel quota allocation (akin to a lease) and selling of the quota ownership right. First, fishing companies could 'operationally combine' their fishing operations during a particular year (i.e., without having to merge companies) in what was known as an Operational Fishing Association (OFA). Each year, upon reporting the OFA and constituent vessels to the regulator, vessel owners could reallocate quota between member vessels. A company could also decide to "trade" across its own vessels. Specifically, companies were not obliged to use all of their authorized ships, and could fish their quota allocation on any vessels they chose. Furthermore, ships not used during a particular year were initially exempt from the annual licensing fee.[7]

Quota sales were permitted through two mechanisms. First, because quota is allocated to vessels (with one exception described next), quota could be moved between firms through the sale of vessels. Second, a vessel could be irrevocably retired from the fishery, at which time the authorities would then give the owner a document with the history of landings and storage capacity of that ship used to allocate the initial quota. This document, stipulating the quota associated with the vessel, could then be transferred to other vessels of the company's fleet or could be sold.

Under the ITQ program, landings are monitored and audited by authorized private companies. Fishing companies pay for this service and must obtain a landing report after each fishing trip. Catch is then reported to the government agency Sernapesca.

In February 2013, the government amended the Fisheries Law to incorporate the following changes: (1) the duration of the quota asset has been extended for another 20 years, with the possibility of renewal; (2) yearly allocations of quota have become fully transferable and divisible; (3) management choices are now formally split between a Scientific-Technical Committee that, among other things, sets the TAC, and a Management Committee that oversees other management decisions; (4) the license fees were raised by 10% and all holders of a valid fishing license with assigned quota must make an annual payment based on the

[6] Prior to the ITQ program the fishery opened in January 2001, but with no restriction on catch in place.

[7] This exemption was valid only for the period 2001-2002. Since January 2003, all registered industrial vessels have to pay an annual licensing fee.

vessel's quota allocation; and (5) for fisheries determined to be fully-exploited, such as jack mackerel, up to 15% of the annual TAC is auctioned off, where the associated quota would have a durability of 20 years (without possibility of renewal; at the end of its duration it has to be auctioned again).

3. Data

We focus our analysis on the Central-South region. The Central-South is the main jack mackerel fishing grounds: from 1996-2005 the yearly catch from the Central-South ranged from 85-98% of total Chilean catch (IFOP 2013).

We use confidential landings data from Chile's Institute of Fisheries Research (IFOP) and the National Fisheries Service (Sernapesca).[8] The datasets contain information including the vessel name, vessel characteristics, date of trip departure and return, port of trip departure and return, area fished, and quantity of jack mackerel and other mackerel species landed.[9] The Sernapesca dataset is available for the years after the ITQ program was enacted and covers all trips. The IFOP dataset consists of a sample of trips, covering 70-90% of landings in pre-ITQ regulated open access years, and is the only available trip-level dataset covering fishing activity during the regulated open access period.

Because IFOP is only a sample of trips and the Sernapesca dataset contains all trips, we need to account for these differences in our estimation. As we describe in the Methods section, we supplement the IFOP landings database with the official register of vessels allocated quota to back out the sampled and un-sampled vessels in any given year. The quota allocation database includes vessel name, vessel capacity, and total jack mackerel landed by month from 1997-2000; the years leading up to the ITQ program implementation.

We combine the data on vessel fishing activity and catch with data on the product mix and fishing costs to calculate revenue and trip costs. To calculate revenue and product type, we use confidential data on vessel deliveries and processor production from Sernapesca. The first database contains monthly deliveries from each vessel to each processor and a second database contains the production of each product type (e.g. fishmeal, fish oil, fresh, canned, etc.) by processor. The product is linked to the input species (e.g. Jack Mackerel, anchovy). Additionally, we use publicly available data linking tons delivered to the processors to the final output produced (Servicio Nacional de Pesca y Acuicultura 1996-2005). This allows us to characterize the product produced from fished tons and the "conversion rate" for each product produced (ratio of tons produced to tons delivered).

We also use two sources of information on prices. Ideally we would use time series data on ex-vessel prices (the price paid prior to processing, and denominated in greenweight tons). However, this data is not available due to the vertically integrated nature of the fishery. To explore trends in prices by product type over time, we follow previous work in the fishery (e.g. Gómez-Lobo, Peña-Torres and Barría (2011)) and use export value. Specifically, we use confidential data obtained from IFOP on export value and tonnage to calculate the average export price per ton for each product type over time. The export prices incorporate the value of

[8] The IFOP data is collected to aid in biological monitoring and stock assessment. The Sernapesca dataset is a catch accounting dataset used to match catch against quota. We describe each dataset in detail in the Appendix.

[9] We sum jack mackerel and other mackerel ('Caballa' in Spanish) catch for our analysis. The mackerel species are typically caught together. See the Appendix for more detail.

the raw material (fish), however, they also include any return to value-added processing, and any costs associated with selling the final product. Therefore, we rescale the export value for our calculations of fishery revenue and profit, using Dresdner, Chávez et al. (2014)'s finding that the ex-vessel price is about 12% of the FOB fishmeal export price. See Appendix for more information on the ex-vessel price derivation.

Finally, we use available cost data to construct estimates of the cost of each trip in the landings databases. Specifically, as listed in Table 2, we use survey data from Gómez-Lobo, Peña-Torres and Barría (2004) supplemented with fuel consumption estimates from Cerda et al. (2014). One limitation of the cost data is that we do not have data on the costs of refrigeration. However, according to Cerda et al. (2014), fuel and labor costs are the main trip-level costs. Additional information on the cost data is available in the Appendix.

Table 2: Summary of cost data from Gómez-Lobo, Peña-Torres and Barría (2004) and fuel consumption data from Cerda et al. (2014).

Cost categories	
Fuel	US$ per liter = $.203 (Precio paridad CNE) Liters used = (.1516*hp-13.248)*hours fished if hp <2500 Liters used =(.0448*hp+240.66)*hours fished if hp >2500 $2002 fuel cost = Liters used * $.203
Lubricant	5% of fuel costs
Landings tax	US$.4 per ton since 2001[10]
Officers	• 6 officers per vessel • Calculate hours fished and convert to estimated days
Crew	• 14 crew if vessel capacity is less than 510m^3, otherwise 16 • Calculate hours fished and convert to estimated days
Clothing	Per crew member per trip, in 2002 $72.51
Food	Per person per day, in 2002 $4.20
Officer bonus	Approx. 1.1 thousandths of 1% of the price of fishmeal, $/ton = $.51 USD/ton
Crew bonus	Approx. .5 thousandths of 1% of the price of fishmeal, $/ton = $.22 USD/ton

4. Descriptive Statistics

We observe significant changes in vessel and trip characteristics over time. In Table 3 we provide descriptive statistics for one pre-ITQ year and two post ITQ years. There is a significant difference in the number of active vessels pre and post ITQ: the number of active vessels decreased from ~ 150 vessels prior to the implementation of the ITQ program to ~50 vessels in 2005. At the same time, the characteristics of the active vessel shifted toward higher-capacity, higher-horsepower vessels (Figure 3a, Table 3).[11] These vessels tended to catch more per trip (Figure 3b, Table 3) and the duration of trips also increased (Figure 3c, Table 3). The shift toward larger vessels taking longer trips, particularly post 2003, may in part be due to the stock shifting further offshore, requiring larger vessels and more travel time to reach the fishing grounds.

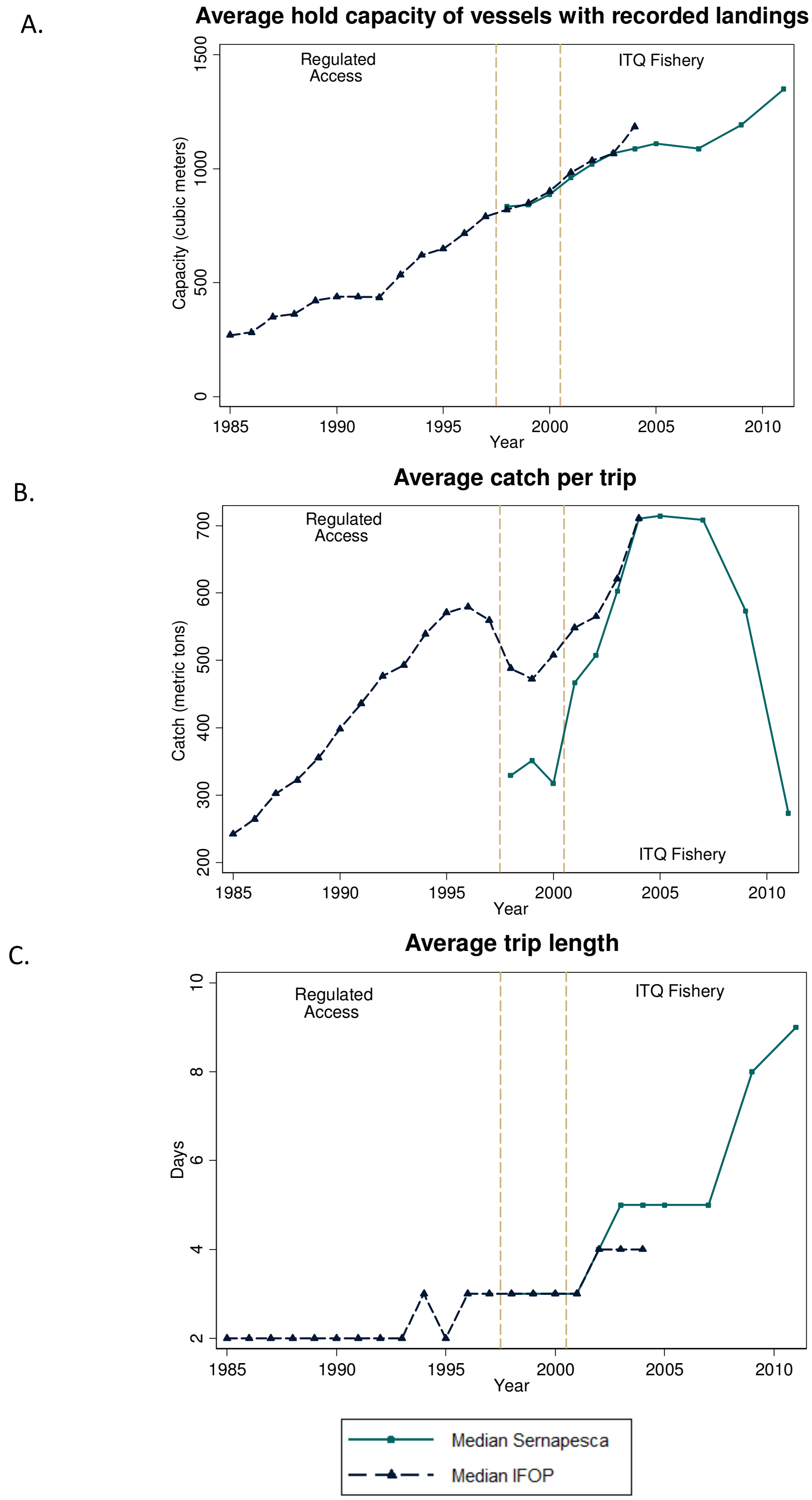
[10] This should be viewed as an approximation as the exact payment depends on the year as well as the extent to which these costs can be deducted from the annual fishing license payment.
[11] A figure showing horsepower over time is qualitatively similar to the capacity figure.

