Evaluation of the Chilean Jack Mackerel ITQ System

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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 economic 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 those 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 approximately 15–19% of ex-vessel prices.

Key words: Catch shares, Chile, individual transferrable quotas (ITQs), jack mackerel.
JEL Code: Q22.

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 (e.g., Kroetz, Sanchirico, and Lew 2015). Most of these performance assessments were conducted 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 et al. 2001; Shotton 2001; Newell, Sanchirico, and Kerr 2005; Newell, Papps, and Sanchirico 2007; Chu 2009; and MRAG 2009).

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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 (e.g., Arnason, Kelleher, and Willmann 2008; and Brinson and Thunberg 2013). Furthermore, efforts are 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 inputs, revenues, and costs; and aggregate fishery statistics, including the number of active vessels, stocks, and season length.

An important motivation in estimating consistent indicators across fisheries is that the empirical literature documenting fishery changes accompanying rights-based management regimes is limited (Smith 2012). As discussed in Wilen (2005), there are "seemingly endless" ways to generate value after an individual transferrable quota (ITQ) program is implemented. Smith (2012) calls for data on additional fisheries to enable us to compare and understand the incentives and outcomes across these many margins and to prevent generalizations from a limited set of case studies.

In this article, we evaluate the impacts of the Chilean jack mackerel 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 (e.g. Homans and Wilen 2005; Wilen 2005; and Smith 2012), as well as cost-side changes.

We contribute to existing literature (specifically Dresdner et al. 2007; Dresdner and Chávez 2010; Hernández and Dresdner 2010; Gómez-Lobo, Peña-Torres, and Barría 2011; and Peña-Torres et al. 2016) in the following ways. First, we use more complete data by constructing trip-level pre- and post-ITQ databases. We are also the first to use detailed production data to examine shifts in products produced (e.g., frozen, canned, or fishmeal and quality of fishmeal (four grades)) over time. Our final contribution is to use this detailed data to explicitly track revenues and costs, which allows us to construct estimates of profit for a counterfactual case where the ITQ program was not implemented. Specifically, we disaggregate the results across the hypothesized margins of change (revenue and cost-side) found in the literature (e.g., revenue (Casey et al. 1995) and cost (Weninger 1998)) and calculate summary statistics appropriate for comparison across fisheries following the model of Brinson and Thunberg (2013).

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. We also observe a change in fishing patterns as catch becomes concentrated on larger vessels that take longer trips and catch 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. A back-of-envelope estimate of the implied annual quota rental rate in the second year of the program is equal to approximately 15–19% of ex-vessel prices.

The structure of the article 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 used to evaluate the impact of the management change. Finally, we provide results, including summary statistics showing margins of change; concluding thoughts; and areas for future study.

BACKGROUND

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.[1] 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 (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 (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 (e.g., Boyd and Dewees 1992; Arnason 1993; Casey 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 (e.g., Boyd and Dewees 1992; Casey et al. 1995; Dupont et al. 2002; Wilen 2005; Branch 2006; and Agar 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 (e.g., Weninger 1998; Kompas and Che 2005; and Solís 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 (e.g., Wang 1995; Sanchirico and Newell 2003; Townsend 2005; Dupont et al. 2005; Brandt and McEvoy 2006; Hamon et al. 2009; and Agar et al. 2014).

1. 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 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.

Researchers have also investigated the overall economic benefits of the programs as measured by quota prices (e.g., Arnason 1993; Newell, Sanchirico, and Kerr 2005; Wilen 2005; Newell, Papps, and Sanchirico 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).

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 a 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.

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.[2] Permit transactions could occur across or within fishing firms, where firms often own multiple fishing vessels.

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 five 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 approximately 32°S to 42°S).[3]

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, 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 could fish for jack mackerel was to participate in a 'research fishing' trip organized and regulated by the

2. 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)).
3. In 2000, capacity constraints were also extended to the southernmost region X in the jack mackerel fishery.

Table 1. Timeline of Key Fishing Regulations for the Jack Mackerel Fishery

	Fishing Year	Fishing Gear Regulations	Catch Regulations		Access Regulations
Pre-ITQ period	Before 1986		No catch regulations.		Vessel permits/licenses were required and limited.
	1986		No catch regulations.		Established a hold capacity cap for the fleet that, in essence, limited entry to the fishery in Regions I to IV and VIII at 1986 levels. Permits tied to vessel and hold capacity.
	1991		No catch regulations.		Aggregate hold capacity includes Regions V up to IX. Regions X, XI, and XII remained outside the aggregate hold capacity restriction. Creation of an artisanal fishing zone prohibiting industrial operations within 5 nm of the coast.
Research period	1998	Minimum catch size instituted via mesh size in purse-seine nets.	Research fishing trips, de facto TAC.		Fishery closed unless govt. 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 subject to hold capacity regulations.
	Jan. 2001		No TAC for this month.		Permits applied.
Post-ITQ period	Feb. 2001		Seasonal and area-based TACs.		Individual quotas tied to vessels catch history and capacity. Initial 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 can be auctioned giving 20-year right to share of the TAC.

Figure 1. Map of Administrative Regions.[4]

Note: The concept of the 'Region' in Chilean laws refers to an administrative/public-sector unit that defines a particular geographical macro-area regarding Chilean Government's administrative division of jurisdictions over fiscal policy and budgetary issues (which, in turn, includes an ample array of other governmental decision areas). The Central-South fishery consists of Regions V–X. Region XIV came into legal existence in 2008; before 2008 it was part of the older and larger Region X. Additionally, until 2007 Region XV was part of "Region I," which prior to 2007 was composed of *current* Regions XV and I.

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.

