Marine Policy xxx (xxxx) xxx–xxx

Contents lists available at ScienceDirect

Marine Policy

journal homepage: www.elsevier.com/locate/marpol

Examination of the Peruvian Anchovy Individual Vessel Quota (IVQ) system

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ARTICLE INFO

Keywords:
Catch shares
Peru
Individual Vessel Quotas (IVQs)
Anchovy

ABSTRACT

The implementation of rights-based management programs is increasing worldwide yet there are few ex post evaluations, especially in developing country contexts. This paper examines changes following the implementation of a catch share system in the Peruvian anchovy fishery, which is the world's largest commercial fishery by volume. After implementation of the Individual Vessel Quota (IVQ) management system, there was a shift toward higher value product and a 105% increase in per-unit revenue with the IVQ program. Additionally, landings are more spread out over the fishing season with an increase in the number of fishing days and fleet consolidation occurs over time with a shift toward larger vessels in the steel fleet. Finally, using cost estimates from a large fishing firm on the cost of steel vessel operation, variable harvesting profit is estimated to have increased from 34% to 41% of the ex-vessel revenue pre-IVQ to 63–65% post.

1. Introduction

The use of rights-based programs to manage fisheries has increased over the past 25 years [2]. Accompanying the rise is an increased emphasis on designing programs to address goals related to fishery-specific socioeconomic conditions (see e.g. Kroetz et al. [29]). This is true in both developed and developing country fisheries. For example, both the Peruvian anchovy and Chilean jack mackerel rights-based management programs have unique design features, such as the restriction of trade in a general quota market but allowance for transfers within firms and associations (see Kroetz et al. [28] for a detailed discussion and analysis of the Chilean program).

Despite developing countries implementing new rights-based management programs over the past 10–15 years, most performance assessments are on developed world fisheries [26]. This bias is a reflection of both where most of the early adopters of rights based systems are found (e.g., Iceland, New Zealand, Canada), as well as the locations where the data are rich enough to measure impacts (see, e.g., Grafton et al. [22], Shotton [44], Arnason [1], Newell et al. [37,36], Chu [11], and MRAG et al. [33]).

This paper explores changes in the margins over which inputs and outputs can be adjusted and resulting economic efficiency [45] after the implementation of the Peruvian Anchovy Maximum Catch Limits per Vessel System (referred to in this paper as the Individual Vessel Quota (IVQ) system). Although the IVQ title suggests quota is assigned and restricted for use on a vessel-by-vessel basis and not tradable like in an Individual Transferable Quota (ITQ) program, the system rules are more nuanced. Functionally, quota can be transferred within firms and through the creation of fishing associations. Therefore, there is the potential for changes similar to those under traditional ITQs programs to occur after implementation.

The basis of analysis is a unique and confidential official government landings database from the Ministry of Production of Peru (known as PRODUCE) containing data on all pre- and post-IVQ landings. Changes such as shifts in product form or quality and season length [9], which in turn can lead to an increase in the per-unit price of the landed fish (see e.g. National Research Council NRC [35], Smith [45] and Wilen [48]), are documented. In addition, other indicators of intensive and extensive margin changes that can impact fishing costs, such as the number of active vessels and vessel capacity, are investigated.

The unique data allows for a detailed characterization of the evolution of the fishery, and generation of statistics specific to fishing fleets and regions. Specifically, the wood and steel hulled vessels are treated as separate fleets because they receive separate quota allocations and

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https://doi.org/10.1016/j.marpol.2018.11.008
Received 6 December 2017; Received in revised form 23 September 2018; Accepted 4 November 2018

Please cite this article as: Kroetz, K., Marine Policy, https://doi.org/10.1016/j.marpol.2018.11.008

quota cannot be transferred between them. Examining the North-Central and South fisheries separately also mimics the total allowable catch (TAC) setting procedure. Because the South TAC only binds in one season due to political-economy reasons stemming from shared fish stocks with Chile, the paper focuses on the North-Central fishing region. This still captures the vast majority of fishery landings, as the South is a small share of total landings (7–18% in the years 2006–2013). Hereafter, when not specified, reported statistics and discussion refer to the North-Central region. See Kroetz et al. [27] for additional information on changes in the South fishery.

The structure of the paper is as follows. Section 2 provides background on the fishery. Section 3 discusses the historical regulation of the Peruvian anchovy fishery and the design of the IVQ program. Section 4 presents the data and methods employed in the paper. The results are presented in Section 5.0 and followed by a discussion and conclusion.

2. Peruvian Anchovy Fishery background

The Peruvian government has historically regulated their anchovy fishery as two distinct stocks, the North-Central stock and the Southern stock. In this section a brief outline of the history of regulation in the fishery is provided; more detail is available in Kroetz et al. [27]. The North-Central stock is much larger, with North-Central landings comprising the vast majority of total annual anchovy landings, and resides solely within Peru's exclusive economic zone [50]. The Southern stock is smaller and is shared with Chile [50]. From 2006 to 2013 the percent of total catch from the South ranged from 7% to 19%.

The Southern stock has traditionally been managed with fewer restrictions and regulations due to difficulties in coordinating management with Chile; for example, the Peruvian government has been reluctant to impose seasonal closures or binding catch limits for the Southern stock out of concern that restricting harvest of the Southern stock would benefit the Chilean fishing industry at the expense of the Peruvian industry [8].

In both regions, anchovy is fished by three different fleets: artisanal, small-scale industrial, and large-scale industrial. Fleets are differentiated by their hold capacity, measured in cubic meters (m^3). The artisanal fleet captures anchovy only for direct human consumption and is composed of boats with capacities not greater than 10 m^3. The small-scale fleet is composed of small boats with hull capacities between 10 m^3 and 32.6 m^3 which primarily catch anchovy for sale in local markets catering to direct human consumption [6].[1] The industrial fleet is made up of purse seiner vessels with hull capacity larger than 32.6 m^3; the anchovy caught by these vessels are mostly used for the production of fishmeal and fish oil [42]. This report focuses exclusively on the industrial fishery, as the artisanal and small scale fisheries do not participate in the IVQ system.

The industrial fleet consists of a steel and wood fleet, based on the hull material of the vessel. The wood vessels are also called Vikingas [25,46]. The steel vessels are generally larger than the wooden vessels and are typically owned by vertically integrated companies. These companies often own multiple vessels and process the fish they catch. The wooden vessels are mostly owned by individuals. For more detail on the fleet differences see Tveteras, Paredes and Peña-Torres [47]. In 2007, prior to the implementation of the IVQ system, steel hulled vessels made up approximately 80% of the hull capacity in the industrial anchovy fishery while wooden-hulled vessels made up about 20% of hull storage capacity [4].

[1] For more information also see the first article of the Legislative Decree 005-2012-PRODUCE.

3. Peruvian Anchovy Fishery management

3.1. Management history

Prior to 1992, industrial fisheries for anchovy in Peru operated under regulated open access conditions. The government regulated fishing gear and opened and closed fishing seasons based on fish reproductive cycles in order to protect juvenile fish and spawning fish. A total allowable catch (TAC) in the North Central zone was implemented, but with weak control on access and with new investment incentives due to the privatization process, the number of industrial vessels increased substantially during the 1990s.

