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Quotas, Productivity and Prices: The Case of Anchovy Fishing

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Abstract

I exploit a 2009 reform that introduced individual fishing quotas (catch shares) for Peruvian anchovy — the largest fishery in the world — to assess the causal impact of production quotas on within-firm productivity and market prices. Unique features of the data allow me to create two alternative counterfactuals: (i) anchovy fishing operations in a region of the country that was mandated to implement quotas with a delay, and (ii) variation in quota allocations across ships. I find that quotas do not increase within-asset or within-firm productivity in quantities. Instead, a 200% increase in anchovy prices benefits extraction firms through higher revenues, consistent with two mechanisms enacted by individual fishing quotas: more orderly industry operations reducing excess supply and an increase in bargaining power of extraction firms with respect to fish-processing. Several market characteristics across geographies differentially affect market prices after the quota regime. Supplementary evidence on fewer operational infractions, higher product quality, and a lower banking delinquency observed during the quota regime suggests the existence of efficiency gains rather than purely rent transfers.

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A rising literature in industrial organization has brought into relief the broad market impact of environmental regulation (Greenstone 2002, Keller and Levinson 2002, Davis 2008, Ryan 2012, Greenstone, List, and Syverson 2012). From an economic standpoint, one of the chief difficulties of regulating the environment consists in addressing the tragedy of the commons in natural resource contexts (Stavins 2011), a problem often requiring the granting of property rights to private firms (Van der Ploeg 2011). This paper presents new causal evidence about the impact of individual fishing quotas on within-firm productivity and market prices by exploiting a 2009 reform that radically changed access to Peruvian anchovy, the largest fishery in the world.

It has been argued that individual fishing quotas — an instrument that restricts free access to the common fishery (Gordon 1954), assigning to each ship a pre-established catch share — can prevent the collapse of global fisheries (Costello, Gaines, and Lynham 2008, Heal and Schlenker 2008). Accordingly, over the last two decades, there has been much interest in analyzing marine resource property rights in the form of individual fishing quotas (see Scott ((1993), (2000) and (2008)), Libecap (2009), and Branch (2009) for broad discussions and reviews). This large body of work has often focused on specific studies of fisheries adopting a quota system[1] or cross-fishery comparisons of quota systems.[2] However, this literature has given relatively little attention to the causal impact of fishing quota regimes on within-firm productivity and market prices, thus remaining somewhat disconnected from ongoing research in industrial organization.

[1]For example, Geen and Nayar (1988) employ a simulation framework to compare a quota system with other regulatory systems in the Southern bluefin tuna fishery in Australia and Japan; Casey et al. (1995) collect descriptive statistics of the impact of a halibut individual fishing quota by conducting a round of 14 interviews with halibut processors in 1993 and by conducting one mail survey of all halibut fishermen in 1994; Herrmann (1996) studies the yearly aggregate time series of halibut prices in Canada before and after the adoption of a quota system; Campbell, Brown, and Battaglene (2000) describe broad economic patterns emerging after the enactment of individual transferrable quotas in Australia's southern bluefin tuna fishery; Dupont and Grafton (2000) analyze multi-species individual transferable quotas; Dupont et al. (2005) also analyze multi-species individual transferable quotas, and while their focus is on productivity and prices, they analyze data in a more aggregate (industry-species level) fashion; Fox et al. (2006) study the posterior introduction in Australia's Southeast trawl fishery of both a brokerage system enhancing the transferability of individual quotas and a government-sponsored buy-back program for fishing licenses; Sharp and Batstone (2008) discuss the simultaneous introduction of total allowable catch (TAC) and individual transferrable quotas in New Zealand's fisheries management environment; Sylvia, Munro Mann, and Pugmire (2008) describe the the introduction of a self-government body, the Pacific Whiting Conservation Cooperative, acknowledged to be quite different from an individual quota system; Lee and Thunberg (2013) analyze a catch share system creating a simulated counterfactual based on pre-regime operations

[2]For instance, Chu (2009) and Essington (2010) conduct cross-fishery comparisons of ITQ adoption and subsequent ecological outputs, with a clear biological emphasis rather than a focus on economic outcomes.