Table 3: Pre- and post-ITQ summary statistics.*

	Pre-ITQ	Post-ITQ	
	1996 (IFOP sample)	2002	2005
Vessels with recorded landings	146	63	52
Trips	6,840	2,752	2,020
Jack mackerel and other mackerel catch (metric tons)	2,542,448	1,538,624	1,453,413
Mean duration of trip (days)	2.90	4.32	5.01
Mean vessel hold capacity (metric tons = cubic meters)	752	1,122	1,267
Mean vessel horsepower	NA	2,677	3,152
Mean catch per trip (metric tons)	597	559	720

* Sources: IFOP (1996) and Sernapesca (2002 and 2005) databases.

Figure 3: Yearly average summary statistics: (A) Hold capacity, (B) Catch per trip, and (C) Trip duration (1980-2011)*.

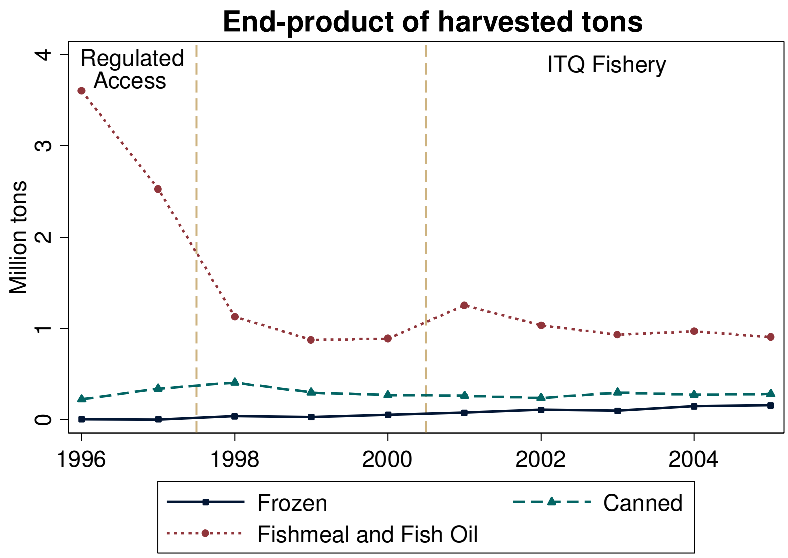


*Source: IFOP and Sernapesca datasets. Note: The first vertical line represents the beginning of the research period and the second the beginning of the ITQ regime.

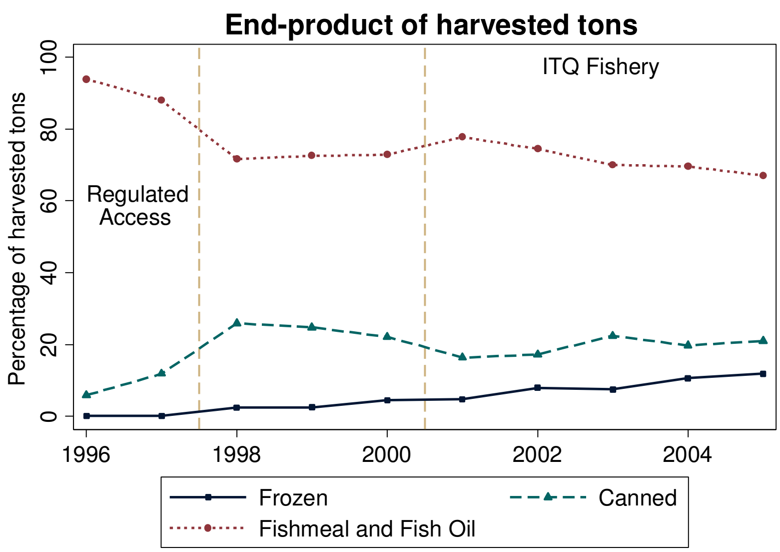
Over time catch became concentrated on a fewer number of vessels with each vessel fishing more per year. In 1997, 167 vessels were recorded fishing 2.8 million tons; an average of 16,800 tons each. In 2002, 63 vessels fished 1.4 million tons, averaging 22,000 tons each and by 2006, 50 vessels fished 1.2 million tons, an average of 24,000 tons per vessel.

Figure 4: End-product of Chilean jack mackerel harvest.*

A.



B.



*Source: Servicio Nacional de Pesca y Acuicultura (1996-2005). Notes: Pre-2000 the information we use is from the "Materia Prima; por especie y línea de elaboración" and "Producción; por especie y línea de elaboración" tables. From 2000-on the information is from the "Materia prima y producción; por especie y línea de elaboración" table. The first vertical line represents the beginning of the research period and the second the beginning of the ITQ regime.

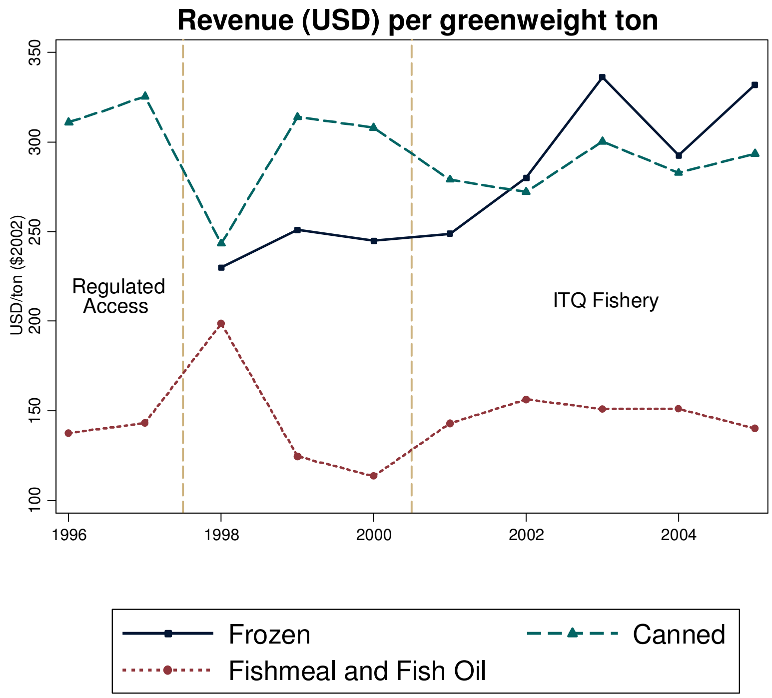
We also find that the deliveries of higher-value human consumption products (relative to fishmeal) increased in the ITQ period (see Figures 4A and 4B).[12] Under the regulated access conditions, 94% of jack mackerel landings in the industrial fishery were converted to fishmeal and fish oil. The proportion of landings used to make fishmeal decreased to 74% in 2002 and 67% by 2005. Simultaneously, deliveries used to make canned products increased from 6% in 1996, to 17% and 21%, in 2002 and 2005, respectively. Deliveries used for frozen products were close to 0% in 1996, but by 2002 8% of the catch was directed to frozen product, and by 2005 close to 12% of the catch was frozen. Finally, the observed export quality of fishmeal increased over the period. According to the IFOP export data, approximately 50% of exported fishmeal was of standard quality in 1996. In 2002 and 2005 the percentage of standard fishmeal exported fell to 13 and 15%, respectively.

Shifts in product type can be accompanied by changes to revenues and costs. In the Jack Mackerel fishery the market price per ton delivered is higher for human consumption end-products relative to those for standard fishmeal (Figure 5A). As a result of the switch, over time we observe an increase in the average revenue per ton delivered (Figure 5B).

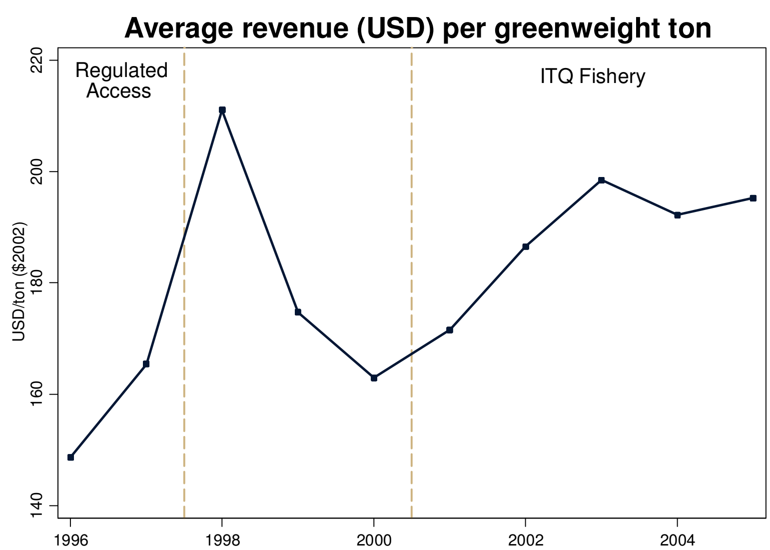
[12] According to official Sernapesca reports (Servicio Nacional de Pesca y Acuicultura 1996-2005), deliveries used for canning increased from 225,936 tons in 1996, to 239,777 tons in 2002, and 283,757 tons by 2005 – an overall increase of 26%. Deliveries used for frozen products increased from 7,520 tons in 1996 to 111,100 tons in 2002 and 160,960 tons in 2005, respectively. This increase of over 2,000% represented a significant shift in the product mix.