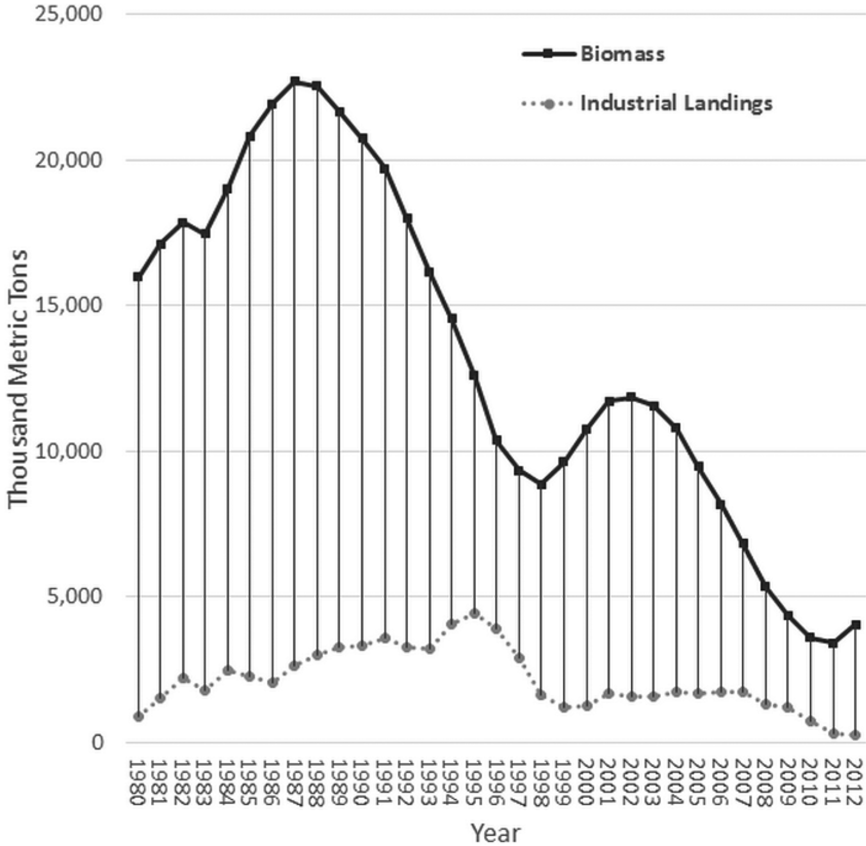

Figure 2. Estimated Jack Mackerel Biomass and Total Chilean Landings over Time

Note: For the period of our analysis, 1996–2005, the Central-South landings comprise the vast majority of landings (74% or greater).

Source: IFOP (2013).

authorities. During a research fishing trip, a participant boat was restricted to fishing a predetermined stretch of sea and had to report existing schools of fish to the authorities.

During the research period, however, there remained 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, 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 operational fleet. For a more detailed description of the research period see Gomez-Lobo, Peña-Torres, and Barria (2011).

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° 19.731 and the amendments passed in December 2002 (Law N° 19.849) and February 2013 (Law N° 20.657), as well as discussion in Gomez-Lobo, Peña-Torres, and Barría (2011).

In February 2001, the quota system was initiated,[5] 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 two-year period. 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 their yearly quota allocation 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.[6]

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 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 (royalty) payment based on the vessel's quota allocation; and (5) for fisheries determined to be fully exploited, such as jack mackerel, up to 15% of the annual TAC can be 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).

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).

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

6. This exemption was valid only for the period 2001–2002. Since January 2003, all registered industrial vessels have had to pay an annual licensing fee.

We use confidential landings data from Chile's Institute of Fisheries Research (IFOP) and the National Fisheries Service (Sernapesca).[7] 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.[8] 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 limited-entry years, and is the only available trip-level dataset covering fishing activity during the limited-entry 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 unsampled 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 green weight 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 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 assuming the ex-vessel price is about 12% of the freight on board (FOB) fishmeal export price.[9] See the online-only 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).

7. 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 online-only appendix.

8. We sum jack mackerel and other mackerel ('Caballa' in Spanish) catch for our analysis. The mackerel species are typically caught together. See the online-only appendix for more detail.

9. Through personal communication with Gerardo Balbontín, CEO of *Blumar*, one of the largest fishing companies operating in the Central-South small-pelagic fisheries,we verified that 12% of the export price of fishmeal is a reasonable (standard) assumption. For our analysis we calculate results for 12 and 15% to obtain the high and low estimates in table 4. We assume that the percentage of revenue per green weight ton returned to the vessel-operator is the same for all product types.

Table 2. Summary of Cost Data[a] and Fuel Consumption Data[b]

Cost categories	
Fuel	US$ per liter = $.203 Liters used = (.1516*hp–13.248)*hours fished if hp <2,500 Liters used =(.0448*hp+240.66)*hours fished if hp >2,500 $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

Sources: [a] Gómez-Lobo, Peña-Torres, and Barría (2004). [b] Cerda et al. (2014).

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

Source: IFOP (1996) and Sernapesca (2002 and 2005) databases.

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 online-only appendix.

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 approximately 150 vessels prior to the implementation of the ITQ program to approximately 50 vessels in 2005. At the same time, the characteristics of the active vessels shifted toward higher-capacity, higher-horsepower vessels (figure 3a, table 3).[11] These vessels tended to

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.