In 1992, the General Fishing Law (Ley General de Pesca No 25977) was passed by the Peruvian government. The law created a limited entry system for the North-Central fishery by setting an industry-wide cap of 200,000 m^3 of ship hold capacity with licenses granted to specific ships with specific hold capacities. Vessels that wanted to enter the fishery needed to purchase permits from existing vessels and the hold capacity of the new vessel could not exceed the hold capacity of the previous vessel that held the permit. Transfers were allowed within and across fishing companies. The 1992 Law also limited fishing operations to one trip per day and banned industrial vessels from fishing within 5 nautical miles (nm) of the North-central coast [7]. However, the 1992 reforms were unsuccessful in controlling entry and limiting capacity, potentially due to weak enforcement and access to bank financing, and the number of vessels and processing plants continued to increase and the fishing season shortened as the “race to fish” continued [47].

Discussions to rationalize the fishery began as early as 2001. The World Bank started providing funding to create a catch share system for the fishery in 2006 [47], which lead the implementation of an individual vessel quota (IVQ) system for the industrial fishery in 2008 with Legislative Decree 1084 [5]. The first article of the Legislative Decree 1084 states that the program objectives include: establishing a regulation mechanism for the extraction of anchoveta (*Engraulis ringens* and *Anchoa nasus*) intended for indirect human consumption to improve the conditions for its modernization and efficiency and to promote sustained development as a source of food, employment and income, and to ensure its responsible use in harmony with the preservation of environment and biodiversity conservation. In this context, the law 1084 is aligned with the Peruvian Organic Law for the Sustainable Use of Natural Resources (Law 26821).

The initial allocation of quota was determined using formulas that differed by vessel hull type and vessel fishing zones (see Kroetz et al. [27] for more detail). Steel vessel quota was allocated based on the vessels' highest catch in the control period of January 2004 through June 2007 and hold capacity. The formula applied 60% weight to historical catch and 40% to hold capacity [17]. Wooden vessel quota was based on vessel catch history only [17].[2] Overall, the steel fleet received approximately 80% of the initial allocation of quota [19]. The program was implemented the first fishing season of 2009,[3] assigning eligible vessels a right to a share of the Total Allowable Catch (TAC). Allocations of fishable tons based on quota holdings are made separately for the two fishing seasons in each year and for the North-Central and Southern stocks.

There are three parameters defining the duration and use of the quota.[4] First, each quota share will be renewed after 10 years

[2] The quota for the Southern region was allocated based on the best catch of the vessel between 2004 and 2007, regardless of vessel type [17].

[3] The IVQ program started in the second season of 2009 for the Southern region.

[4] An additional restriction is that if a vessel owns quota in both the North-Central and Southern regions, the North-Central quota must be fished before a vessel can proceed to fish the Southern region (although this requirement did not bind in the initial season when the IVQ had yet to be implemented in the South).

(Legislative Decree 1084). Second, if a vessel does not fish the quota once every two years (Article 33.8 of the Supreme Decree 004-2002-PRODUCE) or does not catch at least 20% of their individual quota for four consecutive seasons (article 11 of the Law 1084), the vessel can lose its quota allocation. Third, carry-over of unused quota from one season to the next or from one year to the next is not permitted.

The transferability of quota is limited (see Article 16 and the 5th supplementary provision of the Regulation of the Legislative Decree 1084-2008-PRODUCE). Permanent quota allocations are vessel-specific and indivisible; therefore the asset (right to a share of the catch each year in the future) can only be transferred through sale of the vessel. However, the yearly allocations can be transferred among vessels of the same owner [47,50]. Yearly allocations may also be transferred through the formation of associations; within an association, vessel allocations can be moved to any vessel within the association. To maintain fleet composition, transfers between the wooden and steel fleets are prohibited [50].[5] However, within these fleet and region groups there are no restrictions on the amount of quota that any one firm can own. Finally, the smaller scale nature of the wood fleet is preserved, because wood vessels must be less than 110 m^3 in capacity to be eligible to fish the wood quota (Article 2 of the Regulation of Law 26920-1998-PRODUCE).

3.2. Evaluations of fishery management

Several studies have explored the impact of the anchovy management regime change. Tveteras et al. [47] conduct an evaluation of the IVQ system using data from the first two years after implementation. Their results suggest a shift away from low grade fishmeal toward high grade fishmeal and an increase in the landings price with the advent of the IVQ system. The authors also find that the seasons lengthened after the introduction of the IVQ system. Paredes [40] uses cost data to estimate a 316% increase in variable profit post-IVQ.

Most recently, in 2015 Natividad published an analysis of the impact of the IVQ system. Natividad [34] uses high frequency price data from a large fishing firm and finds evidence of a significant increase in ex-vessel price, on the order of 200%. Additionally, using landings data through the first 3 seasons of the IVQ system and calculating productivity as total vessel and firm landings, Natividad [34] models changes in vessel and firm productivity due to the IVQ system. He finds no evidence of an increase in productivity. Natividad [34] identifies these effects using the South region of the fishery as a control and assuming that the effect of the change in management is the same for the wood and steel segments of the fleet. Based on analysis of data on where vessels fish (vessels fish in both regions) and differences in the wood and steel fleet (see below), both of these identifying assumptions are questionable.

4. Data and methods

The analysis consists of two components: (1) calculation and presentation of fishery, fleet, and area-specific metrics fishery performance and (2) a back-of the envelope estimate of the impact of the IVQ program on profit. First, in order to examine the economic changes following the implementation of the IVQ system, values for several indicators identified by NOAA [10] that can influence fishing revenue or cost are presented. To calculate these indicators several datasets are used: a unique confidential data set that includes the official Ministry of Production (Ministerio de la Producción, Dirección General de Extracción y Procesamiento Pesquero, known as "PRODUCE") landings data, which has a record of all landings from 2006 through mid-2014; anchovy ex-vessel prices from PRODUCE for the same period; publicly available biomass estimates from IMARPE; and TACs. Additionally, cost information for steel vessels by vessel size category for the years 2006, 2008, 2011, and 2013 was obtained from a major fishing company. More detail on the data is provided in Kroetz et al. [27].

The first set of statistics generated summarizes biological conditions and revenue. Specifically, biomass, TAC, and landings are presented over time, including pre and post IVQ implementation periods. Revenue is examined by summarizing product type produced by year, ex-vessel price, and the ex-vessel price relative to the export price.

We also examine indicators based on vessel activity data. Statistics on active vessels, capacity, and fleet consolidation are broken down by hull type to consider potential differences between the steel and wood fleets. Most of the statistics presented in this analysis are confined to the North-Central region for two reasons: first, it is the dominant fishing region, with 82–93% of the industrial catch landed in the North-Central from 2006 to 2013; second, the Southern TAC only binds in one season, an important factor in determining fishing incentives. For example, when the stock abundance is variable within the season in the fishing grounds, the lack of a binding TAC – even though an IVQ program is in place - could result in a race-to-fish while the stock is still large enough to be profitability fished. Therefore, changes in the South fishing region following IVQ implementation are unlikely to be as substantial as changes in the North-Central region.[6] We also examine the season length, combining data from both the wood and steel fleets to calculate the number of days with positive landings.