As more direct background to my study, a small number of papers have employed natural experiments to investigate the influence of individual fishing quotas on productivity and prices. Grafton, Squires, and Fox (2000) and Fox et al. (2003) analyze productivity and prices around the introduction of individual harvesting rights in the British Columbia halibut fishery in 1991, utilizing different cross-sectional samples of firms from 1988, 1991, and 1994, and finding changes in outcomes during the quota regime. Brandt (2007) and Walden et al. (2012) employ the introduction of quotas in the Mid-Atlantic surfclam and ocean quahog fisheries to study vessel productivity and participation incentives before and after the reform. Importantly, all this prior work has lacked the econometric advantage of having a control group to isolate the causal impact of the quota system treatment. Moreover, some of these studies have lacked disaggregated information on local market prices and weekly dynamics that would speak to current research on economics mechanisms in vertical markets (e.g., Syverson 2007, Hortaçsu and Syverson 2007).

My analysis of the industrial organization of fishing quotas fills an important gap in the literature because key market outcomes should not be expected to remain unchanged after quotas are enacted. Specifically, individual fishing quotas can be broadly construed as a government-mandated *reduction* of competition in a given market, which may carry implications for firm productivity and market prices (see Holmes and Schmitz (2010) for the more frequently studied cases of *increases* in competition). Moreover, the market structure analysis of fishery reforms is particularly important given their potential redistributive effects (Karpoff 1987). In this paper, I exploit a comprehensive data set to assess the causal impact of individual fishing quotas, with emphasis on the joint analysis of productivity and prices in the context of competitive markets.

In essence, I seek to answer two basic questions: How and why do individual fishing quotas matter for asset-level productivity? And how and why do these quotas matter for market prices? From a conceptual standpoint, answers to the first question can vary widely. By reducing competition (racing behavior) through guaranteeing a catch share to all market participants, a quota system may have a positive impact on within-ship productivity through a smoother, better planned exploitation of the resource. But when such guarantee helps industry participants reduce a significant portion of their assets (ships), the remaining assets would need to be operated more intensively than before, while lacking some of the prior information and incentive mechanisms due to the presence of excess ships, thus becoming less productive with quotas. The question about market prices appears to be more intuitively answered: by granting property rights to fish extraction companies, the price of fish sold downstream should increase. Yet the mechanism for price increases may vary, perhaps enacting a shift in bargaining power over the vertical chain or instead more orderly supply operations due to the benefits of fishing without racing. Generally, there has been much theoretical interest in modeling fishermen's racing behavior and the individual quota instrument (e.g., Gordon 1954, Arnason 1990, Boyce 1992). The causal impact of quotas on productivity and prices is the open empirical question that I address.

The enactment of individual fishing quotas in the Peruvian anchovy fishery implied a significant regulatory shift affecting all firms in the industry. Historically, until 2008, extraction firms operated under a regulatory framework that allowed all ships with a license to fish anchovy for fishmeal — an intermediate good produced by plants on land — until a "total allowable catch" was reached. No individual caps on ship output existed. In this early regime, the primary concern of firms was to find anchovy, extract as much of it as possible, and deliver it quickly to plants to restart this cycle, aware that fish not caught by one firm would be caught by another. In 2008, the government suddenly introduced a new regulatory framework, with the stated goals of reducing overcapacity and discouraging racing behavior that exerted pressure on the natural environment. In the new fishing regime, a total allowable catch was still in place, but each ship received an individual fishing quota, defined as a percentage share of the total allowable catch. Individual fishing quotas were allocated using a formula based on ship characteristics and ship output from 2004–2007 (i.e., a period ending before the announcement of the reform). Moreover, the new regulation allowed firms to transfer quotas across ships, thus fostering the closure of less productive ships once their quotas were transferred away to others.