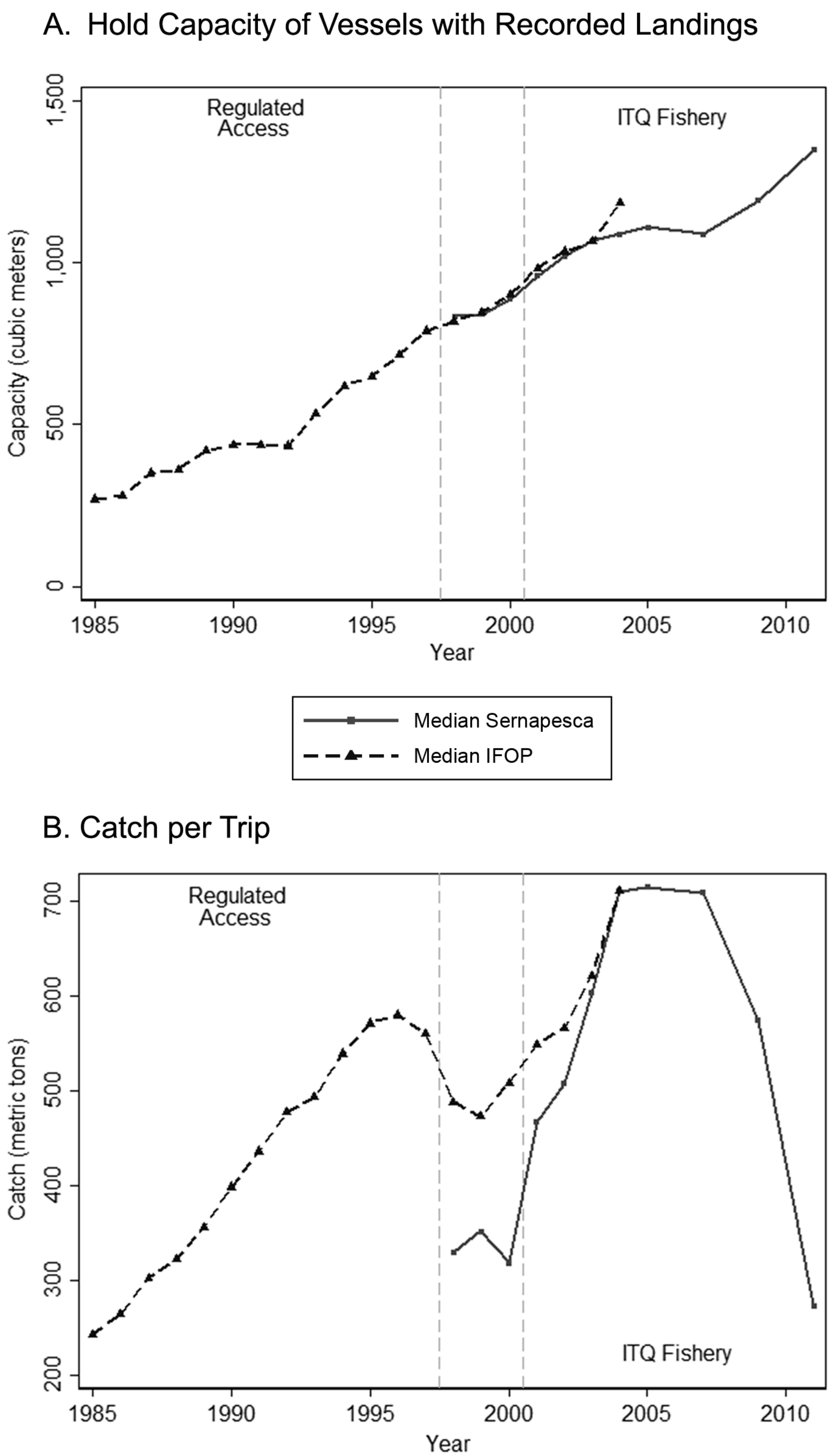

Figure 3. Yearly Summary Statistics: A. Hold Capacity, B. Catch per Trip, and C. Trip Duration (1980–2011)

Note: The first vertical line represents the beginning of the research period and the second the beginning of the ITQ regime. The IFOP database covers a sample of trips, as discussed in the text and online-only appendix.

Source: IFOP and Sernapesca datasets.

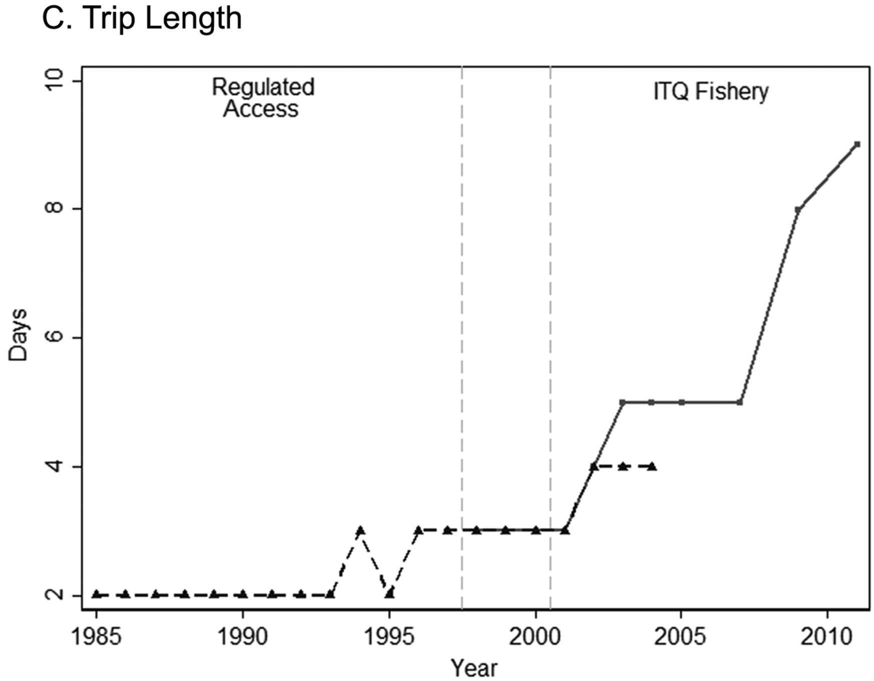

Figure 3. (*Continued*)

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 be due, in part, to the stock shifting further offshore, requiring larger vessels and more travel time to reach the fishing grounds.

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. By 2006, 50 vessels fished 1.2 million tons, an average of 24,000 tons per vessel.

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 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.[13] 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. By 2005 close to 12% of the catch was frozen. Finally, the observed export quality of fishmeal increased over the period.

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. This increase of over 2,000% represented a significant shift in the product mix.

13. For deliveries used to produce fishmeal, there was also a shift toward production of higher-grade fishmeal. The higher grades are associated with higher market prices.