For the product type, ex-vessel price, and vessel activity indicators we examine changes over time, testing whether statistically significant changes in the indicators coincide with the implementation of the IVQ, using two methods. First, we form two groups for each indicator variable by pooling all pre-IVQ observations into one group all post-IVQ observations into a second group. We then use a *t*-test, allowing for unequal variances, to detect differences in means between the two groups. However, the results from the simple *t*-tests are arguably limited because the *t*-tests do not take into account time trends.

In our second analysis we construct a time series model for each indicator and use a structural break test to determine whether there was a change in the indicator value coinciding with IVQ implementation (Eq. (1)). In the model we include a dummy variable (D_t) that equals one post-IVQ and zero otherwise, a seasonal dummy variable (S_t) equal to one for all season two observations and zero otherwise, and a quadratic time trend to control for potential pre-existing trends. We do not include the seasonal dummy variable for those indicator variables only available at the yearly scale. The error term (ε_t) is estimated using the Newey-West estimator [38]. Under this specification testing whether a structural break occurred with IVQ implementation is equivalent to testing whether $\beta_1 = 0$.

$$I_t = \beta_0 + \beta_1 D_t + \beta_2 S_t + \beta_3 t + \beta_4 t^2 + \varepsilon_t \quad (1)$$

Variable cost and profit for trips in the two pre-IVQ years (2006 and 2008) and two post-IVQ years (2011 and 2013) for which data is available are calculated. Using data on vessel attributes and trips for 2006, 2008, 2011, and 2013, each trip is assigned an estimate of total variable costs. Costs are available as cost/metric ton, so the total variable cost is calculated by multiplying the cost/metric ton by the metric tons caught. Developing cost estimates specific to the pre- and post-IVQ years is important to account for possible changes in

[5] Transfers between the North-Central and Southern stocks are also not permitted.

[6] A race-to-fish could occur for reasons other than a non-binding TAC in either the North-Central or South. As discussed in Costello and Deacon [12] and Smith [45], a race-to-fish could occur if the profitability of fishing changes over the course of the season. But it is important to point out that the characteristics of a race-to-fish with secure tenure (right to share of the catch) is not synonymous with the race to fish with insecure tenure. Later in the paper it is shown that the number of days in the fishery with landings increased post-IVQ in the North-Central.

technology or fishing practices, such as the fuel use of engines and trip length. Using monthly ex-vessel price data from PRODUCE, the revenue is calculated as the landings multiplied by the average monthly ex-vessel price. Finally, the variable profit for each trip is calculated as the difference between the trip revenue and variable cost.

After calculating the profit for each trip, the revenues and variable costs across all trips are summed for each of the four years. Because the TACs vary from year-to-year, an estimate of average revenue per ton landed, average variable cost per ton landing, and variable profit per ton landed, is calculated for each year. Another source of information on profitability for some ITQ and IVQ fisheries is quota prices. Unfortunately, the Peruvian government does not record transfer prices.

Establishing the status quo is an important step in understanding how fisheries may change with the implementation of quota programs, however, a before-after comparison may not accurately capture the impact of the policy due to confounding factors such as capital and labor dynamics, fish stock dynamics, and changes to product quality and form. In past work researchers have controlled for these confounding factors by using other fisheries or subsets of fisheries as a control group to construct counterfactual estimates of indicator values had the policy not been implemented (see e.g. Branch [23], Jardine et al. [51], Kroetz et al. [29], and Birkenbach et al. [9]).

Without an appropriate comparison fishery for the Peru anchovy fishery during the IVQ transition period, the estimation of the values of indicators in the absence of the change to IVQs must rely only on before-after fishery data,[7] and is more limited. Under a set of assumptions, a back-of-the-envelope estimate of the 2011 average profit had the IVQ program not been implemented is constructed.

The starting point for the back-of-the-envelope calculation is the steel fleet cost statistics described above. For the back-of-the-envelope calculation it is assumed that, in real terms, capital, fuel, and labor costs would have been similar in 2011 to what was observed in 2008. Using 2008 costs as representative of 2011 costs helps control for potential interactions between cost and stock levels. Specifically, in forage fish fisheries, costs may depend on how aggregated the stock is and how costly it is to search and find the stock aggregations. All else equal, the per-ton fishing costs are expected to be the same or higher when the stock is lower. Additionally, assuming upward sloping marginal costs curves, the per-unit cost and the average cost per unit will increase as total landings increase. Comparing the biomass estimates for season 1 and 2 of each year cost data is available, one can observe that 2006 is a relatively low stock year and 2013 a relatively high stock year. However, 2008 and 2011 have similar stock levels. Additionally, the 2008 and 2011 landings are similar, but slightly higher in 2011. All else equal, and assuming increasing marginal costs, the slightly higher landings would increase per-unit costs post-IVQ and decrease profits.

To construct an estimate of what profit would have been in the absence of IVQ implementation, in addition to an estimate of counterfactual costs, it is also necessary to predict counterfactual revenue. To separate out effects of world demand on fishery revenue from the effects of the IVQ program implementation, a set of counterfactual revenues had the IVQ program not been implemented is calculated under the following assumptions; (1) the ex-vessel price in Peru would be the same percentage of the export price per ton observed in 2008; (2) the product mix in Peru would be the same as that observed in 2008; (3) the total catch in Peru would have been the same as that observed with the IVQ program in place; (4) the world fishmeal export prices for different types of fishmeal are well approximated by Chilean export prices; and (5) the IVQ had no impact on world prices.

This paper utilizes Chilean prices for fishmeal, because product-type specific ex-vessel and export prices per ton are unavailable for Peru. First the average real export value per ton implied by the 2008 Peru product quantities and the 2008 Chilean export price data is calculated. Next, the average value assuming the same 2008 Peru product mix but 2011 Chilean export values is calculated. Then, the percentage increase in export value from 2008 to 2011, for the same product mix, is calculated. Finally, a counterfactual no-IVQ 2011 Peru ex-vessel price is calculated, under the assumption that it would have increased by this same percentage. See Kroetz et al. [28] for information on Chilean export prices. Together with the cost assumptions, the 2011 counterfactual revenue-per-ton estimates allow a back-of-the-envelope estimate of the 2011 profit-per-ton expected had the IVQ not been implemented.

5. Analysis and results

In this section background information on fishery stocks and TACs is provided, followed by an analysis of indicators related to revenue and cost, and finally a back-of-the-envelope estimate of counterfactual profit had the IVQ not been implemented.

Fluctuating stock sizes are common for small pelagic species, and the Peru anchovy is no exception. In the Peruvian anchovy fishery, the TAC tends to fluctuate, following the assessed stock size. The anchovy stock fluctuates significantly between seasons within a year and year-to-year, with estimated biomass varying by as much as 200% over the course of the years for which data are available (see Fig. 1). The TAC generally binds or is close to binding, with the exception of season 2 of 2010. Season 2 of 2010 is the lowest landings year in the data studied and corresponds to a low-point in the stock abundance and an early closure of the fishery.

5.1. Change in per-unit revenue

The commercial anchovy catch is used to produce fishmeal, with quality ranging from low-quality residual fishmeal, to standard, prime, and high-quality super-prime. A dramatic change in product type is observed in the fishery coinciding with the IVQ (Fig. 2, Table 1), with a shift toward production of higher value products.[8] The share of prime and super-prime fishmeal both increased post IVQ (by 7% and 5%, respectively, Table 2) while the share of standard decreased (by 10%, Table 2).