Figure 5: Fishing revenue over time.*

A.



B.



*Source: Servicio Nacional de Pesca y Acuicultura (1996-2005). Notes: Panel A is the export revenue per ton. Panel B is the average fishery-wide export revenue per ton greenweight. In panel A, we assume oil is produced as a byproduct of fishmeal production only. The spike in the average revenue per ton delivered in 1998 parallels the price spike that occurred in the world market for fishmeal. The first vertical line represents the beginning of the research period and the second the beginning of the ITQ regime.

On the other hand, higher value end-products, such as canned and frozen human consumption products and higher-grade fishmeal require different fishing practices than standard-grade fishmeal. For example, the timeframe between when the fish is caught and when it is processed can be shortened to increase product quality or refrigeration systems can be used. Additionally, higher grades of fishmeal can be achieved by packing fish less tightly, achieved by filling a lower percentage of the hold.

In addition to fleet structure and product type, the fishable biomass and fishing locations have changed over time. Starting around 1985 there has been a dramatic decline in the fishable biomass (see Figure 2). A short period of rebuilding is evident after the 1997-1998 El Niño event, but beginning in 2003 the stock has again been declining (Hintzen, Corten et al. 2014).[13] There is also evidence of changes in the spatial pattern of fishing over time in response to potential shifts in the location of the fishable stock (Subsecretaria de pesca 2005, South Pacific Regional Fisheries Management Organisation 2015). Canales and Serra (2008) suggest a shift of the stock offshore may have begun around 2003. On the other hand, effort outside the EEZ has fluctuated over time, with foreign fleets exerting pressure outside the EEZ in the 1980's and again in early to mid 2000's – this time joined by Chilean vessels (IFOP 2013).

5. Evaluation Methods

Estimation of the impact of policy change in fisheries is complicated by the inability to randomize the treatment, and therefore infeasibility of experimental methods. However, several methods have been used to evaluate the impact of changes in fisheries management regimes, with specific focus on the adoption of an ITQ regime (see e.g. Grafton, Kirkley et al. (2001) and Arnason (2012)). In some cases an appropriate comparison fishery and data are available allowing for construction of a control group. Examples of potential control groups include a separate but similar fishery (see e.g. Branch (2006) and Jardine, Lin and Sanchirico (2014)) or another segment of the fishery (see e.g. Kroetz, Sanchirico and Lew (2015)).

Another approach, which is what we do, is to estimate the values of indicators in the absence of the change to ITQs. Valid counterfactuals can be constructed through incorporation of capital and labor dynamics, fish stock dynamics, and changes to product quality and form. The benefits and costs of the policy change are calculated as the difference between the indicator in the observed scenario and the counterfactual, the operation of the fishery without ITQs. Studies that also use data from pre and post implementation of a quota program to examine the impact of quotas include Chu (2009), Agar et al. (2014), and Reimer et al. (2014).

5.1 Counterfactuals

We measure the change in profitability attributable to the ITQ program in the Central-South region by estimating the profit with ITQs in place relative to a counterfactual profit had ITQs not been implemented. We evaluate the ITQ program after it is in place (ex-post or retrospective) using own-fishery data (Khandker, Koolwal and Samad (2010) and Gertler, Martinez et al. (2011)). Our challenge is to identify the change in indicators attributable to the ITQ program, versus changes which would have occurred anyway (see discussion in Gertler, Martinez et al. (2011) on counterfeit counterfactuals).

We consider a counterfactual that involves comparing 1996 with 2002 and 2005. The advantage of comparing 1996 and 2002 is that in these years the biomass level was

[13] In addition to biomass declines, a decrease in the reproductive potential of the stock may have occurred after the 1997-1998 El Niño event (Subsecretaria de pesca 2005).

approximately equal (10.3 million tons in 1996 and 11.8 million tons in 2002) and major shifts of the stock offshore had yet to be recorded and agreed (Canales and Serra 2008). The year 2002 was, however, immediately after the ITQ system was put in place. In 2005, the biomass was estimated to be 9.5 million tons, still relatively close to the 1996 stock. We include 2005 because it allows more time (~5 years after start of program) for potential investments in cost saving fishing methods and revenue increases through changes in product form and development of new markets to occur (Weninger and Just 1997).

We construct a counterfactual that mimics a limited entry program, like that in place in 1996, except that we include seasonal TACs like those that were incorporated into the ITQ regime. We then calculate the hypothetical profit if the 1996 vessels (fishing trips) had fished subject to the 2002 and 2005 TACs, and the resulting product mix was the same as that observed in 1996. This scenario is hypothetical in the sense we assume a TAC exists in the counterfactual, when in reality there were no catch limits, fishing was permitted year-round, and the catch was much higher. Specifically, to construct the counterfactual, we sample trips from 1996 from the start of each season until the TAC is reached. We consider the case where seasons and TACs are equal to those in the observed ITQ program in 2002 (Scenario A) and 2005 (Scenario B).

For our analysis we use detailed data on product type (e.g. frozen, canned, or fishmeal) and quality (four grades of fishmeal), to calculate observed 2002 and 2005 revenue. We have the same level of detail on the prices and quantities produced for the various products and qualities in 1996. For the counterfactual, where we consider what the profit would have been in the fishery had the ITQ not been implemented, we assume that Chile sells into a world market, that Chile's production of a product does not influence the world price, and therefore that the world price would be the same in the absence of the switch to the ITQ program in Chile. This is reasonable given that the products we focus on are sold into global, not local, markets and are storable (to a certain extent). Therefore, we calculate the counterfactual revenue assuming that the product-mix would have been the same as during the regulated open access period. This calculation allows for changes on the revenue-side to have occurred through changes in product form or quality, only.[14]

As a robustness check we consider a second counterfactual: the profit if the 1996 Jack Mackerel catch were fished with the vessels (fishing trips) fishing in the ITQ regime, and the mix of product types produced was the same as those in 2002 and 2005. We compare these post-ITQ fishing profits against the profits of 1996 fishing vessels and trips. This provides an estimate of the gains that would have occurred had the ITQ regime and all of the changes in fleet capacity and effort that accompanied it been present in 1996. In this scenario we include trips occurring throughout the year in 1996, and do not assume any seasons, as there were no seasons in 1996. The extent to which the per unit variable costs of the two counterfactuals differ can be attributed to the seasonality assumptions.

This approach is conservative in that it does not fully account for potential stock changes and trends in capital and trips characteristics over time. The observed decline in the biomass over time likely increases per-unit fishing costs due to the stock effect. Furthermore, it is likely

[14] To the extent that other changes influence revenue per ton, by applying the post-ITQ product-quality prices to the pre-ITQ counterfactual landings, we likely underestimate the revenue-side gains, and our estimate of the change in profit due to the ITQ will likely be conservative. We prefer this approach to an approach where we measure the change in price over time, as global demand for the products likely plays a role in the final world price.

that the primary impact of a shift in the stock offshore is increased travel time and fuel costs. Taken together, it is likely that changes to the stock over time will result in our estimates of the post-ITQ profit being lower than we would expect to have observed had the changes not occurred. Therefore, our estimation of the difference in profits between the pre and post ITQ periods is likely lower than it would have been if the stock changes had not occurred and an underestimate estimate of the impact of the ITQ program.

Additionally, our estimates potentially confound pre-existing trends with changes post-ITQ, for example, we do not account for the trend toward larger vessels and associated increased catch per trip that appears to have started before the program was implemented. It is possible that the vessel size would have continued to increase if the ITQ had not been implemented, consistent with a race-to-fish. However, the fishing cost per ton landed tends to be higher on larger vessels. If we were to ignore any trends and create a counterfactual with the 1996 fleet, we are likely underestimating the counterfactual fishing costs and therefore we are underestimating the gain from ITQs.

On the other hand, our calculation assumes that the change in product type and quality between 1996 (Limited Entry) and 2002 and 2005 is due to the ITQ program. To the extent that some of these changes would have taken place anyway, our results are an over-estimate of the gain from ITQs. Having said that, it is highly unlikely that the changes in product type to higher end fishmeal and human consumption could have occurred without a slowing down of the race to fish, especially the necessary requirements of lower utilization rates of the hold capacity and investments in refrigeration. Further, even within the fishmeal deliveries, export data suggest that an increased share of deliveries went to higher-value fishmeal post-ITQ (Figure A2).

6. Results

We calculate observed and counterfactual revenue and cost (Tables 4) (see Appendix for details on measuring revenues and costs). To do this, we calculate the average export revenue per ton landed for the post-ITQ period using the quantity landed, quantity produced, and export prices per ton produced. To find the average export revenue per ton landed for the counterfactual cases without an ITQ program, we calculate the pre-ITQ product mix and conversation rates based on published data from Sernapesca (Servicio Nacional de Pesca y Acuicultura 1996-2005). We then apply the corresponding post-ITQ product export price and derive the ex-vessel price (see appendix for details).