Key features of this regulatory reform allow me to study the causal impact of quotas in a reduced-form fashion.[3] To be sure, a quota reform is an event among others potentially affecting industry structure, so it is typically difficult to isolate the causal effect of quotas without a clear counterfactual. By contrast, the reform studied here allows me to exploit two counterfactuals for the question of interest: (i) anchovy fishing operations in a region of the country that was ruled to implement quotas with a delay with respect to the region of interest, and (ii) variation in quota allocations across ships. In a first set of tests, I exploit data on anchovy fishing in the South region of the Peruvian sea, which was scheduled to begin its own quota regime a few months later than the North-Center region (i.e., the region of interest for my study, totaling over 87% of historical anchovy catches.) The results of within-ship and within-firm panel difference-in-differences regressions with respect to the South region counterfactual show no positive influence of the advent of the quota regime on productivity measured in quantities. In a second set of tests, I exploit ship-specific quota allocations to study the within-ship and within-firm effect of quotas on the productivity of continuing ships and firms. These tests are motivated by the above argument that a larger quota may allow firms to plan their operations better than otherwise, thus attaining higher subsequent productivity. But the panel specifications using quota allocations as the explanatory variable yield no significant impact of quotas on within-ship or within-firm productivity measured in quantities. Overall, the findings suggest that the impact of individual fishing quotas is not beneficial for within-firm productivity on average.

In contrast to the non-positive impact of quotas on productivity in quantities, I find a 200% increase in anchovy prices following the enactment of individual fishing quotas. Because the total allowed catch levels during the quota regime are not significantly lower than those before the quota regime, this enormous price increase cannot be attributed to changes in aggregate supply. Importantly, the large price increase is also observed after controlling for demand-side changes that could be attributed to global commodity demand for fishmeal and its substitutes. Moreover, a difference-in-differences analysis exploiting the South region's anchovy prices also yields a large price increase attributable to the individual fishing quota regime.

[3] See Huang and Smith (2010) for a structural estimation of common pool extraction efficiency in the U.S. shrimp industry in which policy experiments different from individual fishing quotas are discussed.

I thus delve into more granular data to explore the mechanisms behind such a large increase in prices occurring without an aggregate decrease in anchovy supply. Specifically I find that, after the quota regime is enacted, *daily* anchovy markets change in two important ways. First, the duration of a fishing season becomes significantly longer during the quota regime, suggesting that ships spread their fishing effort over longer periods with less pressure for the resource. Second, the daily quantity of anchovy extracted on a given day across the industry is significantly lower during the quota regime, as would be expected following the extended duration of the fishing season. The direct implication of these two features is a contraction of daily anchovy supply leading to a large increase in equilibrium anchovy prices. Interestingly, the steepness of the demand curve for anchovy revealed by the large price increase can also be explained by the regulatory framework already in place, which prohibits multi-species fishing for fishmeal, essentially maintaining anchovy as the single authorized input for fishmeal processing firms.

Several economic characteristics across geographies on the coastline appear to differentially affect local market prices after the quota regime. Specifically, buyer (i.e., fishmeal plant) concentration, the relative abundance of ships vs. plants, and the vertically organized structure of ships and plants are factors that seem to modify the impact of individual fishing quotas on local market prices. While these factors help suggest a nuanced role of market heterogeneity in price formation, the industrywide reduction in daily supply caused by individual fishing quotas carries the most significant weight in explaining the large increase in prices across markets.

Finally, to draw some welfare implications, the evidence of flat productivity in quantities and substantially higher prices under the quota regime can be viewed in the broader context of other impacts of the reform. Specifically, I find fewer operational infractions, higher product quality, and lower banking delinquency during the quota regime, and view these patterns as consistent with an efficiency-gains explanation. Thus, the overall evidence suggests that pure rent transfers from downstream processing companies to upstream extraction companies do not fully explain the impact of the quota reform on market structure.

This paper provides rare evidence on both the within-firm and industrywide impacts of government-granted property rights over natural resources, a theme with broad ramifications for current research in industrial organization. First, the quota reform studied here allows for the direct analysis of a government's intrusive intervention in firm-level allocations, which contrasts with regulations that also simultaneously start regulating industry-level totals (e.g., cap-and-trade programs for gas emissions). My findings suggest that the firm-level imposition of quotas did not seriously disrupt within-firm productivity in quantities. Second, my analysis of market structure before and after the quota regime goes beyond aggregate supply mechanisms to incorporate the dynamics of daily supply (e.g., Graddy 1995), a dimension often overlooked in research due to lack of granular data. The results suggest that supply-side factors make the analysis of prices particularly relevant in the study of productivity, thus complementing prior work on demand-side heterogeneity (Foster, Haltiwanger, and Syverson 2008).