Ex-vessel prices are also examined over time. A weighted average price for each year is calculated, where monthly landings are used as weights for monthly prices (PRODUCE ex-vessel price data). The data from PRODUCE are based on prices recorded for independent market transactions; because of the vertically integrated nature of the steel fleet, most of the ex-vessel price data is based on landings by the wood fleet. This market price is applied to steel fleet landings under the assumption that if the steel vessels were not owned by vertically integrated processors, then they would negotiate the same price as the wood fleet. Because no formal transactions between vertically integrated vessels and processors take place, this is an “implicit” price.

The ex-vessel price of anchovy increased after the start of the IVQ system (Fig. 3a, Table 1). Post-IVQ, using the regression results controlling for a time trend, we find there was a 105% rise in the real ex-vessel price (Table 2). These estimates are higher than Tveteras et al. [47], who use government data and report that prices rose 37% from 2008 to 2009, but lower than Natividad [34], who calculates a 200% increase in anchovy prices from 2008 to 2010.[9]

[7] Studies that use data from pre and post implementation of a quota program to examine the impact of quotas include Chu [11], Agar et al. [3], and Reimer et al. [41].

[8] The data on product type and ex-vessel price used for this paper is not region-specific. Therefore, to the extent that product quality and prices are lower in the South due to a continued race-to-fish, the estimates here are likely underestimates of revenue changes in the North-Central.

[9] For more information on daily prices, see Natividad [34], who obtained and

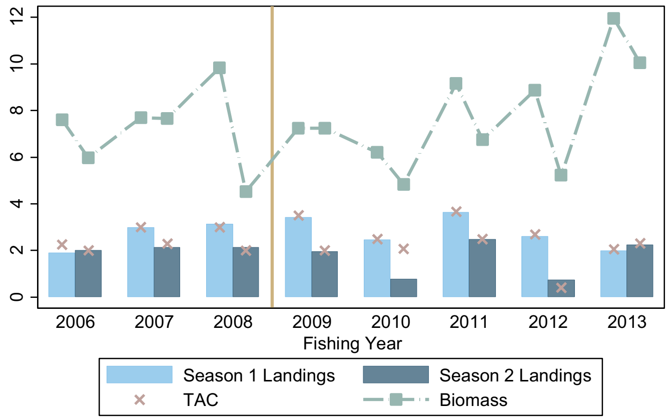

Fig. 1. Biomass, TAC, and landings (million metric tons). Sources: PRODUCE landings and TAC data. Note: All statistics are for the North-Central region. The solid vertical line corresponds to the start of the IVQ system in the North-Central region.

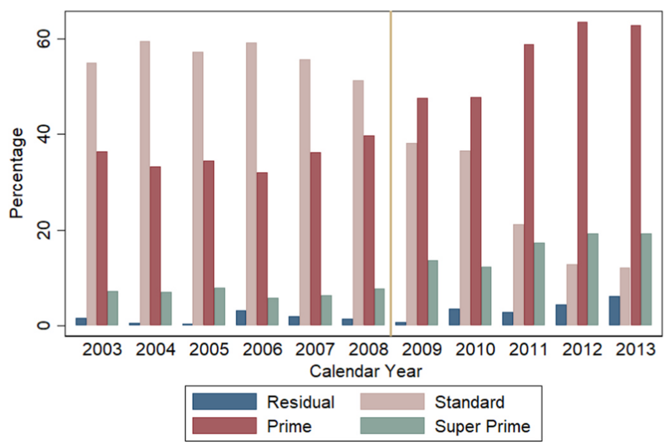

Fig. 2. Production of fishmeal, by grade, over time. Source: Ministerio De Producción – Anuario Estadístico 2010, 2011, 2013.

Table 1
Hypothesis testing of difference in indicators pre- and post IVQ.

Indicator variable	Mean (SE) Pre	Mean (SE) Post	Difference (post-pre)
Product Form (%)			
Residual	1.48 (0.42)	3.49 (0.88)	2.00*
Standard	56.22 (1.24)	24.11 (5.62)	− 32.11***
Prime	35.32 (1.12)	56.05 (3.52)	20.74***
Super Prime	6.98 (0.35)	16.35 (1.45)	9.37***
Ex-Vessel Price			
Weighted Price	139.45 (13.25)	249.57 (18.14)	110.12***
Ex-Vessel as a % of Export	12.36 (0.70)	17.10 (0.22)	4.74**
Export – Ex-Vessel	913.86 (27.08)	1153.0 (87.46)	239.14*
Steel Vessel Characteristics			
Active Vessels			
Season 1	551.67 (1.45)	369.6 (18.61)	− 182.07***
Season 2	545.33 (3.28)	347.8 (14.89)	− 197.53***
Median Hull Capacity			
Season 1	296.09 (2.00)	349.69 (5.38)	53.60***
Season 2	298.49 (2.10)	355.16 (4.36)	56.68***
Median Vessel % of Total Catch			
Season 1	16.28 (0.39)	24.63 (1.54)	8.35***
Season 2	16.78 (0.20)	26.77 (1.49)	10.00***
Wood Vessel Characteristics			
Active Vessels			
Season 1	607 (11.85)	501.6 (16.26)	− 105.4***
Season 2	604.67 (6.69)	454.4 (32.21)	− 150.27***
Median Hull Capacity			
Season 1	54.96 (0.62)	67.29 (1.46)	12.33***
Season 2	55.81 (0.76)	70.01 (2.57)	14.20***
Median Vessel % of Total Catch			
Season 1	13.82 (0.17)	17.15 (0.72)	3.33***
Season 2	13.75 (0.25)	18.38 (1.01)	4.64***
Season Length (Days with Landings)			
Season 1	27.67 (3.18)	88.8 (8.08)	61.13***
Season 2	20.67 (1.67)	65 (9.38)	44.33***

Notes: A *t*-test, assuming unequal variances, was used to compare the indicator variables pre and post IVQ implementation. We report the difference in the rightmost column and the p-value associated with the test of whether the difference in means is zero using asterisks (*p < 0.1, ** p < 0.05, *** p < 0.01). The IVQ system began in the first season of 2009 in the North-Central region.

The increase in prices could be due to several factors. First, the increase could be due to changes induced by IVQ- implementation, such as product quality increases due to more careful handling of the fish on-board, less tightly packed fish on-board, a decrease in time between catch and delivery, or spreading out of landings so that processing can be done at a slower rate [18]. These margins of changes are discussed more in the next section.