Table 4: Counterfactual results.*

	Scenario A		Scenario B	
	Pre-ITQ Counterfactual 1996	Post-ITQ 2002	Pre-ITQ Counterfactual 1996	Post-ITQ 2005
Summary statistics				
Number of vessels	123	63	123	52
Number of trips	4,535	2,752	4,045	2,020
Catch-weighted mean hold capacity	964	1,293	981	1,309
Catch-weighted mean horsepower	2,360	3,223	2,396	3,274
Mean catch per trip	331	559	331	720
Mean catch per hour	7.2	7.0	7.2	7.47
Total catch (jack mackerel and other mackerel)	1,538,624		1,453,413	
Per-unit revenue and cost				
Export price per ton green weight ($2002)	$143.66	$186.58	$127.21	$195.27
Ex-vessel price (50-63% of export value per ton green weight)	($72.13, $90.16)	($93.68, $117.10)	($63.87,$79.84)	($98.04, $122.55)
Average variable fuel cost per ton	$8.50	$10.70	$7.38	$10.18
Average variable cost per ton	$13.35	$14.07	$13.03	$13.06
Pre-processing trip profit per ton	($58.78, $76.81)	($79.61, $103.03)	($50.84, $66.81)	($84.98, $109.49)
Revenue and cost				
Ex-vessel revenue	$111-139 million	$144-180 million	$92-116 million	$142-178 million
Fishing trip costs	$21 million	$22 million	$19 million	$19 million
Pre-processing trip profit	$90-118 million	$122-159 million	$74-97 million	$124-159 million
Gain from ITQs ($2002)	**$32-40 million**		**$50-62 million**	
Gain from ITQs (% of 2002/5 revenue)	**22%**		**35%**	

*Notes: To account for the pre-ITQ IFOP data being a sample of trips, we also use the 1997 landings data, which provides a complete landings record for each vessel in 1997. We use the 1997 landings to calculate the proportion of total landings fished by each vessel. We do not use 1997 trip data because the research fishing trips began in 1997. Instead, we use the 1997 distribution of landings and 1996 total catch to calculate a pre-ITQ catch estimate for each vessel. We then randomly sample, with replacement, trips from the 1996 set of trips we observe for each vessel and calculate the statistics in the table. We then repeat this exercise 1,000 times and calculate a 95% CI for all our pre-ITQ cost estimates. The sampling yields 95% confidences interval bounds that are within 2% of the mean. Therefore, we do not report the confidence intervals. The nominal values are adjusted for inflation using the U.S.Wholesale price index from the World Bank's World Development Indicators dataset.

We see an increase post-ITQ in revenue generated per green weight ton, even in the first full year of the ITQ program (2002). Our estimates of the ex-vessel price also increase post-ITQ. It is possible the structured research period enabled firms to make changes to their fishing operations including products delivered and product quality. These changes could have benefited firms during the Research Period, as well as early on in the ITQ program.

We also observe changes in the nature of fishing during the ITQ period relative to the pre-ITQ regime. We see a shift toward larger and higher-horsepower vessels that take longer and fewer trips. Under each counterfactual 60% more trips are required under the pre-ITQ structure. The average catch per trip is greater in both 2002 and 2005 relative to the pre-ITQ scenarios. However, there is not a clear trend in the average catch per hour.

There are some changes to the per-unit cost between the observed 2002 and 2005 post-ITQ years and the pre-ITQ counterfactual. Under each scenario the post-ITQ regime is associated with higher fuel costs per ton landed. The increase in these costs in the counterfactual scenarios is the result of larger vessels with higher horsepower fishing more hours. Furthermore, over time fuel costs make up a larger share of the total, suggesting a shift over time toward less reliance on labor.

On net, the difference in per ton costs between regimes is relatively small and dominated by the much larger changes in revenue per greenweight ton landed and the associated ex-vessel prices. Revenues are estimated to be about 30% greater in the second year of the program ITQ program and about 54% higher in 2005 relative to the counterfactual. Estimates of variable costs are higher under the ITQ in 2002, but only slightly. In 2005 they are approximately equal. Results are qualitatively similar, with the revenue impact dominating any cost increases, for the second counterfactual (see the Appendix for results).

The higher post-ITQ revenue per ton results in higher post-ITQ profit. Variable profit under the ITQ program in 2002 is $32-40 million higher than in the limited entry counterfactual. This is approximately 22% of 2002 ex-vessel revenue. In 2005 the estimated ITQ profit is $50-62 million higher than in the counterfactual case where ITQs were not implemented; an amount equal to approximately 35% of the 2005 ex-vessel revenue.

Although not directly comparable, these results are consistent with the prior analysis by Gómez-Lobo, Peña-Torres and Barría (2011). Gómez-Lobo, Peña-Torres and Barría (2011) model vessel entry and exit and include a payment to vessel capital. The authors calculate the change in total profit (as opposed to variable profit) due to the ITQs to be $166 million. Annualized using a discount rate of 10%, this is approximately $18 million of incremental profits per year. Our estimate of the annual increase in variable profit is higher. However, we estimate variable profit, and do not include payments to fixed factors of production. Furthermore, Gómez-Lobo, Peña-Torres and Barría (2011) only focus on fishmeal production, and therefore do not explore the potential of gains from product type expansion as we do here. [15]

7. Back-of-the-envelope quota lease price

We use the 2002 ex-vessel price estimate from Dresdner, Chávez et al. (2014) to calculate an implied quota lease price for 2002, the second year in the post-ITQ period. This complements the calculations in the previous section of variable profit. Specifically, the quota lease price, as shown below, is an equilibrium outcome based on the expected marginal return to a unit of quota. It represents the return to the resource. The variable profit includes returns to fixed factors of production that include resource rent as well as fixed factors including capital and skill.

To derive a back-of-the envelope estimate of the quota lease price, we assume the expected profit of each vessel is maximized and the TAC is binding. Under perfect expectations, the profit maximizing choice of q_i is such that: $0 = P - VC_i(q_i)' - m,$ where m is the implied quota lease price and VC' refers to the marginal cost function. Then, the implied quota lease price, which is the per-ton resource rent, is: $m = p\text{-}VC_i'$, where the q_i are such that the marginal profit of the final unit fished across vessels is equalized and their sum equals the TAC.

[15] For our robustness check, where we estimate the gains from ITQs in the scenario where the post-ITQ TAC was set equal to the pre-ITQ catch, we observe little change in the cost per ton. This suggests that imposing seasons to constrain the catch in our hypothetical Limited Entry program does not result in significant changes to per unit costs (see the Appendix for the full results).

We expect a vessel to take a trip if the expected trip profit per ton (p- VC_i') is greater than or equal to the quota lease price.[16] Under the assumption of increasing marginal costs, vessels will continue to add trips, until the expected return of an additional trip is less than the quota price. In equilibrium we expect the return to the final unit of catch by each vessel to equal the quota price. However, the quota price is a function of both the ex-vessel price and the cost, and because multiple product types are produced in this fishery, there is the potential for variability in terms of the ex-vessel price per ton delivered and the cost to catch a ton (although given an efficient quota market we would expect the difference between the two terms to be constant across product types).

As described in the Appendix, we calculate the yearly average percentage of a vessel's 2002 deliveries going to each product type. We find that some vessels only deliver to processors that exclusively process fishmeal. Using just these vessels allows us to construct a set of trips that have known ex-vessel prices (equal to the fishmeal ex-vessel price, as opposed to trips where the delivery could go to fishmeal, canned, or frozen) and fishing costs and therefore a "cleaner" estimate of the implied quota (lease) price. Given the equilibrium condition that all vessels equate the return to the trip they expect to yield the lowest marginal profit, we expect that with a frictionless and competitive quota market the implied quota price will be equalized across the trips for the various product types.

Given Dresdner, Chávez et al. (2014)'s estimate the ex-vessel price is about 12% of the FOB export price for fishmeal, and the 2002 average FOB price per ton of fishmeal of $630.38, we calculate an ex-vessel price for fish delivered for fishmeal of $76/ton. Then we use our estimates of the variable cost of each trip to estimate a return per trip per ton harvested. This yields a distribution of the average return per ton at the trip level. We do not know how fishermen and firms develop their expectations of returns. Under the assumption that they have fairly accurate expectations we can use the distribution of observed returns per ton, particularly the lower end of the distribution (because it should correspond to the highest marginal fishing cost), to approximate a quota price.

To perform the estimation we take the 379 (or 14% of total) trips that we determine are destined for fishmeal processing. These trips are made by 8 vessels out of the total 63 vessels with positive catch in 2002. These vessels are all active in the jack mackerel fishery, each landing at least 0.5% of the total catch for 2002. If trip profit per ton could be known with certainty, we would expect the lowest value of trip profit per ton to be a good approximation of the quota price. In reality, there is variability in trip profit per ton and so there may be trips in the database that return less than the expected trip profit per ton. Therefore, we base our estimate on a range of observations at the higher end of the trip cost distribution.

We assume the ex-vessel price is constant over the course of the year. Given our assumption that the trip will go forward based on *expected* returns, it is likely that some of the values in the cost distribution are above the expected cost. Therefore, we use the value from the 90th percentile of the distribution, 58 USD, to approximate the expected marginal trip cost (see the Appendix for more detail). Given an ex-vessel price of $76/ton, the resource rent per ton is $18/ton, which implies that the quota lease price is on the order of 15-19% of the ex-vessel prices.

[16] There are no publicly recorded quota trading prices. Given that firms are vertically integrated and the markets are informal, with movement of quota occurring within firms or the OFAs, we calculate an "implied" lease rate.

Our estimate is lower than other published estimates. In the British Columbian halibut fishery reported lease values were 68% of the ex-vessel value (Casey, Dewees et al. 1995) and values for the U.S. Gulf of Red Snapper fishery vary between 58-70% (Agar, Stephen et al. 2014). However, examination of the New Zealand quota markets suggests that the returns depend on the fishing technology and output market, and therefore are not consistent across fisheries. The more highly capitalized fisheries, such as those in the offshore sector (deep-water), had lower rates of return than the more high valued inshore and shellfish fisheries (Newell, Papps and Sanchirico 2007). Our results are consistent with this prior literature as the Jack Mackerel fishery would be best compared to the "offshore" New Zealand fisheries, whereas the halibut and snapper fisheries would both be better compared to near-shore fisheries.

8. Conclusion

Our analysis suggests significant economic gains coincide with the change in management regime in the Chilean Jack Mackerel fishery. Most interestingly, we find these gains without a decrease in the cost of fishing. This finding emphasizes the importance of revenue-side gains that can occur as the result of policy changes (see e.g. Wilen (2005) and Smith (2012)).

Of course, there are several areas we do not pursue in this paper that could be the subject of future work. First, we focus on the early years of the ITQ program. Since then, the fish stock has declined significantly. Potential causes include changing oceanic conditions and resulting changes in stock abundance and distribution. Understanding the interactions between stock location and size, management regime, and fishing area choice is an ongoing research question (see e.g. Peña-Torres, Dresdner and Vasquez (2015) who examine the potential impact of El Niño on fishing and stock location).