My findings enhance the understanding of the economic impact of fishing quotas, a fast-growing property rights mechanism that has been touted as crucial for the future of fisheries (Costello, Gaines, and Lynham 2008). There has been much interest in quota systems, but causal evidence is very limited. This paper offers general insight into the mechanisms linking the commons problem, property rights, productivity, and market prices that should be more broadly useful in current policy debates on the strategic management of natural resources.

1 Institutional Background

1.1 Industrial fishing

The marine ecosystem off the Peruvian coast is the world's leading producer of exploitable fish biomass, yielding more than 20 times the tonnage of fishery landings in comparable marine ecosystems (Bakun and Weeks 2008). Anchovy (*engraulis ringens*) is its most abundant species, with over 95% of its catches used for fishmeal. Fishmeal is a flour-like substance used as high-protein feed in livestock production and in aquaculture. The processing of fishmeal yields a by-product, fish oil, which is also used as a protein supplement for livestock and in aquaculture.

The global production of fishmeal is about 6.5 million tons[4] per year, which at 2010 average world prices of $1,646 per ton totals $10.7 billion. Peru is the largest producer of fishmeal with approximately 30% of global production, other producers including Chile, Denmark, and Iceland. Fishmeal market participants interact through international brokers, determining prices and quantities according to a derived demand from downstream industries (e.g., fish farming, poultry) and the supply of both fishmeal and imperfect substitute products (e.g., rapeseed oil, soybean meal). Price variation in these markets is typically weekly. While Peru as a whole plays a significant role on the supply side, this supply is not coordinated across Peruvian firms; moreover, there are several other factors such as rapeseed and soybean price dynamics that set bounds on fishmeal prices. A direct comparison of the prices of anchovy, fishmeal and its substitutes will be performed in more detail in the empirical section below.

The fishmeal sector includes three activities: fish extraction, processing, and fishmeal sales. This paper focuses on anchovy extraction for fishmeal in the population of firms for the period 2004–2010. Until 2008, extraction of anchovy was performed by over 1,100 industrial fishing ships. These ships, called purse seiners,[5] surround a shoal with a net that is then closed at the bottom by tightening a rope. Purse seiners can be classified as steel-made or wood-made, a distinction that is also reflected in regulation because wood ships are much smaller than steel ships. Panel A of Table 1 reports summary statistics on the hold capacity and age of these ships.

Anchovy is the only species allowed by the Peruvian government for fishmeal production. This species typically has two reproductive cycles per year and is distributed in dense surface aggregations, thus being highly accessible to ship operators though not easy to find in the vast (i.e., over 370,000 square miles) area of the sea. Anchovy has a small size (under 4.9 inches of length) and it is exclusively used for an animal feed, fishmeal; these commodity features of the species make it unlikely that fishermen start discarding anchovy, or fishing it more selectively,

[4] A metric ton is equal to one thousand kilograms. One ton of anchovy fits approximately in one cubic meter of ship hold capacity.

[5] Small artisanal boats can also fish anchovy; however, historically these boats have accounted for less than 1% of total catch; I therefore exclude them from the study.

after the enactment of an individual fishing quota regime.

A common time unit of analysis in the industry is the "fishing season," defined as a period authorized by the government in which anchovy can be extracted for fishmeal. Directly related to the anchovy reproductive cycles, the two fishing seasons of each year have no fixed duration, as they end automatically when the total allowable catch, determined by the government at the beginning of the season, is reached. Hereafter, for ease of reading, seasons are numbered with respect to the enactment of the individual fishing quota regime which, as will be detailed later, was announced immediately after the end of Season -1 and started being enforced at the beginning of Season 1. In between these seasons lay Season 0, which followed the same regulation as earlier seasons with the difference that information about ship quota allocations had already been disclosed by the government immediately before Season 0.