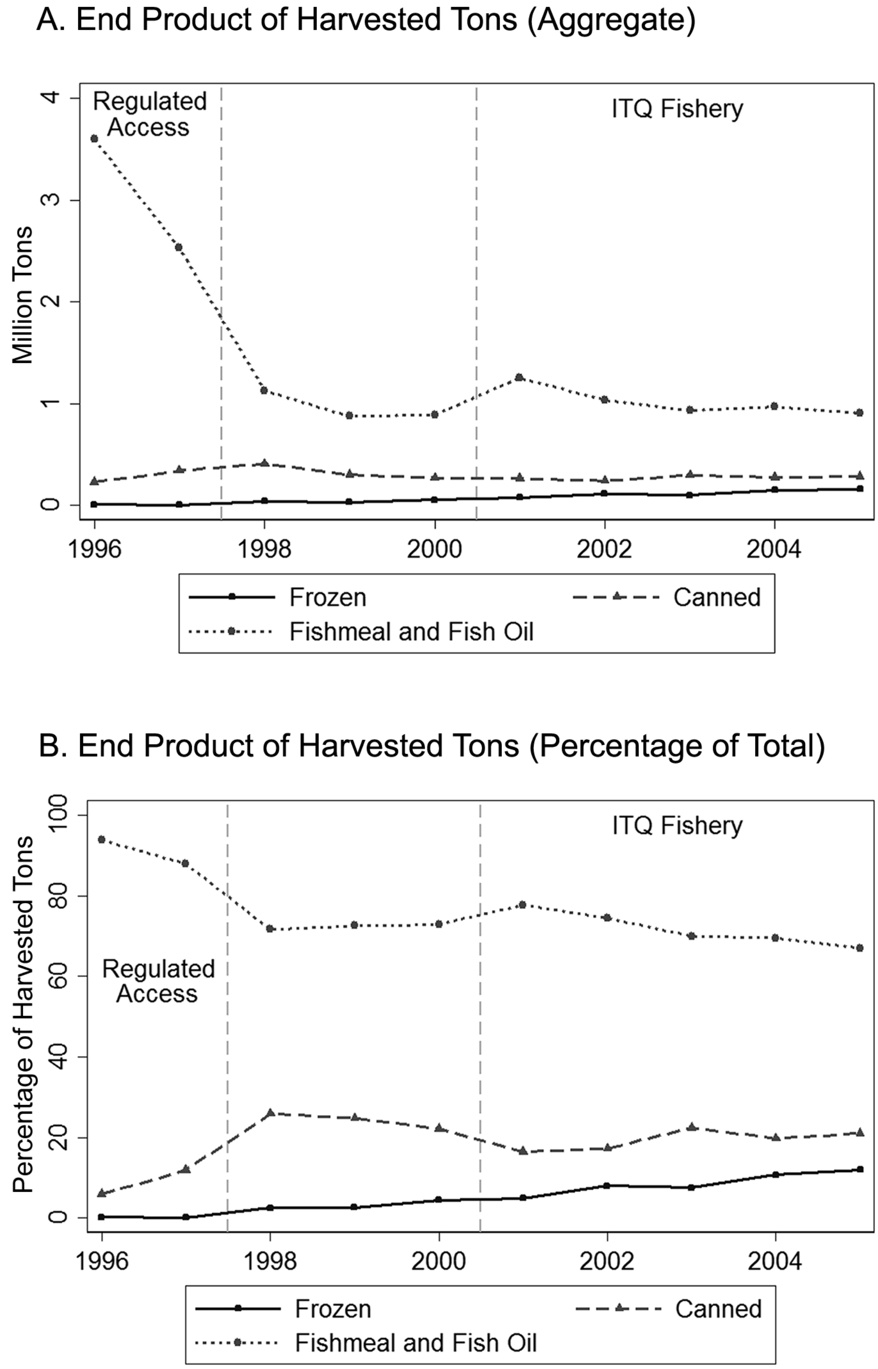

Figure 4. End Product of Chilean Jack Mackerel Harvest

Note: The first vertical line represents the beginning of the research period and the second the beginning of the ITQ regime.

Source: Servicio Nacional de Pesca y Acuicultura (1996–2005). Pre-2000 information is from the “Materia Prima; por especie y linea 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.