In addition to decreasing stocks over time, beginning in 2007 there was a period where the TAC was not binding. This is a key consideration in limiting our analysis to the early to mid 2000's. However, further work could explore how a non-binding TAC impacts the performance of ITQ programs. Additionally, focusing on the early years may miss important innovations and operational changes that can take place due to the ITQ program but which take longer to be implemented. For example, over time we see new larger vessels with refrigeration capacity enter the fishery. Because of this, our estimates are likely conservative.

Another potential source of cost-side gains from ITQs that we do not monetize are any reductions in fixed costs associated with fewer active vessels. To the extent there are fixed costs paid to operate in the fishery (e.g. license fees, gear modification, and costs associated with managing association membership), our estimates of the gains from the ITQ program will be underestimates. One challenge to including these costs is understanding alternative vessel uses, including uses over the course of the year in Chile as well as the value if retrofitted for another fishery, the value if sold for fishing in another region, and the scrap value.

Additionally, although we find evidence of consolidation over the course of the ITQ program, we do not explore the mechanism. The restriction that yearly quota allocations can only be transferred within firms or through membership in an OFA, and that permanent transfers require retirement or sale of a vessel, may limit transfers. Understanding the evolution of de facto quota leasing within firms and OFAs could lead to a better understanding of the role of associations in facilitating efficiency gains from ITQ programs. We leave estimating efficiency gains from associations, and potentially inefficiencies due to lack of full transferability, for future work.

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Appendix

In the Appendix we provide additional information on the fishery, data sources, and estimation methods.

Landings Databases

We have access to two landings datasets. The first is from the Institute of Fisheries Development (IFOP) and the second is from the National Fisheries Service (Sernapesca). Each dataset has information on basic vessel characteristics and trip departures and landings. Table A1 summarizes the variables in the datasets.

Table A1: IFOP and Sernapesca datasets.

	IFOP data	Sernapesca data
Time period	1985-2004, 2006, 2008, 2010	1997-2014
Fishing regions covered	Central-South fishing region only	Fishing in all regions
Vessel attributes	Length, hull capacity, gross tonnage	Length, hull capacity, horsepower
Fish species	Jack mackerel and other forage fish: caballa/other mackerel, anchoveta, sardine, merluza/"Chilean hake/gayi"	Jack mackerel and other commercial species
Fishing location	Latitude and longitude	Fishing (macro)-regions
Departures and landings details	Date of departure, port of departure, date of return, and port of return for all trips making jack mackerel landings	
Firm	No data on firm	Name of firm owning the vessel making a landing

The two landings databases differ because they are designed for different purposes. Sernapesca is used for catch accounting and therefore tracks all catch certified as landed. The IFOP dataset is used by the Chilean government for stock assessment purposes.

The IFOP database contains records for a sample of fishing activity, not all trips and catch that occur in the fishery. The percentage of the total Central-South catch sampled by IFOP varies year-to-year; the minimum coverage of 17% of total landings occurred in 2010, while the maximum coverage occurred in 1997 when over 90% of the landings were sampled. The IFOP dataset provides more information than Sernapesca in two respects. First, IFOP provides a latitude and longitude associated with each trip. Second, the temporal resolution of the IFOP datasets differs from the Sernapesca data; IFOP provides a precise hour and minute associated with each departure and return, whereas Sernapesca only records the day of departure and landing.

The data we use for estimation is governed by the fact that each dataset has limited coverage over the years of interest. The Sernapesca landings database starts in 1997, meaning for pre-ITQ years, we only have IFOP data. For robustness we use years where we have both IFOP and Sernapesca data to compare the two datasets. We use publically available data to compare the pre-ITQ IFOP sample to the total fishing activity that occurred. We discuss other assumptions we make in the sections that follow.

C-S Definition

There are two main macro regions in the Chilean fishery: the North and the Central-South. To assess the performance of the ITQ program in the Central-South we need a definition of the Central-South fishery. In the Sernapesca database each landing has a fishing (macro-) region associated with it. Therefore, we can identify catch that occurs in the Central-South Chilean waters (Regions V up to X, including XIV in Figure 1). However, any fishing outside the EEZ can be counted against the Central-South or North quota (pers. Communication Sernapesca staff). Given that the North catch is relatively small, we count all the trips outside the EEZ as Central-South. The IFOP database includes trips that occur below 32 10 00 latitude, which is consistent with the border of Region V.

Because of the ambiguity of the region assigned to catch outside the EEZ, we proxy for the seasonal TAC with the actual catch observed in each season in 2002 and 2005.

Trip Definition

Our analysis is complicated by the lack of information we have regarding the IFOP sampling process, and therefore we need to make several assumptions. We begin by noting that a vessel id and departure date form a unique combination in the IFOP database. This is because only one latitude and longitude and one landing location is recorded in the database through 2004.

On the other hand, a vessel id and departure date do not represent a unique combination in the Sernapesca data. A given departure date may be associated with multiple fishing regions, ports of delivery, and delivery dates. For the purposes of trip counting and estimation we aggregate to a trip level, defining a trip as a unique vessel ID and departure date combination. We test the sensitivity of the landings date using both the earliest landings date for a given departure date and the latest landings date for a given departure date. For our primary estimates we present in the descriptive statistics and results section we use the latest recorded landings date, but results are similar if we use the earliest date.

Our analysis with the Sernapesca database is also complicated because the database contains records for many fisheries in addition to jack mackerel. Therefore, we needed to identify the trips of interest for our analysis of the Jack Mackerel fishery. We keep trips where jack mackerel comprises greater than 40% of the catch. This cutoff is selected to parallel as closely as possible the criteria that was used to develop the IFOP database we have – we observe the distribution of the percentage of trip catch that is jack mackerel in the IFOP database and find the minimum percentage is 40%.

Product Type and Processor Data

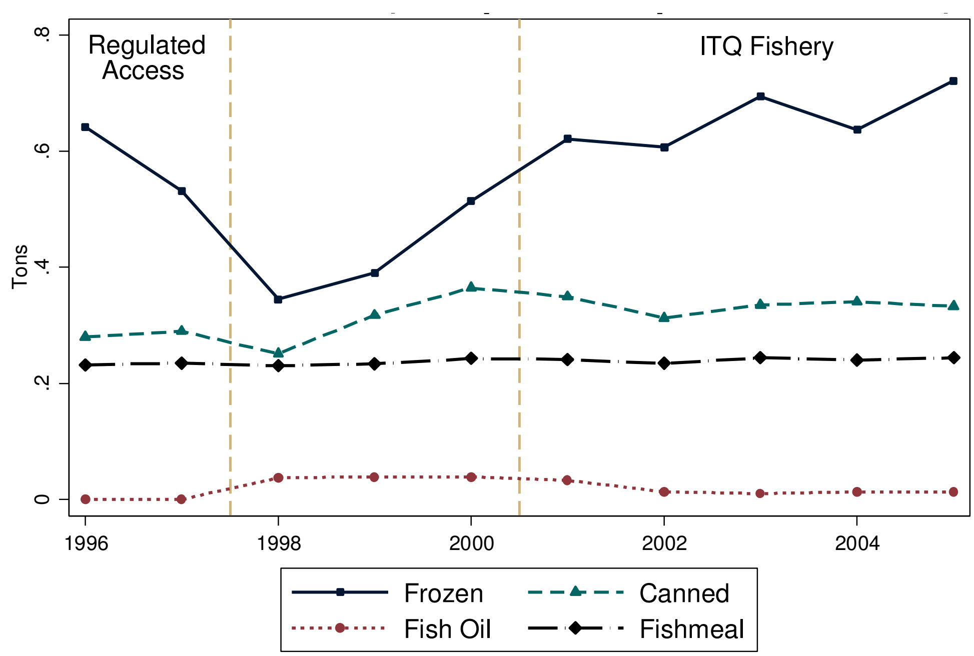
We use data obtained from Sernapesca on vessel deliveries and processor end products to construct a vessel-level estimate of end-product type. Specifically, we have access to two databases. First, we have a database that records monthly deliveries by each vessel to each processor. Second, we have a database recording the monthly level of production for each product type (e.g. fishmeal, fish oil, frozen, canned, etc.) at each processor. The product is linked to the input species (e.g. jack mackerel, anchovy). For the purposes of this analysis we group jack mackerel and other mackerel species. Each database also contains a region identifier. We only use vessel-month-delivery records for regions in the Central-South macro-region.

Two important points to note: (1) there is variation across the year in products produced (we see this in aggregate) and (2) products delivered in one month may be processed and recorded as produced in a subsequent month. To the later point, we observe instances of months where deliveries occur but no product is recorded and vice versa.

Because of (2) we do not account for (1) at this time, and instead construct a year-level breakdown of the average quantity of each product-type produced by each processor per ton delivered. Acknowledging the potential for vessels to deliver to more than one processor, we then construct a vessel-level yearly average quantity of each product-type produced per ton delivered, weighting by the quantity delivered to each processor.

To estimate the revenue per green weight ton we use official yearly fishery-wide statistics (Sernapesca 1996-2006) to calculate the conversion rate. The one exception is that in July and August 2002, we observe production is unrealistically high relative to deliveries. We apply the conversion rate from the remainder of 2002 to recalculate the production for those months. We graph the resulting yearly conversion rates in Figure A1.

Figure A1: Conversion rates by product type. Conversion rate (tons produced per ton delivered).



Export Price Data

We use official Chilean Customs Office data from IFOP on the total export quantity to graph fishmeal exports by grade listed (Figure A2). We also use the total revenue to calculate a yearly export price per ton of each product type produced (Figures A3 and A4).

Figure A2: Fishmeal export quality.