Geographically, anchovy fishing operations are classified into two regions of the Peruvian coastline: the North-Center region (i.e., north of parallel 16^{O}S) and the South region (i.e., south of parallel 16^{O}S). About 87% of catches during the sample period were obtained from the North-Center region. Figure 1 displays a representation of the 20 largest anchovy ports on a stylized North to South coastline. The relative geographic isolation of the South ports and their proximity to Chile, a neighboring country with a maritime dispute with Peru, are some of the conditions that may have made fishing in the South different from fishing in the North, but the anchovy species is biologically the same across these regions. With the exception of the counterfactual analyses that exploit the South region data, this study focuses exclusively on anchovy fishing in the North-Center region, which extends over 1,000 miles of the coastline.

1.2 Regulatory environment before the enactment of individual fishing quotas

The extraction of anchovy, a common resource, is regulated by the Ministry of Production. Originally, under the regulatory regime lasting through 2008, three regulatory instruments were in place: (i) a cap on total extractive capacity, equivalent to an entry restriction applied to both ships and plants and to a prohibition to expand an asset's licensed capacity; (ii) a total allowable catch of anchovy for each season, which depended on the predicted abundance of anchovy; and (iii) extraction and transformation bans and moratoriums to protect the growth of juvenile fish between seasons or within a given season. None of these instruments, described briefly below, amounted to individual fishing quotas.

The cap on firm entry and asset expansion took the form of government licenses throughout the sample period and stayed essentially fixed around 200,000 cubic meters of ships' total hold capacity before 2008. A license to participate in anchovy fishing was attached to each ship and was specified for a fixed hold capacity, that is, the physical hold capacity of a ship in cubic meters, but it was also transferable across ships at owners' will. For example, a ship owner with one license for 500 cubic meters could replace its 500-cubic-meter ship with a new ship only if it also had a maximum hold of 500 cubic meters and if it effectively replaced the old ship permanently. All ships with a license were allowed to fish as much anchovy as they wanted, up to completing the total allowable catch.

The levels of total allowable catch varied from season to season, yet the general procedure to determine this industrywide anchovy cap was maintained throughout all periods studied. At the beginning of a fishing season, IMARPE, the government-sponsored scientific board, determined the total allowable catch of anchovy for the season, which was subsequently enforced by officers of the Ministry of Production in their supervision of commercial firms. Figure 2 shows the time series of total allowed catch, with comparable values both before and after the reform.

Finally, regulation also mandated the cease of fishing operations after each season ended (i.e., when the total allowable catch was reached) as well as shorter-term moratoriums prompted by unusual levels of juvenile anchovy within a given season.

Fishing operations under this early regulatory environment showed features of a competitive racing regime. According to interviews with industry participants, a primary concern of firms under the racing regime was to find fish and deliver it to plants as fast as possible, knowing that each trip not made because of delays would likely be a loss of anchovy to faster firms. In other words, without individual quotas over fish, speed provided a competitive advantage to some firms. Given this environment, ships raced to extract as much fish as possible before the global quota was reached, and efficient firms obtained a higher share of the total allowed catch than their share of installed capacity. Panel B of Table 1 provides summary statistics on the operation of ships during the racing regime.

Importantly, firms seldom considered exit or ship closure during the racing regime. Because the license to fish was attached to the extant stock of active ships for their full hold capacity, it was in the best interest of firms to fish with all their ships regardless of their productivity.

1.3 The enactment of individual fishing quotas

The Decree Law 1084 of 6 June 2008 modified the existing Fishing Law of Peru by introducing an individual ship quota regime, while it also maintained much of the existing regulatory framework in place. This Decree Law was followed by a regulatory code (*Decreto Supremo 021-2008-PRODUCE*), made public on 12 December 2008, which provided the specific details for its application. Under the new regulatory environment, which would become enforced in April 2009, each active ship as of June 2008 would be allowed to fish a catch share of a season's total allowed catch. A fishing season of transition from November 2008 to December 2008 (i.e., Season 0) was scheduled, allowing it to maintain the same rules of the old regime.