Another consideration is that, with the implementation of the IVQ, bargaining power shifted from processing plants to IVQ-holders. Specifically, under a race-to-fish, processors may have exerted monopsony power, implying that vessels had limited bargaining power in their ability to negotiate prices with processors. Reasons for this might include travel time between processors and/or any time spent negotiating may have been time not spent fishing or time during which catch was degrading. Under an IVQ the scarce resource is the catch, and vessels can bargain with processors, not going out until they negotiate an acceptable price (for further discussion see e.g. Matulich and Clark [32], Herrmann and Criddle [24], and Fell and Haynie [15]). It is possible the IVQ increased vessel negotiation power, particularly of the wood fleet; steel vessels often belong to vertically integrated companies that also process anchovy (see e.g. Galarza [18] and Fréon et al. [16]). Additionally, there may be differences in how changes in bargaining power manifest themselves over the longer run. For example, it is possible that the change to the IVQ program and the increase in number of days fished resulted in some redundant capital in the processing sector, such that some plants may stay open in the short run and pay higher ex-vessel prices than the plants would pay in a long-run equilibrium (see e.g. Matulich [31] and Wilen [49] and citations therein for further discussion of the impacts of quota programs on the processing sector).

To explore changes in the ex-vessel price over time, ex-vessel price is graphed as a percentage of the export price (Fig. 3b) and the difference between the export price and the ex-vessel price (Fig. 3c). Preliminary *t*-tests suggest there is an increase over time in both measures (Table 1). After controlling for time trends we estimate the percentage of the export price going to harvesters increased by 5% (Table 2) post-IVQ. We do not find statistically significant evidence the difference changed after controlling for time trends: the first year after the IVQ the real dollar amount per ton going to processors decreased, but in every other year post-IVQ the processors received more per ton than any year pre-IVQ (Fig. 3b, Table 2).

(footnote continued)
summarized confidential daily-level price data from a single (large) fishing firm.

Table 2
Structural break testing of indicators pre- and post IVQ.

Indicator variable	Regression coefficients				
	Dummy Variable = 1 if post-IVQ period	Dummy Variable = 1 if Season 2	Time	Time^2	Constant
Product Form					
Residual	− 1.53 (0.82)		− 7.25** (2.41)	0.82** (0.02)	161.52** (58.05)
Standard	− 9.68** (2.90)		54.39*** (9.42)	−0.61*** (0.10)	− 1160.34 *** (216.27)
Prime	6.53** (2.53)		− 32.18*** (8.02)	0.36*** (0.09)	751.47*** (186.39)
Super Prime	4.68*** (1.05)		− 14.96*** (2.94)	0.16*** (0.03)	347.35*** (68.08)
Ex-Vessel Price					
Weighted Price	104.83** (36.48)		5.32 (23.13)	− 0.48 (2.46)	131.05** (33.87)
Ex-Vessel as a % of Export	4.78** (1.18)		− 0.18 (0.91)	0.02 (0.08)	12.62*** (1.40)
Export – Ex-Vessel	71.79 (144.58)		− 13.11 (73.70)	6.59 (8.18)	909.31*** (113.61)
Steel Vessel Characteristics					
Active Vessels	− 127.55*** (21.43)	− 7.94 (5.22)	− 8.23 (10.99)	− 0.83 (1.11)	575.79*** (21.05)
Median Hull Capacity	34.11*** (6.63)	1.72 (2.08)	6.00* (3.22)	− 0.8 (0.32)	283.42*** (6.24)
Median Vessel % of Total Catch	3.65* (1.80)	0.80 (0.57)	0.53 (0.86)	0.10 (0.09)	14.37*** (1.56)
Wood Vessel Characteristics					
Active Vessels	− 74.98*** (15.39)	− 22.73 (15.80)	14.22 (17.34)	− 3.11 (1.87)	603.20*** (32.93)
Median Hull Capacity	5.99*** (1.26)	1.09 (1.23)	1.23 (1.06)	0.07 (0.13)	51.68*** (1.77)
Median Vessel % of Total Catch	1.19*** (0.28)	0.37 (0.43)	0.01 (0.42)	0.08 (0.05)	13.13*** (0.75)
Season Length					
Days with Landings	50.24*** (14.26)	− 17.69 (10.01)	3.93 (5.48)	− 0.37 (0.53)	26.34** (10.21)

Notes: Regression coefficients from estimation of Eq. (1). The IVQ system began in the first season of 2009 in the North-Central region. *$p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

Finally, the price increase observed could be due, in part, to a global increase in the demand for fishmeal. Peruvian fishmeal is sold into a global market and over this period the world price of fishmeal increased. Understanding prices in Peru relative to world demand is complicated though, as according to FishStat which reports country-level fishmeal production statistics, Peru's contribution to the aggregate global fishmeal supply has ranged from 23% to 38% over the period from 2006 to 2011 (FAO, 2014).

5.2. Changes in fleet inputs

In this section fleet input use over time is examined. Both extensive margins, such as the number of vessels active in the fishery, as well as intensive margins, such as the number of trips, are examined. Incentives to increase revenue, such as the higher prices associated with higher-value fishmeal can motivate changes in inputs. Specifically, increasing product quality often requires slower fishing, shorter trips, and/or less product in the hold per hold capacity unit.

A consolidation in the number of active vessels - where an active vessel is defined as a vessel with positive anchovy landings – is found post-IVQ (Figs. 4A and 4D, Table 1). The drop in number of active vessels in the steel fleet is faster and more significant than the wood fleet, with the number of active vessels decreasing by approximately 40% over the period observed; the structural break test suggesting a decrease of 128 vessels post-IVQ (Table 2). The wood fleet decrease is smaller, around 25%; the structural break test suggesting a decrease of 75 vessels post-IVQ (Table 2). However, there are some seasonal fluctuations. The most significant fluctuations occur in season 2 of 2010 and season 2 of 2012, the years with the lowest TACs for the North-Central region.

Accompanying the decrease in the number of active vessels is an increase in the capacity of active vessels (Figs. 4B and 4E, Table 1). We find that in the steel fleet the vessels that remained active post-IVQ were relatively larger – the median higher by about 34 m^3 (Table 2), suggesting vessels with smaller capacity stopped fishing. There is a slight increase, about 6 m^3, in the median capacity of the wood vessels (Table 2).

The number of days of activity in each fishing season is also examined. Under an IVQ system there is considerable flexibility to spread catch out within a season, therefore the number of days with at least one vessel making a landing is calculated. There is an increase of 50 days with at least one positive landings post-IVQ (Table 2), reflecting landings spread out more over the course of the season (Fig. 5). An increase is evident if the data are broken down by hull type as well.

Next, changes to the nature of catch concentration are explored by looking at concentration in catch per vessel and trips per vessel. There is significant variability in absolute measures, such as catch per vessel and trips per vessel, over time. However, given the possibility that variability may be driven by fluctuating stocks and landings, the concentration of vessel catch as a percentage of total landings is also calculated. Post-IVQ the median catch per vessel (measured as a percentage of the TAC) increases by 4% and 1% in the steel and wood fleets, respectively (Figs. 4C and 4F, Table 2). The trends are similar for the median number of vessel trips as a percentage of the total trips.[10]

5.3. Profitability of steel vessels

Table 3 presents estimates of real revenues, variable costs, and variable profit of harvesting, both in total and by average-per-metric ton, for each year and season for which cost data is available. To compare across seasons and years the per-unit costs, revenues, and profits are presented. This helps account for differences in total landings that influence total revenues and costs.