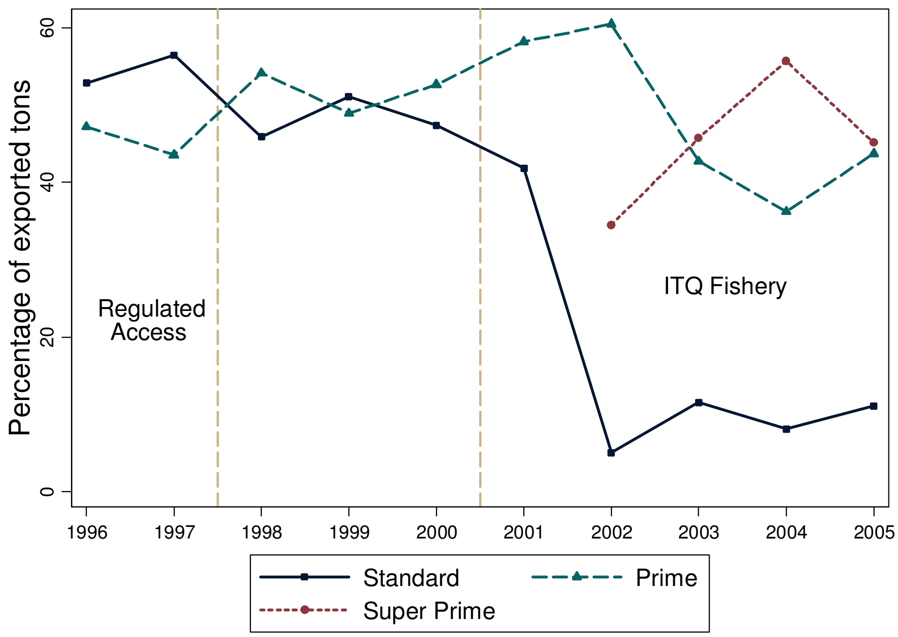


Figure A3: Export prices. Average yearly export price per ton.

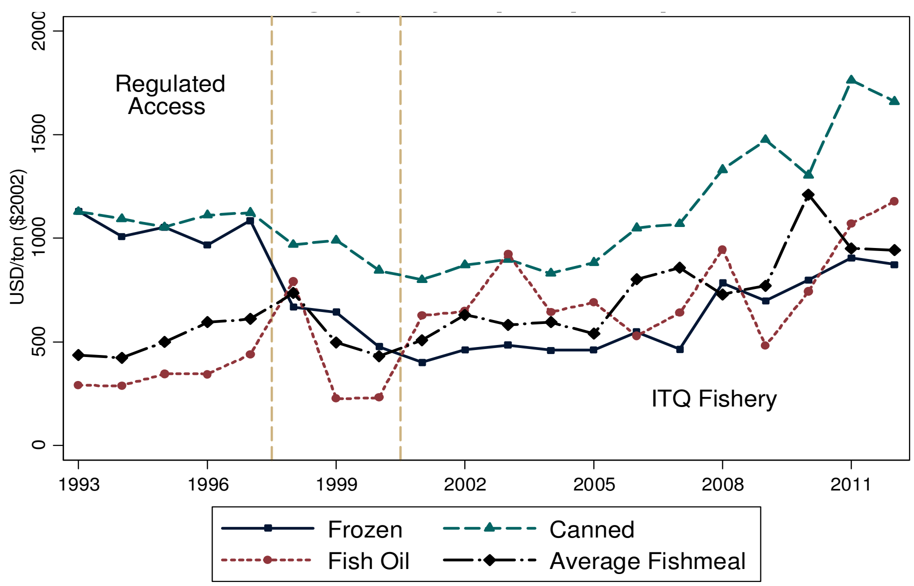
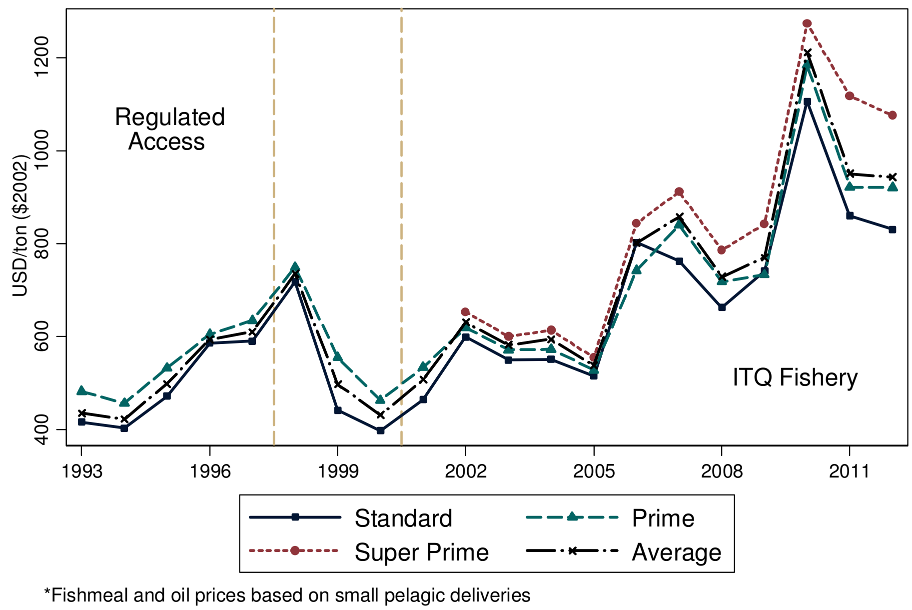


Figure A4: Fishmeal export prices. Fishmeal average yearly export price.



Export Value per Greenweight Ton

We use data on the export price for each product, as well as the conversion rates to calculate the actual and counterfactual average export value of a greenweight ton. In Figure 4 of the paper we graph the average export price per ton greenweight delivered observed in the fishery from 1997-2005.

We calculate the counterfactual prices as follows. In 2002 the average revenue per ton of fishmeal produced was $619.6052 per ton for prime fishmeal, and $589.7692 per ton standard fishmeal, and the average revenue per ton of canned production was $870.337. In 1996 deliveries were mainly made for fishmeal and canning; no fish oil production from jack mackerel was recorded. Of the fishmeal and canning deliveries 94% went to fishmeal and 6% to canning. Using export data from IFOP, and assuming the production percentage is the same as the export percentage, the breakdown of fishmeal by quality type, when quality is recorded is 90% standard and 10% prime. The conversion rates were .2316 tons fishmeal per ton delivered and .2798 tons canned per ton delivered. Therefore, the average revenue per-ton of the 1996 product-mix delivered, at 2002 prices, is .94*.2316*(.9*589.7692+.1*619.6052) + .06*.2798*(870.337) = $143.66.

In 2005 the average revenue per ton of fishmeal produced was $666.06 per ton of super-prime fishmeal, $633.45 per ton for prime fishmeal, and $618.29 per ton standard fishmeal, and the average revenue per ton of canned production was $1,058.99. Using the 1996 conversion rates of .2316 tons fishmeal per ton delivered and .2798 tons canned per ton delivered, the average revenue per-ton of the 1996 product-mix delivered, at 2005 prices, is .94*.2316*(.9*618.29 +.1*633.45) + .06*.2798*(1,058.99) = $152.71, which is $127.21 in $2002.

Ex-vessel Price

There are not official ex-vessel price statistics for this fishery. One contributing factor is significant vertical integration between fishing and processing stages.

Therefore, we use the detailed export data, and Dresdner, Chávez et al. (2014)'s finding that the ex-vessel price is about 12% of the FOB fishmeal export price, to calculate fishery revenue and profit. This estimate is for 2004-2012 and applies to the sardine and anchovy artisanal fisheries deliveries bound for fishmeal production. The species type can make a difference in the price; in particular, jack mackerel is a more oily fish and therefore may have a higher ex-vessel price. For lack of better data, we apply their estimate outside their sample to jack mackerel industrial landings throughout our timeframe of analysis. As a robustness check we compare the Dresdner, Chávez et al. (2014) calculation to a point estimate by Borquez and Hernandez (2009) who estimated the 2006 ex-vessel price for jack mackerel industrial fishmeal landings to be $110/ton with a range of $53.20/ton-$151.40/ton. In 2006 the average export price of fishmeal per ton was $1,006, implying (according to the 12% calculation rule) an ex-vessel price of $121, which is consistent with the range given by Borquez and Hernandez (2009).

We use the export data and point estimate of ex-vessel price to calculate the percentage of the export price per ton green weight that goes to the vessel versus the processor. We know, using the 2006 conversion rate of .239, that the export revenue to a processor per green weight ton delivered for fishmeal was .239*$1,006. What fraction of this export revenue goes to the fishing operation (X%*.239*$1,006)? Equating the former equation with the ex-vessel price estimate suggests that 50% of the revenue per green weight ton went to the vessel operator.

Considering a range of values for the fraction of the export price (12-15%) used to calculate the ex-vessel price, we estimate that the vessel operator receives in the range of 50-63% of the revenue per greenweight ton delivered. We apply this percentage without regard to product type, although it is likely to vary as fishing costs and processing costs vary by product type.

IFOP Sample

IFOP only contains a sample of the total trips taken in a given year. In our pre-ITQ year, 1996, 71% of the catch is recorded in the IFOP database. However, we do have a list of all vessels active in 1997 and their total landings (the quota allocation dataset). We assume that the 1997 data is a good approximation of the vessels that we would expect to have continued to fish, and their relative landings, had the Research Period not begun.

We use 1996, rather than 1997 trips because the fishery closed at the end of 1997 to begin the Research Period, and therefore does not represent behavior in a typical Limited Entry year. Instead, we use IFOP data and quota allocation data to create a representative pre-ITQ limited entry fishing year. We follow these steps:

1. We begin with the quota allocation dataset. This dataset contains a complete record of landings for vessels fishing in 1997. We take the 1997 catch history as a reasonable approximation for the vessel types and relative distribution of landings across the types of vessels that existed pre-ITQ. This is our starting point for creating a pre-ITQ set of "representative trips."