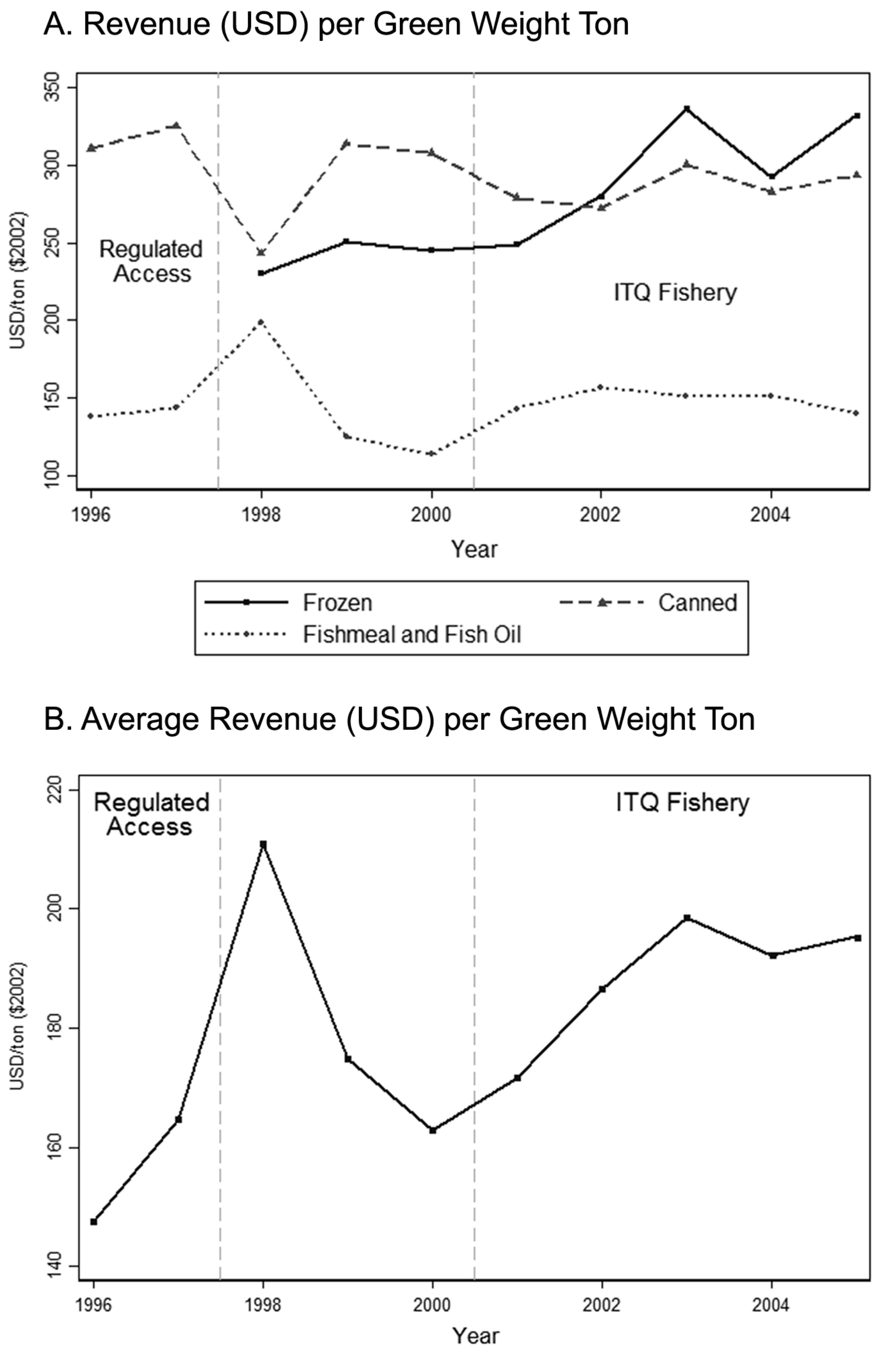

Figure 5. Fishing Revenue over Time

Note: Panel A is the export revenue per green weight ton. Panel B is the average fishery-wide export revenue per green weight ton. 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.

Source: Servicio Nacional de Pesca y Acuicultura (1996–2005).

According to 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 in 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, we observe an increase in the average revenue per ton delivered over time (figure 5b).

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 et al. 2014). There is also evidence of changes in the spatial pattern of fishing over time in response to potential shifts in the location of 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 exclusive economic zone (EEZ) has fluctuated over time, with foreign fleets exerting pressure outside the EEZ in the 1980's and again in early- to mid-2000s—this time joined by Chilean vessels (IFOP 2013).

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 (e.g., Grafton et al. 2001; 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 (e.g., Branch 2006; Jardine, Lin, and Sanchirico 2014) or another segment of the fishery (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. When constructing valid counterfactuals, changes to the system, such as capital and labor dynamics, fish stock dynamics, and changes to product quality and form should be considered. 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, Abbott, and Wilen (2014).

COUNTERFACTUALS

We measure the change in profitability attributable to the ITQ program in the Central-South region by estimating 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; Gertler et al. 2011). Our challenge is to identify the change in indicators attributable to the ITQ program, versus changes which would have occurred without it (see discussion in Gertler 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 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 upon (Canales and Serra 2008). The year 2002 was, however, immediately after the ITQ system was put in place. Uncertainty over the program and profit-maximizing behavior may have impacted program outcomes. 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 (approximately 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 (i.e., fishing trips that occurred in 1996) 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 that 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's observed fishing trips 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 limited-entry period. This calculation allows for changes on the revenue side to have occurred only through changes in product form or quality. Functionally this entails using the 1996 product mix and conversion rates, 2002 fuel price and other per-unit cost data (table 2), and 2002 product-specific prices to calculate the real 2002 counterfactual profit.[14,15]

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.

15. To allow for comparison between the 2002 and 2005 Scenarios, we report values for the 2005 observed and counterfactual cases in real 2002 USD. For the observed 2005 calculations, we use 2005 conversion rates and product-specific prices, which we deflate to 2002 USD, and 2002 real fuel and other per-unit costs in our calculations. For the counterfactual, we use the 1996 product mix and conversion rates; 2005 product-specific prices, deflated to 2002 dollars; and 2002 fuel price and other per-unit cost data (table 2).

As a robustness check, we consider a second counterfactual in the online-only appendix: 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 would have been the same as those in 2002 and 2005. We compare these counterfactual post-ITQ fishing profits against the profits of the 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 variation in per unit fishing costs occurring over the course of the fishing year. In the first set of counterfactuals we use 2002 and 2005 TACs and seasons and sample trips from 1996 corresponding to the beginning of the seasons set post-ITQ; in this second set of counterfactuals we use all the 1996 trips and sample 2002 and 2005 trips to reach the 1996 catch.

Our approach to developing these counterfactuals is likely conservative, particularly for 2005, in that it does not fully account for potential fish stock changes and trends in capital and trips characteristics over time. Relative to the 1996 stock, the fish stock is estimated to be slightly higher in 2002 and slightly lower in 2005 (figure 2). The observed decline in 2005 likely increases per-unit fishing costs due to the stock effect. Furthermore, the most likely primary impact of the accompanying shift in the stock offshore is increased travel time and fuel costs. Taken together, changes to the stock (in biomass levels and its spatial distribution) imply that our estimates of the post-ITQ profit, particularly for 2005, are lower than those resulting exclusively from ITQ-triggered changes (i.e., including the cost impacts resulting from changes in the stock). Therefore, our estimation of the increase in profit due to the ITQ program (observed 2005 ITQ profits minus counterfactual profit) is likely lower than it would have been if the stock changes had not occurred.

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. This trend is consistent with rent dissipation in fisheries regulated via limited-entry or other input controls (e.g., Wilen 1988; Reimer and Wilen 2013). Economic theory suggests that had the limited-entry program continued, incentives would have persisted to dissipate rent via expansion of fishing effort over available margins (e.g., Wilen 1988; Reimer and Wilen 2013). Theory suggests, therefore, that by using the 1996 fleet in the counterfactual we are likely underestimating the counterfactual fishing costs and, therefore, underestimating the gain from ITQs.[16]

Another consideration is that 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, because the change in product type to higher-end fishmeal and human consumption required lower utilization rates of the hold capacity and investments in refrigeration, it is highly unlikely that the changes could have occurred without a slowing down of the race to fish. Further, even within the fishmeal deliveries, export data suggest that

16. We define ITQ-triggered gains as follows. $ITQTriggeredGain = Variable\pi_{ITQ} - Variable\pi_{Counterfactual} = (Revenue_{ITQ} - Revenue_{Counterfactual}) - (Variable\ Cost_{ITQ} - Variable\ Cost_{Counterfactual})$

an increased share of deliveries went to higher-value fishmeal post-ITQ (figure A2 in the online-only appendix).