The average per-ton harvesting cost is relatively stable prior to the IVQ system, then decreases in 2011 and increases in 2013. Average per-ton costs are approximately \$94/ton prior to the IVQ system implementation, dropping to \$84/ton in 2011, and then increasing to

[10] With-in trip catch is also calculated, looking at landings-per-trip and hold-capacity-filled. It is not clear what, if any, direction these statistics would be expected to move post-IVQ. In fact, given the many dimensions of inputs in the fishing production process (see e.g. Reimer et al. [41]), the productivity measure of quantity caught per trip is a measure of partial productivity. In other words, it is a measure of output per one unit of a particular input, in a context in which there are multiple inputs. Furthermore, this examination is limited because an important margin, the length of the trip, is not available in the dataset. Changes in the distribution from year-to-year are found, with no clear trend post-IVQ. Therefore, no conclusion about changes over these margins is offered.

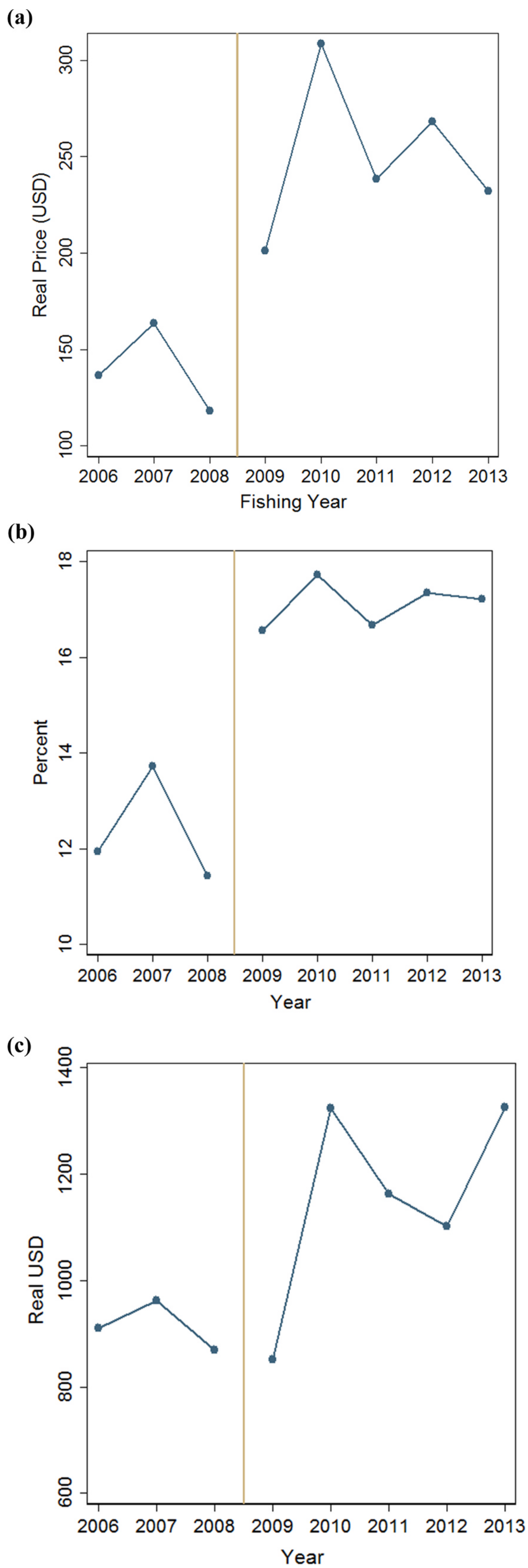

Fig. 3. (a) Weighted average ex-vessel price; (b) ex-vessel price as a percentage of export price; and (c) difference between export and ex-vessel price. Sources: PRODUCE (ex-vessel price data), World Bank (Peruvian Wholesale Price Index), and UN Treasury (Operational Rates of Exchange). Note: the solid vertical line corresponds to the start of the IVQ system prior to the 2009 fishing year. The weighted price is calculated using monthly prices and the total monthly catch as the weight.

around $121/ton in 2013.[11]

The cost change is relatively small compared to the revenue changes. Aggregated to the year level, post-IVQ revenue per ton is more than 75% greater than pre-IVQ revenue per ton. The large revenue increases combined with relatively small cost changes result in an increased profit-per-ton post-IVQ. Pre-IVQ profit-per-ton is 33% of ex-vessel revenue in 2006, 20% in 2008, and 64% and 51% in the post-IVQ years 2011 and 2013, respectively.

In Table 4, the counterfactual 2011 results are presented. Estimates of the revenue, variable cost, and variable profit per-ton, had the IVQ not been implemented, are presented. Also, to give a sense of the absolute magnitude of the change in terms of overall fishery harvesting profit, per-unit increases in profit are multiplied by the total harvest. In season 1 of 2011 the observed profit-per-ton is $91/ton higher relative to the no-IVQ counterfactual; in season 2 of 2011 the observed profit-per-ton is $96/ton greater. Multiplying the gain in profit per ton by the total 2011 seasonal landings, the aggregate gain is $265 million in season 1 and $191 million in season 2. In relative terms this equates to a 138% increase in profit for season 1 and a 196% increase in profit in season 2. In terms of ex-vessel revenue, this represents an increase from profit comprising 34–41% of ex-vessel revenue in 2008 to 63–65% in 2011. However, the total seasonal gains depend on the stock and TAC; in 2011 the TAC and stock were high relative to other post-IVQ years (the lowest post-IVQ season1 landings were 55% of the 2011 season 1 landings and the lowest post-IVQ season 2 landings were 33% of the 2011 season 2 landings), so gains of this magnitude should not be expected to occur in all years.

These estimates are consistent with previous estimates of the quota lease price. When comparing estimates one should expect the estimates in this paper of average profit to be higher than the quota lease price.[12] The estimates of average North-Central steel fleet profit-per-ton are: $157 (2013 USD) in season 1 and $145 in season 2 of 2011 and $115 in season 1 (2013 USD) and $138 in season 2 of 2013. These are higher than the Paredes [40] estimated quota price of approximately $100/metric ton and Galarza and Collado's [20] estimate of $103/metric ton.

[11] It is possible that significant changes occurred within cost categories that are not observable from the aggregated cost statistics. For example, in the steel fleet crew remuneration is often based on ex-vessel or export value, and so can increase if product quality and price increase.

[12] The profit maximizing condition where the profit of each vessel is maximized is: $0=P - VC_i(q_i)' - m$, where m is the implied quota lease price and P is the ex-vessel price. Therefore, the implied quota lease price, which is the per ton resource rent, is: $m = P - VC_i(q_i)'$. A vessel is expected to take a trip if the expected trip profit per ton $P - VC_i(q_i)'$ is greater than or equal to the quota lease price. For this fishery an "implied" lease rate is considered given that the markets are informal and movement of quota occurs through firms or the associations. Under the assumption of increasing marginal costs, vessels will continue to add trips until the expected value of an additional trip is less than the quota price. In equilibrium, the return to the final unit of catch by each vessel is expected to equal the quota price; i.e., equalization of the marginal return, not the average. Given an increasing marginal cost curve, the marginal cost would be greater than the average and the average cost per ton would be a lower bound on a measure of the marginal cost per ton. The higher the cost per ton, the lower the quota price, suggesting the estimates of average profit should be an upper bound on the quota lease price.