2. We include all vessels with 1997 landings with the following exceptions. We eliminate vessels built in 1996 or 1997 that likely did not fish in 1996, or did not fish the full year. This reduces the sample of vessels from 167 to 154. We then eliminate 19 vessels that landed less than 50 tons total in 1997 (a small amount in this fishery). Next we search the IFOP database for trips by the remaining vessels. We eliminate 4 vessels with names that we do not see in any other databases, 3 that have relatively small 1997 landings and we do not see in the earlier IFOP data, and one vessel with a relatively large 1997 landing amount that does not appear in earlier data. This leaves 127 vessels that we use for our pre-ITQ representative trips.
3. All but 9 of these vessels have recorded trips in the 1996 IFOP database. For the remaining 9 vessels we search earlier years in the database to compile a sample of trips.
4. We calculate the pre-ITQ representative landings for each of the vessels by multiplying the percentage of the 1997 landings made by each vessel in our selected vessel set by the 1996 total jack mackerel catch.[17] In other words, the 1997 landings provide the relative amount of landings for each vessel, and the 1996 actual landings scale to the total.
5. We observe cases where the total observed landings in the IFOP data fall above and below the representative landings. Given the data we use this is not surprising. We did not expect any exact matches; the only question was whether the catch in the IFOP 1996 trip sample was higher or lower than the estimated total catch. We observe 82% of vessels with lower catch than we expect they caught for the year, and 18% where the total observed is lower than the total yearly estimated catch. Those with lower catch are lower by a median of 36% of the total yearly catch and those that are higher are higher by a median of 34% of the yearly catch estimate.
6. For vessels where the observed IFOP total landings fall far below the representative landings, such that the difference divided by the vessel's average trip catch is lower than the total number of observed trips, we duplicate the entire set of trips.
7. Given the revised set of trips, we calculate, for each vessel, the total catch across all trips. If the total is less than the vessel's representative landings, and less by greater than the vessel's average trip catch, we randomly sample trips to increase the catch. Specifically, we sample with replacement, a number of trips equal to the closest integer to the difference between the vessel's representative landings and vessel's total catch divided by the vessel's average catch per trip.
8. Similarly, for vessels where the total catch in the database is greater than the representative landings, we randomly sample trips to remove. Specifically, we sample such that the number of trips dropped is the closest integer to the difference between the vessel's total catch and the vessel's representative catch divided by the vessel's average trip catch.
9. Now, for our set of total trips, we use observed IFOP trip variables (trip length, vessel characteristics) to estimate trip costs.

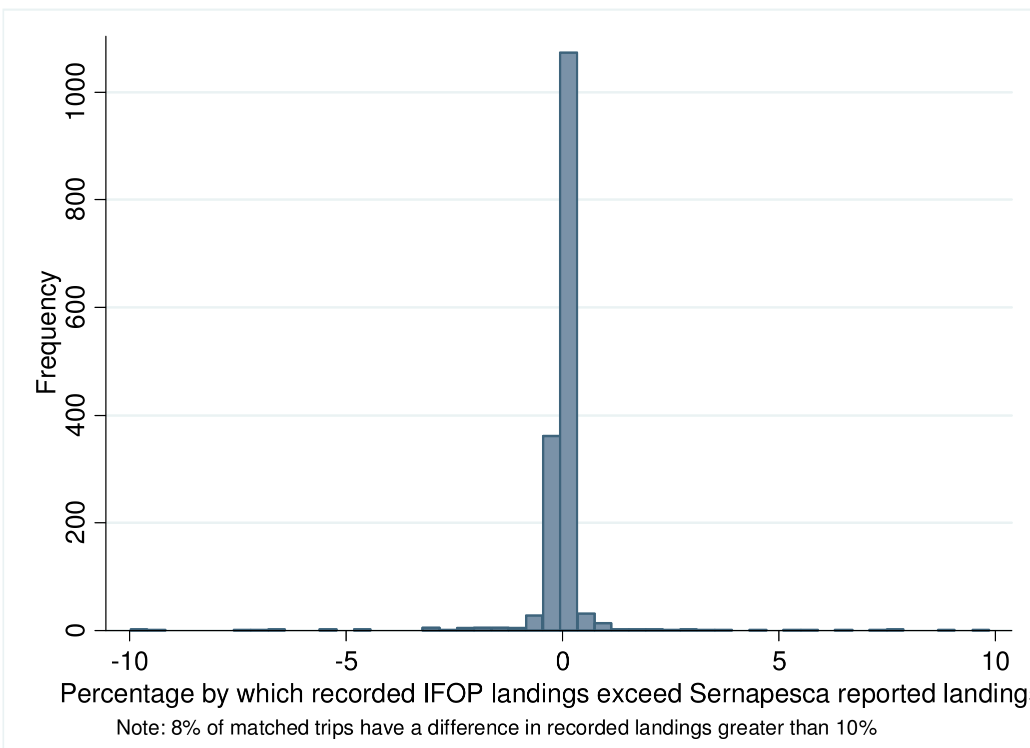
[17] Pre-2000 recorded catch was predominantly jack mackerel (99% or greater). Beginning in 2000 the percentage of the catch recorded as other mackerel began to increase.

10. Next, as we describe in the main text, we select trips for the counterfactual. We select trips, beginning at the start of the season and continuing until the seasonal TAC is reached, for both 2002 and 2005.
11. Of course, because we select entire trips (and no partial trips), the total catch for the counterfactual will never exactly equal the seasonal TACs from 2002 and 2005. Therefore, we calculate the per-ton statistics (Summary Statistics section of Table 4) and use the 2002/5 actual catch to calculate total revenues and costs, to ensure the estimates of the totals are directly comparable.

This sampling assures the vessels included in the cost estimation are representative of the fleet in terms of attributes such as capacity. In other words, we avoid sampling issues related to selection on vessel or firm. This does assume, however, that IFOP sampling is such that the trips of each vessel are randomly sampled. One important factor that would bias our results would be selection on trip duration, month, or port.

If IFOP only recorded a portion of trip catch this could also pose a problem. We use 2002 IFOP and Sernapesca data, and match trips based on vessel and departure date. We compare the IFOP reported trip catch to the Sernapesca reported trip catch for the matched trips. We find that for the vast majority (about 90%) of trips the difference is less than 2% (Figure A5).

Figure A5: Difference between IFOP and Sernapesca trip landings.



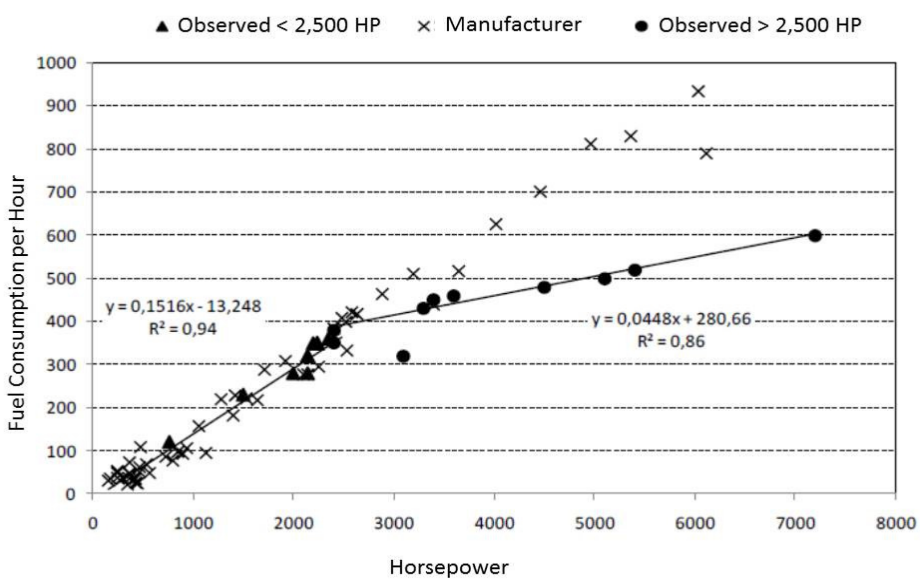
Cost Data

We use data described in Gómez-Lobo, Peña-Torres and Barría (2004). Funding for the project was provided by Proyecto Fondecyt/Conycit. The authors compiled the costs through interviews with several major fishing companies in 2003. Additional information is from the Comisión Nacional de Energia. The costs provided are all in $2002 USD.

Fuel Oil Consumption

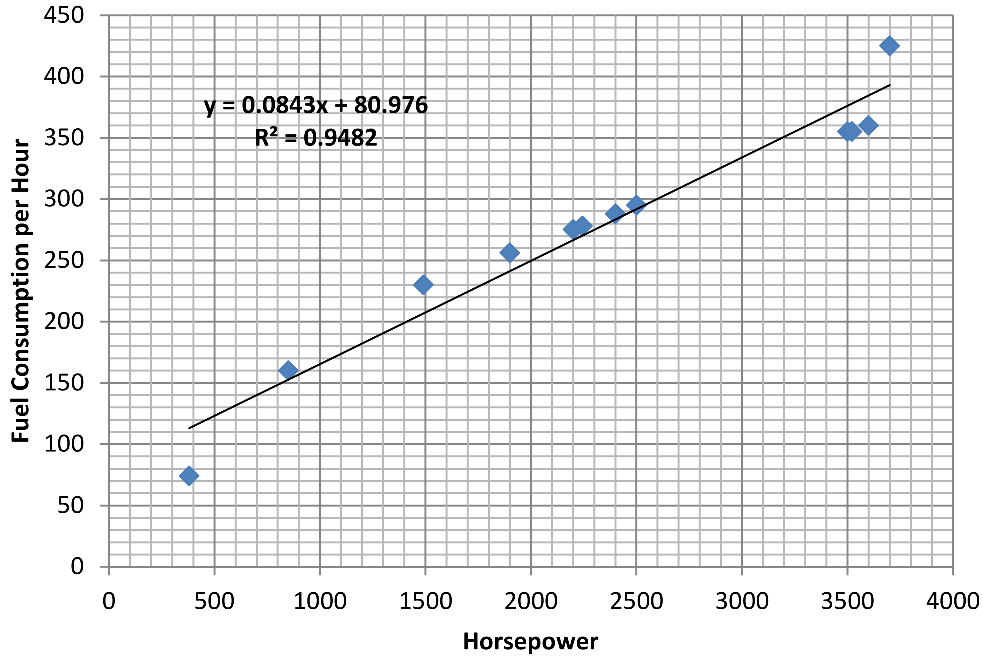
We use data from Gómez-Lobo, Peña-Torres and Barría (2004) to perform a robustness check on the relationship between fuel consumption per hour and horsepower. The Gómez-Lobo, Peña-Torres and Barría (2004) report has information on fuel consumption per hour for a smaller sample of vessel horsepowers (notably a lower range). As shown in Figures A6 and A7, the trend across this sample is similar to that presented in the Cerda, Ahumada et al. (2014) paper.