RESULTS

We calculate observed and counterfactual revenue and cost (in table 4 we compare observed and counterfactual profit for 2002 (Scenario A) and 2005 (Scenario B)) (see online-only 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 conversion 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 the online-only appendix for details).

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, 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 than the counterfactual. The increase is the result of larger vessels with higher horsepower fishing more hours. Furthermore, comparing 2002 and 2005, fuel costs make up a larger share of the total.

On net, the difference in per-ton costs between regimes is relatively small and dominated by the much larger changes in revenue per green weight ton landed and the associated ex-vessel prices. Revenues are estimated to be about 30% greater in the second year of the program (2002) 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 online-only 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). These authors model vessel entry and exit and include a (fixed cost) payment to vessel capital. They 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

Table 4. Counterfactual Results

	Scenario A		Scenario B	
	Pre-ITQ Counterfactual 1996	Post-ITQ (observed) 2002	Pre-ITQ Counterfactual 1996	Post-ITQ (observed) 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 green weight per ton ($2002)	$143.66	$186.58	$127.21	$195.27
Ex-vessel price (50–63% of export value green weight per ton)	($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%	

Note: 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% confidence 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 US wholesale price index from the World Bank's World Development Indicators dataset (World Bank 2016).

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) focus only on fishmeal production, and therefore do not explore the potential gains from product type expansion as we do here.[17]

BACK-OF-THE-ENVELOPE QUOTA LEASE PRICE

We calculate an implied quota lease price for 2002, the second year in the post-ITQ period. The estimate is hypothetical because during this period no formal market for quota existed. Furthermore, our estimate is conditional on the program trading rules and represents the price we expect firms to negotiate for quota transfers via associations. 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, while also assuming that the quota market behaves as a competitive market. Thus, the quota lease price represents the return to the fish resource.

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: $m = p - VC_i'$, 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.

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.[18] 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 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 (perfectly competitive) quota market we would expect the difference between the two terms to be constant across product types).

As described in the online-only 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.

17. 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 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 online-only appendix for the full results).

18. 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.

Given the same assumption from the variable profit calculations that the ex-vessel price is 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, 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/ton, to approximate the expected marginal trip cost. Given an ex-vessel price of \$76/ton, the resource rent is \$18/ton, which implies that the quota lease price is on the order of 15–19% of the ex-vessel prices.

There is no theory or empirical results we know of to suggest the appropriate percentile of the distribution to use to match expectations; therefore, we provide details on the distribution in the online-only appendix. It is also likely that association level negotiated transfer prices may differ from this estimate due to the transaction costs associated with the transfer. A similar methodology to ours could be applied in a fishery with trip-level profit data and an active quota market to investigate these issues in more detail.

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 et al. 1995) and values for the US Gulf red snapper fishery vary between 58–70% (Agar 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. In New Zealand the more highly capitalized fisheries, such as those in the offshore sector (deep-water) that fished higher volumes of lower-value species, had lower rates of return than the lower-volume but higher-value 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 red snapper fisheries would both be better compared to near-shore fisheries.

CONCLUSION

Our analysis suggests significant economic gains coincide with the change in management regime in the Chilean jack mackerel fishery. Most interestingly, using cost survey data and vessel input data, we find that the average variable cost per ton of fishing did not decrease with the implementation of ITQs. This is true in 2002, when the stock was slightly higher than in 1996 and when the shift of the stock offshore had yet to be documented. Further work should be done to more fully understand the potential increase in per-unit fishing costs post-ITQ, and disentangle responses to stock and management changes.

The lack of evidence of a decrease in per-unit variable costs with implementation of the ITQ system emphasizes, even more, the importance of revenue-side gains that can occur as the result of policy changes (e.g., Homans and Wilen 2005; Wilen 2005; Smith 2012). More generally, this highlights the importance of focusing on profit when evaluating the impact of a management change, examining both revenue and cost changes. This work raises questions about the validity of assuming both revenue increases and cost decreases occur contemporaneously with the implementation of catch shares (Costello et al. 2016). Instead, the changes are more nuanced and context specific across the margins of change post-implementation, suggesting that understanding and predicting impacts of catch shares should consider changes along each margin. Such an analysis requires complete and consistent data from before and after the management change, a need that has been formalized recently by policymakers in the United States (Brinson and Thunberg 2013). Increasing consistency in data collection and analysis worldwide would improve the ability to compare impacts across fisheries and predict impacts of proposed management regime changes.

Of course, there are several areas we do not pursue herein 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 (e.g., Peña-Torres, Dresdner, and Vasquez (forthcoming 2017) who examine the potential impact of *El Niño* events in the Chilean jack mackerel fishery).

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-2000s. 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.

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. Given there are fixed costs paid to operate in the fishery (e.g., license fees, gear modification, annual maintenance costs, and costs associated with managing association membership), our estimates of the gains from the ITQ program will be underestimates. Further work is needed to understand 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 (for further discussion related to these considerations, see Gomez-Lobo, Peña-Torres, and Barria 2011).

Additionally, we do not compare the efficiency gains or benefits of the current program design to outcomes under alternative program designs. 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 (during the period analyzed), likely limit quota transfers. Understanding the mechanism for the consolidation we observe in the program and 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 exploring benefits of the association structure, efficiency gains from associations, and potentially inefficiencies due to lack of full transferability, for future work.

REFERENCES

Agar, J. J., J. A. Stephen, A. Strelcheck, and A. Diagne. 2014. "The Gulf of Mexico Red Snapper IFQ Program: The First Five Years." *Marine Resource Economics* 29(2):177–98.

Arnason, R. 1993. "The Icelandic Individual Transferable Quota System: A Descriptive Account." *Marine Resource Economics* 8(3):201–18.

———. 2012. "Property Rights in Fisheries: How Much Can Individual Transferable Quotas Accomplish?" *Review of Environmental Economics and Policy* 6(2):217–36.

Arnason, R., K. Kelleher, and R. Willmann. 2008. *The Sunken Billions: The Economic Justification for Fisheries Reform.* Washington, DC: Joint Publication of the World Bank and the FAO.

Boyd, R. O., and C. M. Dewees. 1992. "Putting Theory into Practice: Individual Transferable Quotas in New Zealand's Fisheries." *Society & Natural Resources: An International Journal* 5(2):179–98.