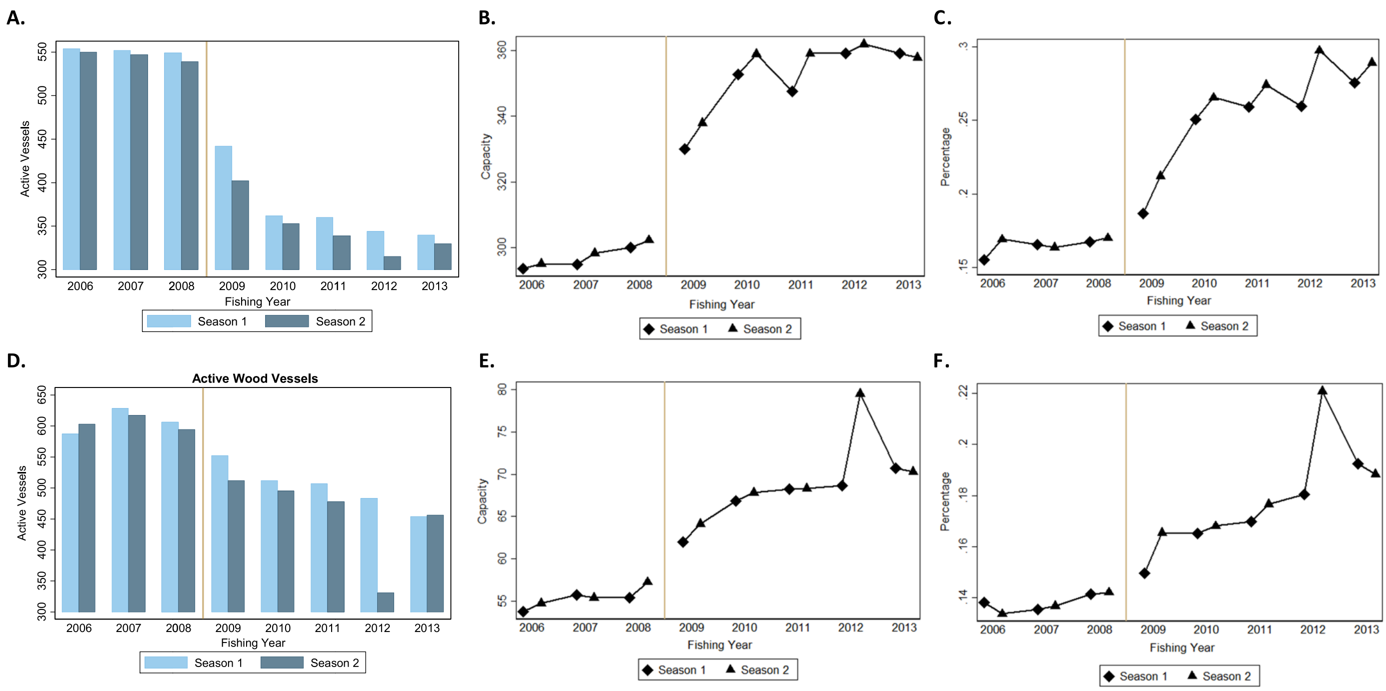

Fig. 4. Changes in active vessels and vessel utilization. North-Central steel vessel summary statistics: (A) Number of active vessels; (B) Median hull capacity of active vessels; (C) Median vessel percentage of steel vessel catch. North-Central wood vessel summary statistics: (D) Number of active vessels; (E) Median hull capacity of active vessels; (F) Median vessel percentage of wood vessel catch. Source: PRODUCE landings data. Note: The solid vertical line corresponds to the start of the IVQ system in the North-Central region.

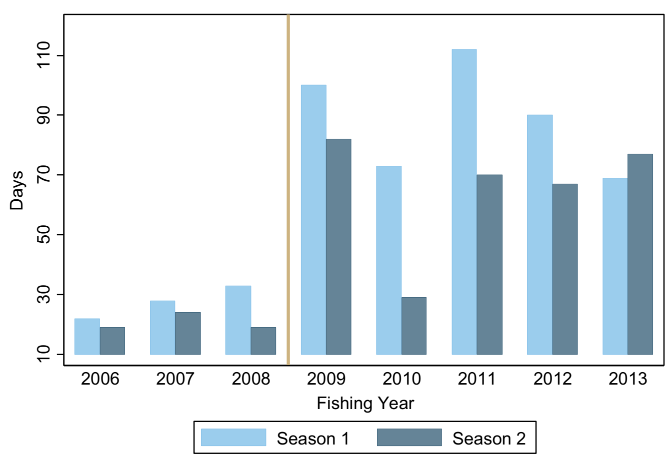

Fig. 5. Number of days per fishing season with at least one landing record in the North-Central. Source: PRODUCE landings data. Note: The solid vertical line corresponds to the start of the IVQ system in the North-Central region.

6. Discussion

In the analysis of the changes to harvesting revenues and costs coinciding with the IVQ system, there is evidence that revenue-side gains are significant and large relative to cost-side changes. This finding emphasizes the importance of revenue-side changes that can occur due to ITQ implementation. This finding is consistent with observations in other fisheries. For example, there is evidence of fishermen investing in less-efficient gears after the race to fish is eliminated with an ITQ as a means to increase the quality of the output. Red snapper quota holders in New Zealand went from using trawl gear prior to the introduction of ITQs to longlines to eventually relying on traps after the ITQ, as their product type shifted from frozen to fresh to live fish that were shipped to Japan and China [14].

Furthermore, these findings counter concerns that IVQs and ITQs

Table 3
Steel variable profit (2013 USD).

	North-Central							
Fishing Year	2006		2008		2011		2013	
Season	1	2	1	2	1	2	1	2
Total Revenue (million USD)	191	249	310	191	707	458	378	469
Total Variable Cost (million USD)	144	154	236	162	248	168	194	220
Total Profit (million USD)	47	95	74	28	459	290	184	250
Revenue per metric ton	124	152	124	111	242	230	235	258
Cost per metric ton	94	94	94	94	84	84	121	121
Profit per metric ton	30	58	29	17	157	145	115	138
Per-Ton Profit as % of Ex-Vessel Revenue/Ton	**24%**	**38%**	**23%**	**15%**	**65%**	**63%**	**49%**	**53%**

Note: The IVQ system began in the first season of 2009 in the North-Central region.

Table 4
Counterfactual steel variable profit (2013 USD).

North-Central				
	No-IVQ Counterfactual		**2011 Observed**	
Season	**1**	**2**	**1**	**2**
Revenue per metric ton	160	143	242	230
Cost per metric ton	94	94	84	84
Profit per metric ton	66	49	157	145
Per-Ton Profit as % of Ex-Vessel Revenue/Ton	**41%**	**34%**	**65%**	**63%**

Note: We compare the observed 2011 revenue, cost, and profit to an estimate (assumptions described in the text) of what the 2011 revenue, cost, and profit would have been had the IVQ not been implemented.

may not be able to successfully manage fluctuating stocks [13] and allay concerns over excessive corruption in the fishery (see e.g. Kroetz et al. [27]). Specifically, that industry has reduced the number of active vessels through firm or association level transfers suggests that quota transfers can still occur with fluctuating stocks and that there is some confidence in the government's ability to set TACs, enforce, and monitor.