Figure A6: Relationship between fuel consumption per hour and horsepower.



*Notes: Reproduced from Cerda, Ahumada et al. (2014)

Figure A7: Relationship between fuel consumption per hour and horsepower from Gómez-Lobo, Peña-Torres and Barría (2004).



*Notes: The coefficients are estimated using a linear regression.

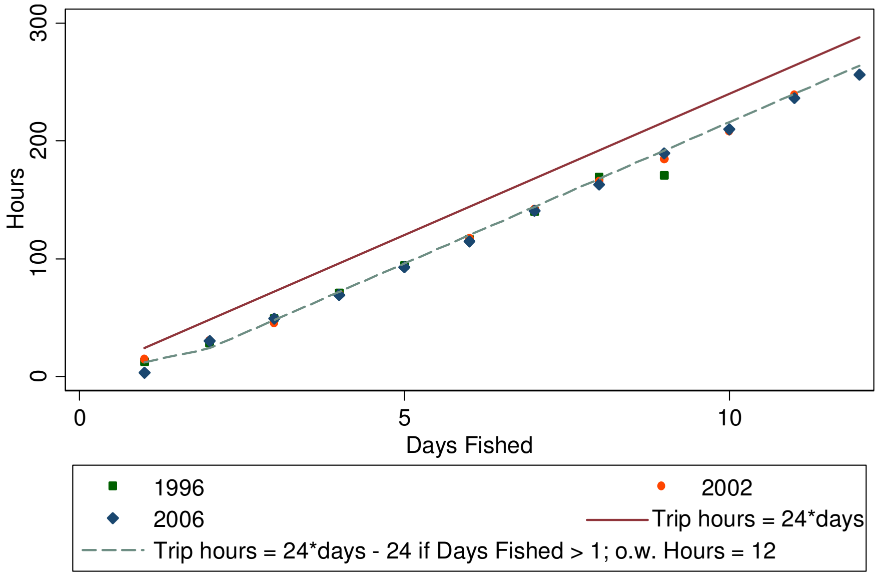
Trip Length

Another complication is that we need an estimate of trip length. The trip length is important in the profit analysis because we calculate expenditures, such as fuel costs, based on trip duration.

We notice some records where we believe there was a recording mistake in the Sernapesca database. Therefore, we replace the duration of the two trips with negative duration with the absolute value of trip length, assuming the departure and arrival dates were entered in the opposite cells when the trip was recorded. We also replace the duration of any trip longer than 21 days with the average trip length for the year (4 instances in 2002).

The Sernapesca landings database contains a day of departure and return. Therefore, we use the available IFOP sample with the precise hour of departure and return to infer trip duration in the Sernapesca database (in 2002 the IFOP covers 60-65% of total official landings; in 2006 the coverage is 76-86%). To convert the observed Sernapesca days to hours we first use the IFOP database to compare the distribution of days fished that would have been calculated had the hours not been included, to the actual days fished (which now includes a fraction of a day representing hours). We convert one day in the Sernapesca database to 12 hours and greater than one day to the observed days multiplied by 24 and then subtract 24 hours. As shown in Appendix Figure A8, this provides an acceptable approximation for the duration of the trip in hours across the years we use for estimation.

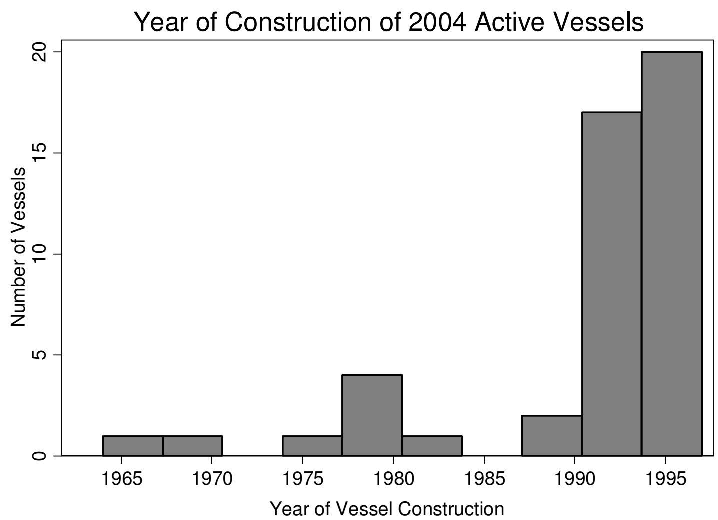
Figure A8: Plot of hours fished against days fished. Source: IFOP data.



Vessel Vintage

In the early years of the ITQ program we do not observe entry of new vessels. New vessels could have cost structures different from the pre-ITQ set of vessels and could be better optimized to fish in the ITQ fishery. Figure A9 shows that all active vessels in the 2004 IFOP sample, the latest year for which we have recorded data on vessel age, were constructed prior to 1998. Therefore, we use the same per-unit costs in the pre and post calculations.

Figure A9: Year of construction of 2004 active vessels. Source: IFOP data.



Counterfactual 2 Results

For our primary estimation we consider what the profit would have been in 2002 and 2005 had the ITQ program not been implemented, but instead a limited entry program was used to manage the catch. We construct a counterfactual that mimics a limited entry program, like that in place in 1996, except that we include seasonal TACs like those that were incorporated into the ITQ regime. We then calculate the hypothetical profit if the 1996 vessels (fishing trips) had fished subject to the 2002 and 2005 TACs, and the resulting product mix was the same as that observed in 1996. To construct the counterfactual, we sample trips from 1996 from the start of each season until the TAC is reached. The catch and the number of trips were both higher in 1996. The imposition of the seasonal assumption results in the selection of trips occurring toward the beginning of the seasons, and conversely, leads to exclusion of trips that occurred toward the end of the season.

As a robustness check, we consider a second counterfactual: the profit if the 1996 Jack Mackerel catch were fished with the vessels (fishing trips) fishing in the ITQ regime, and the mix of product types produced was the same as those in 2002 and 2005. This requires scaling up (resampling) the relatively fewer number of trips and lower catch we observe in 2002 and 2005 to the much higher 1996 catch. We compare these post-ITQ fishing profits against the profits of 1996 fishing vessels and trips. This provides an estimate of the gains that would have occurred had the ITQ regime and all of the changes in fleet capacity and effort that accompanied it been present in 1996. In this scenario we include trips occurring throughout the year in 1996, and do not assume any seasons, as there were no seasons in 1996.

This counterfactual yields an estimate of the gain from an ITQ program at the pre-ITQ catch levels. Additionally, it allows us to examine whether the imposition of seasons in our main counterfactual, which results in the selection of trips toward the beginning of the season and omission of trips toward the end, impacts our results. We will observe whether the cost per ton varies between scenarios. If the difference is significant, we would conclude that any change in the profitability due to the ITQ program would be dependent on the choice of seasons had the ITQ program not been implemented.

The results of this analysis are in Table A2. As expected, the total costs and revenue in this scenario are higher because the catch is larger. We are also interested in comparing the per-unit costs to examine the impact of season choice on fishing costs. The per-unit cost in 1996 is $12.82. This is only slightly less than the $13.35 (2002 counterfactual) and $13.03 (2005 counterfactual) from the main analysis. This is suggestive of the fact that there is not significant variability between the average cost per ton over all trips taken in 1996, versus the average taken for the subsets of the trips included when selecting the subsets of trips to match the 2002 and 2005 catches. If anything, the lower costs per unit in the main counterfactual would result in lower gains attributed to the ITQ program, and thus our estimates in the main text of the gains from ITQs are conservative.

Table A2: Counterfactual 2 results.

	Scenario A		Scenario B	
	Pre-ITQ Counterfactual 1996	Post-ITQ 2002	Pre-ITQ Counterfactual 1996	Post-ITQ 2005
Summary statistics				
Number of vessels	123	63	123	52
Number of trips	10,829	6,594	10,829	4,990
Catch-weighted mean hold capacity	978	1,293	978	1,309
Catch-weighted mean horsepower	2,390	3,223	2,390	3,274
Mean catch per trip	331	559	331	720
Mean catch per hour	7.2	7.0	7.2	7.47
Total catch (jack mackerel and other mackerel)	3,586,784		3,586,784	
Per-unit revenue and cost				
Export price per ton green weight ($2002)	$143.66	$186.58	$127.21	$195.27
Ex-vessel price (50-63% of export value per ton green weight)	($71.83, $91.88)	($93.68, $117.10)	($63.61,$81.34)	($98.04, $122.55)
Average variable fuel cost per ton	$8.01	$10.70	$8.01	$10.18
Average variable cost per ton	$12.82	$14.07	$12.82	$13.06
Pre-processing trip profit per ton	($59.31, $77.34)	($79.61, $103.03)	($51.05, $67.02)	($84.98, $109.49)
Revenue and cost				
Ex-vessel revenue	$258-323 million	$336-420 million	$229-286 million	$351-439 million
Fishing trip costs	$46 million	$50 million	$46 million	$47 million
Pre-processing trip profit	$213-277 million	$286-370 million	$183-240 million	$305-392 million
Gain from ITQs ($2002)	**$73-92 million**		**$121-152 million**	

Fishmeal Trip Costs

To perform the quota lease price estimation we take the 379 (or 14% of total) trips that we determine are destined for fishmeal processing. These trips are made by 8 vessels out of the total 63 vessels with positive catch in 2002. These vessels are all active in the jack mackerel fishery, each landing at least 0.5% of the total catch for 2002. In Table A3 we list the values for various percentiles of the cost distribution.

Table A3: Percentiles of the trip cost per ton for vessels with landings only going to fishmeal production.

Percentile of cost distribution	Cost per ton ($2002 USD)
1%	*4.7*
5%	*6.6*
10%	*7.5*
25%	*10.2*
50%	*17.3*
75%	*30.1*
90%	*58.1*
95%	*100.6*
99%	*388.8*

Note: This is based on 379 trips made by vessels that only deliver for fishmeal production, out of a total of 2,752 trips in 2002.

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