Branch, T. A. 2006. "Discards and Revenues in Multispecies Groundfish Trawl Fisheries Managed by Trip Limits on the U.S. West Coast and by ITQ in British Columbia." *Bulletin of Marine Science* 78(3):669–89.

Brandt, S., and D. McEvoy. 2006. "Distributional Effects of Property Rights: Transitions in the Atlantic Herring Fishery." *Marine Policy* 30(6):659–70.

Brinson, A. A., and E. M. Thunberg. 2013. "The Economic Performance of U.S. Catch Share Programs." U.S. Department of Commerce, NOAA Technical Memorandum NMFS–F/SFO–133:160.

Canales, C., and R. Serra. 2008. "Chilean Jack Mackerel Stock Assessment Model." Chilean Jack Mackerel Workshop. CHJMWS pap #20.

Casey, K. E., C. M. Dewees, B. R. Turris, and J. E. Wilen. 1995. "The Effects of Individual Vessel Quotas in the British Columbia Halibut Fishery." *Marine Resource Economics* 10(3):211–30.

Castilla, J. C. 2010. "Fisheries in Chile: Small Pelagics, Management, Rights, and Sea Zoning." *Bulletin of Marine Science* 86(2):221–34.

Cerda, R., M. Ahumada, E. González, and D. Queirolo. 2014. "Modelo Estructura de Costos de la Flota Pesquera Nacional y Plantas de Proceso." Informe Final. Licitación Nº 4728–57–LE13, 101 pp.

Chu, C. 2009. "Thirty Years Later: The Global Growth of ITQs and Their Influence on Stock Status in Marine Fisheries." *Fish and Fisheries* 10(2):217–30.

Costello, C., D. Ovando, T. Clavelle, C. K. Strauss, R. Hilborn, M. C. Melnychuk, T. A. Branch, S. D. Gaines, C. S. Szuwalski, R. B. Cabral, D. N. Rader, and A. Leland. 2016. " Global Fishery Prospects under Contrasting Management Regimes." *Proceedings of the National Academy of Sciences* 113(18):5125–9.

Dresdner, J., N. Campos, and C. Chávez. 2010. "The Impact of Individual Quotas on Technical Efficiency: Does Quality Matter?" *Environment and Development Economics* 15(5):585–607.

Dresdner, J., C. Chávez, M. Villena, G. Henríquez, M. Baquedano, N. Campos, N. González, C. Salazar, and C. Sobenes. 2007. "Evaluación del Impacto de la Aplicación de LMCA en la Estructura de la Industria Extractiva Industrial, en una Perspectiva Histórica, año 2007." Informe Final. Proyecto FIP 2005–23, 708 pp.

Dupont, D. P., K. J. Fox, D. V. Gordon, and R. Q. Grafton. 2005. "Profit and Price Effects of Multi-Species Individual Transferable Quotas." *Journal of Agricultural Economics* 56(1):31–57.

Dupont, D. P., R. Q. Grafton, J. Kirkley, and D. Squires. 2002. "Capacity Utilization Measures and Excess Capacity in Multi-Product Privatized Fisheries." *Resource and Energy Economics* 24(3):193–210.

Gertler, P. J., S. Martinez, P. Premand, L. B. Rawlings, and C. M. Vermeersch. 2011. *Impact Evaluation in Practice*. Washington, DC: World Bank Publications.

Gómez-Lobo, A., J. Peña-Torres, and P. Barría. 2004. "Modelo Bioeconómico de la Pesquería Pelágica Industrial en la Zona Centro-Sur: Proyecto Fondecyt #1020765." Informe Final. Santiago, Chile.

———. 2011. "ITQs in Chile: Measuring the Economic Benefits of Reform." *Environmental and Resource Economics* 48(4):651–78.

Grafton, R. Q., J. Kirkley, D. Squires, and Q. Weninger. 2001. "A Guide to the Economic Evaluation of Individual Transferable Quota Fisheries." In *Proceedings of the Tenth Biennial Conference of the International Institute of Fisheries Economics & Trade: Macrobehavior and Macroresults*, July 10–14, 2000, Corvallis, Oregon. Corvallis, OR: IIFET.

Hamon, K. G., O. Thébaud, S. Frusher, and L. Richard Little. 2009. "A Retrospective Analysis of the Effects of Adopting Individual Transferable Quotas in the Tasmanian Red Rock Lobster, *Jasus edwardsii,* Fishery." *Aquatic Living Resources* 22(04):549–58.

Hernández, A., and J. Dresdner. 2010. "The Effect of Temporal Closures and Individual Quotas on Fishing Trip Duration: A Hazard Function Analysis." *Applied Economics* 42(29):3767–76.

Herrmann, M. 1996. "Estimating the Induced Price Increase for Canadian Pacific Halibut with the Introduction of the Individual Vessel Quota Program." *Canadian Journal of Agricultural Economics* 44(2):151–64.

Hintzen, N., A. Corten, F. Gerlotto, J. Habasque, A. Bertrand, P. Lehodey, T. Brunel, A.-C. Dragon, and I. Senina. 2014. "Hydrography and Jack Mackerel Stock in the South Pacific – Final Report." Report number C176.14. IMARES—Institute for Marine Resources & Ecosystem Studies, Netherlands.

Homans, F., and J. E. Wilen. 2005. "Markets and Rent Dissipation in Regulated Open Access Fisheries." *Journal of Environmental Economics and Management* 49(2):381–404.

IFOP (Institute of Fisheries Research). 2013. Segundo Informe—Final. Convenio II: Estatus y Posibilidades de Explotación Biológicamente Sustentables de los Principales Recursos Pesqueros Nacionales, Año 2014. Subsecretaria de Economia. Proyecto 2.1: Investigación del Estatus y Posibilidades de Explotación Biológicamente Sustentables en Jurel, año 2014, Jurel, 2014.

Jardine, S. L., C.-Y. C. Lin, and J. N. Sanchirico. 2014. "Measuring Benefits from a Marketing Cooperative in the Copper River Fishery." *American Journal of Agricultural Economics* 96(4):1084–101.