The relative success of the North-Central anchovy IVQ system raises questions about related management schemes including the anchovy IVQ system in the South and management of the artisanal and smaller scale anchovy fisheries. Although in the most recent year of data (2013) the Southern catch is only 12% of the total industrial anchovy catch in Peru, the ex-vessel value of the approximately 575,000 metric tons landed is ~$134 million USD. If the South and North-Central were considered separate fisheries, then the Southern anchovy catch would be the second-largest species catch by volume in Peru [43]. Without binding individual quotas, a race-to-fish will likely continue (see Kroetz et al. [27] for information on how days of active fishing do not appear to increase post-IVQ as they did in the North-Central) and stocks will likely remain lower than maximum economic yield. Furthermore, around 40% of active steel vessels fish in both regions. Understanding how the fishing management regime in the South affects the optimal fishing strategy and potentially the profitability of fishing in the North-Central region warrants further investigation.

Another important management question with implications for industrial North-Central IVQ profitability needing further study is management of the small-scale artisanal fleet. The artisanal and small scale fleets operate outside of the IVQ system in essentially an open-access regime [18,19]. The industrial and artisanal fleets fish the same stock, and so overfishing in the artisanal fleet can impact the stock and thus profitability of the industrial fleet. The artisanal fleet also delivers some product for fishmeal (see e.g. Fréon et al. [16]). Furthermore, the fishing grounds of the fleets are spatially delineated with the artisanal fleet fishing closest to shore, then the small-scale fleet beyond that, and finally the industrial fleet fishing furthest from shore. This has essentially created an open-access regime operating from nearest to shore where the artisanal and small-scale fleets fish and an IVQ system in the region beyond the zone for the small-scale fleet to the Exclusive Economic Zone. Because the spatial distribution of the stock with respect to distance to the coast has historically been influenced by El Niño events (appearing closer in El Niño years) this situation has the potential to increase the conflicts between the two fleets and undercut the potential security of the quota asset (and hence reduce its value).

This analysis also helps highlight the need for more standardized collection of indicators in catch share fisheries. No government-collected cost data are available. Compared to another source of cost information, Paredes [39], the reported costs here are higher, and therefore the profit estimates may be conservative. There is also no trip departure and arrival information, limiting the ability to identify increases in handling times and improved product recovery rates, one of the IVQ system goals [50]. Given the data and policy-setting limitations, going beyond the back-of the-envelope estimate for 2011 and establishing a causal link between the changes across the many margins that occur post-IVQ and implementation of the IVQ program, is left to future work (see discussion in Gertler et al. [21] on counterfeit counterfactuals).

Also left for further investigation is the performance of the program beyond impacts related to the economics of harvesting anchovy. This includes evaluating outcomes relative to other program goals including the use of anchovy for sustained development as a source of food, employment and income, and to ensure its responsible use in harmony with the preservation of environment and biodiversity conservation. Additionally, given the vertically integrated nature of the firms owning most of the steel vessels, a more extensive evaluation of the economic impact of the program would include evaluation of profit along the entire value chain from harvest, to processing, and then sale, as well as the possibility that industry size and structure impacted IVQ outcomes.

Finally, the difference in degree and speed of consolidation across hull types is an important source of variation that can have economic and social impacts, but has yet to be fully explored. Steel fleet crew members and wood vessels owners, which controlled the minority of vessel and processing capacity, were initially opposed to the IVQ system implementation (see e.g. La Republica [30]). One reason for opposition by wood vessel owners was their concern their production would be reduced (see e.g. La Republica [30]). Owners of processing plants and vessels, primarily from the steel fleet, committed to a landings tax to finance a social support program in response to the controversy. To that end, the government created a social fund, FONCOPES, to provide a benefits program for early retirement of crew, training in technical careers, and assistance for crew to start small businesses. Vessels in the IVQ system supported the fund though a mandatory fee based on the amount of quota per vessel and the number of crew members [17]. Young and Lankester [50] report that during its first three years FONCOPES collected $10 million (USD), assisted in the voluntary retirement of 350 fishermen, and helped 400 workers transition out of the fishery. Furthermore, Galarza [17] reports fewer accidents following the start of the IVQ system. Understanding the political economy questions related to support by stakeholders for catch shares, the mechanisms through which consolidation occurred, and the economic and social costs and benefits of association and firm transfer provisions and the fleet-specific allocation structure of the system, are also left for future work.

7. Conclusion

In analyzing the Peruvian anchovy fishery, there is evidence that changes have occurred in the fishery that are consistent with the economic goals of the management system, including lengthened seasons, production of higher-value products, fleet consolidation, and increased per-ton variable profit. Although an IVQ system in name, allowances for within firm transfers of quota and the formation of associations through which quota can be transferred to vessels of other firms appear to have provided sufficient flexibility for some changes to occur.

Relative to earlier studies the scope of this paper is broader as more margins of change are examined over a longer time period. The paper also breaks the analysis down by the hull-type and region. In the North-Central region, heterogeneity between the steel and wood fleets is revealed. Specifically, the contraction in fleet size and the shift toward larger capacity vessel is much more pronounced in the steel fleet. This highlights the importance of conducting separate examinations of each group of participants that receives a quota allocation.

A shift toward higher-value product forms is observed and an increase in the ex-vessel price after IVQ system implementation is calculated. Specifically, a 105% increase in the ex-vessel price occurs with the IVQ program.

There is also evidence of changes in capital utilization, potentially the result of association and firm-level transfer provisions. Post-IVQ landings are more spread out over the season, with a greater number of days with at least one landing. In addition to changes in when landings occur, in both the steel and wood fleets a decrease in the number of active vessels and total capacity (calculated as the sum of the capacity of active vessels) is observed. This is accompanied by consolidation of landings and trips (measured as a percentage of total landings per season and total trips per season). The steel fleet also experiences an increase in median vessel capacity, suggesting that larger vessels were more apt to remain active in the fishery.

To understand potential changes in economic efficiency data from a large fishing firm on cost-per-ton fished by the steel fleet was used and a back-of-the-envelope estimate of profit had the IVQ not been implemented is made. In the North-Central in 2011 profit was approximately 63–65% of ex-vessel revenue, higher than the 34–41% of ex-vessel revenue estimated under the counterfactual no-IVQ scenario.

Acknowledgements

(1) Funding for this research was provided by the Inter-American Development Bank under the Economic Sector Work RG-K1350 “Evaluation of Market-Based Fisheries Policies in Latin America” and Resources for the Future. The views and opinions expressed in this paper are the authors’ own, and do not necessarily reflect those of the Inter-American Development Bank, Resources for the Future, Research Center of Universidad del Pacifico, or the University of California, Davis.
(2) The authors thank the Ministry of Production of Perú - PRODUCE (both the General Office of Fishery Landings and Processing and the General Office of Surveillance and Fiscalization) and the Institution of the Peruvian Sea – IMARPE for compiling, providing access to, and explaining the databases.
(3) The authors thank the Peruvian National Society of Fisheries (SNP) for providing access to and assisting in the understanding of fishing cost data.
(4) The authors thank an anonymous reviewer for helpful comments on the manuscript and Jacqueline Ho and Gregoire Yves Philippe Garsous for research assistance.
(5) A considerable part of the work was carried when David Corderi-Novoa was a staff member of the Inter-American Development Bank.

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