Jardine, S. L., and J. N. Sanchirico. 2012. "Catch Share Programs in Developing Countries: A Survey of the Literature." *Marine Policy* 36(6):1242–54.

Khandker, S. R., G. B. Koolwal, and H. A. Samad. 2010. *Handbook on Impact Evaluation: Quantitative Methods and Practices*. Washington, DC: World Bank Publications.

Knapp, G. 1997. "Initial Effects of the Alaska Halibut IFQ Program: Survey Comments of Alaska Fishermen." *Marine Resource Economics* 12(3):239–48.

Kompas, T., and T. N. Che. 2005. "Efficiency Gains and Cost Reductions from Individual Transferable Quotas: A Stochastic Cost Frontier for the Australian South East Fishery." *Journal of Productivity Analysis* 23(3):285–307.

Kroetz, K., and J. N. Sanchirico. 2009. "Economic Insights in the Costs of Design Restrictions in ITQ Programs." Resources for the Future Report, Washington, DC.

Kroetz, K., J. N. Sanchirico, and D. K. Lew. 2015. "Efficiency Costs of Social Objectives in Tradable Permit Programs." *Journal of the Association of Environmental and Resource Economists* 2(3):339–66.

MRAG, IFM, CEFAS, AZTI Tecnalia, and PolEM. 2009. "An Analysis of Existing Rights Based Management (RBM) Instruments in Member States and on Setting up Best Practices in the EU." Final Report. London: MRAG Ltd., 117 pages.

Newell, R. G., K. L. Papps, and J. N. Sanchirico. 2007. "Asset Pricing in Created Markets." *American Journal of Agricultural Economics* 89(2):259–72.

Newell, R. G., J. N. Sanchirico, and S. Kerr. 2005. "Fishing Quota Markets." *Journal of Environmental Economics and Management* 49(3):437–62.

Peña-Torres, J. 1997. "The Political Economy of Fishing Regulation: The Case of Chile." *Marine Resource Economics* 12(4):239–320.

Peña-Torres, J., and M. Basch. 2000. "Harvesting in a Pelagic Fishery: The Case of Northern Chile." *Annals of Operations Research* 94(1–4):295–320.

Peña-Torres, J., J. Dresdner, and F. Vasquez. Forthcoming 2017. "El Niño and Fishing Location Decisions: The Chilean Straddling Jack Mackerel Fishery." *Marine Resource Economics*.

Pollock Conservation Cooperative and High Seas Catchers' Cooperative. 2007. "Pollock Conservation Cooperative and High Seas Catchers' Cooperative Final Joint Annual Report 2006 to the North Pacific Fishery Management Council." Pollock Conservation Cooperative, Seattle, WA.

Reimer, M. N., J. K. Abbott, and J. E. Wilen. 2014. "Unraveling the Multiple Margins of Rent Generation from Individual Transferable Quotas." *Land Economics* 90(3):538–59.

Reimer, M. N., and J. E. Wilen. 2013. "Regulated Open Access and Regulated Restricted Access Fisheries." *Encyclopedia of Energy, Natural Resource, and Environmental Economics* 2:215–33.

Sanchirico, J. N., and R. Newell. 2003. "Catching Market Efficiencies–Quota-Based Fisheries Management." The RFF Reader in Environmental and Resource Policy. Resources for the Future, Washington, DC.

Servicio Nacional de Pesca y Acuicultura. 1996–2005. "Anuario Estadístico de Pesca." https://www.sernapesca.cl/index.php?option = com_remository&Itemid = 54&func = select&id = 2.

Shotton, R. 2001. "Case Studies on the Allocation of Transferable Quota Rights in Fisheries." Technical Paper 411. Food and Agriculture Organization, Rome.

Smith, M. D. 2012. "The New Fisheries Economics: Incentives across Many Margins." *Annual Review of Resource Economics* 4(1):379–402.

Solís, D., J. del Corral, L. Perruso, and J. J. Agar. 2014. "Evaluating the Impact of Individual Fishing Quotas (IFQs) on the Technical Efficiency and Composition of the US Gulf of Mexico Red Snapper Commercial Fishing Fleet." *Food Policy* 46(0):74–83.

South Pacific Regional Fisheries Management Organisation. 2015. 3rd Report of the Scientific Committee: Annex 8—Jack Mackerel Assessment. S. Committee. Port Vila, Vanuatu.

Subsecretaria de Pesca. 2005. "Chilean Fleet Operations on the Jack Mackerel Fishery 2004." Document Prepared for the Third Bilateral Consultation on Fisheries Conservation between the Governments of Chile and the People's Republic of China, April 18–20.

Sylvia, G., H. M. Mann, and C. Pugmire. 2008. "Achievements of the Pacific Whiting Conservation Cooperative: Rational Collaboration in a Sea of Irrational Competition." *FAO Fisheries Technical Paper* 504. Rome, Italy.

Townsend, R. E. 2005. "Producer Organizations and Agreements in Fisheries: Integrating Regulation and Coasean Bargaining." In *Evolving Property Rights in Marine Fisheries*, ed. D. Leal, 127–148. Lanham, MD: Rowan and Littlefield.

Wang, S. 1995. "The Surf Clam ITQ Management: An Evaluation." *Marine Resource Economics* 10(1): 93–8.

Weninger, Q. 1998. "Assessing Efficiency Gains from Individual Transferable Quotas: An Application to the Mid-Atlantic Surf Clam and Ocean Quahog Fishery." *American Journal of Agricultural Economics* 80(4):750–64.

Weninger, Q. R., and R. E. Just. 1997. "An Analysis of Transition from Limited Entry to Transferable Quota: Non-Marshallian Principles for Fisheries Management." *Natural Resource Modeling* 10(1):53–83.

Wilen, J. E. 1988. "Limited Entry Licensing: A Retrospective Assessment." *Marine Resource Economics* 5 (4):313–24.

———. 2005. "Property Rights and the Texture of Rents in Fisheries." In *Evolving Property Rights in Marine Fisheries*, ed. D. R. Leal, 49–67. Lanham, MD: Rowman & Littlefield.

World Bank. 2016. "World Development Indicators. Wholesale Price Index." http://data.worldbank.org/indicator/FP.WPI.TOTL.