It is important to consider whether knowledge about the upcoming quota regime might have influenced firms' production efforts. Although precise estimates of the duration of the lead-up period before June 2008 in which the quota regime was discussed are not available, this period can be seen as clearly shorter than the output period of 1 January 2004 through 31 December 2007 that formed the basis for quota allocations. Firms plausibly could not influence their past.

The goals of the new regime explicitly stated in the June 2008 law were: (i) the elimination of an exacerbated race for fish observed in the past; (ii) the improvement of environmental management of anchovy through reduced fishing pressure; (iii) the provision of adequate conditions for enhanced technology, investment, and value-added economic activity to prepare for a Free Trade Agreement with the United States, which effectively was signed soon after; and (iv) the reallocation of workers from the excess-capacity industry (fishing for fishmeal) into other activities related or unrelated to fishing.

Key Features of the Individual Fishing Quota Reform

- *Nature of the individual fishing quotas.*- As in the old regime, only the fishing license provided rights to conduct fishing operations; the individual fishing quota, allocated for free to all firms with a license in the industry, only determined the maximum quantity for the exercise of that right.

- *Calculation.*- Individual ship quotas were determined by the government using a non-linear formula made public only in June 2008 and not before. This formula, which differed for steel and wood ships, was based on the annual catches of each ship between 2004 and 2007, the annual volume extracted across the industry, each ship's hold capacity, and the total hold capacity of the industry. The values calculated by the government were posted on the Ministry's website (www.produce.gob.pe) immediately after the regulatory code was published. The exact inputs and allocation formula were also observable.

- *Transferability.*- Once an individual fishing quota in percentage terms of the total allowable catch was determined and assigned to a ship, it was inherently linked to the license of that ship. This quota could be transferred to other ships, but not while the original ship for the quota was still in operation. The law did not prohibit the sale of ships in order to consolidate quotas. After each season, the unused portion of a ship's quota could not be carried over to the next season.

- *Ship selection.*- Ship owners deciding not to use all their ships had to notify the Ministry before the beginning of a season, stating which ships would be used. The new regime did not oblige ships to exit; this was left to the discretionary decision of each firm.

1.4 Data sources and sample

There are two main data sources employed in the analysis. First, the Ministry of Production's Fishing System Database provides information on regulation, assets, operations, and extraction quantities in the country.[6] The Ministry receives daily quantity reports on each landing from each of the 1,105 ships in the country, but does not collect detailed price information. The Ministry also maintains a registry of all active and inactive ships and plants, information that I use in addition to external industry sources to establish their corporate affiliation.[7] IMARPE, the government-sponsored scientific institute, provided detailed biological information. Overall, the data sources help characterize the fishing industry at an unusual level of precision.

A second data source draws from the confidential production input records and market transactions of a large firm that owned both a fleet of ships and a geographically diversified set of fishmeal plants on the coastline. Importantly, this firm not only sourced its anchovy internally from its own upstream ships but also acquired it from hundreds of third-party ships, thus providing detailed anchovy price information for the analysis. Concerned that the pricing conditions faced by this firm when sourcing anchovy may be systematically different from average conditions, I collected two additional price series, one from a different large fishing firm and another from a small extraction firm operating a small number of ships. Though these two additional price series were coarse and limited in coverage, in untabulated tests I found that they correlated above 96% with the granular price data from the first firm, suggesting that the price analysis introduced in this paper is not systematically biased by the data source employed. I supplement the anchovy market data repository with information on global fishmeal prices and other commodities from the International Fishmeal Organization in London and information on

[6]Although part of this database is available online, I accessed the system through a research agreement that includes a confidentiality clause.

[7]To understand the corporate ownership structure of the industry I supplemented the official records by meeting with fishing industry experts and asked them to code the ownership of assets and firms based on their personal experience. This was required because the Ministry does not record the controlling interest, but rather the identity of the corporate entity holding an asset at any point in time. Then, I corroborated and expanded this information with internet searches of local newspapers to detail all mergers and acquisitions in the industry in the period covered. Again, this was required because the Ministry does not keep track of ownership changes at the level of shareholders.

bank loans from the Superintendency of Banks.

The sample for this study is the population of industrial firms fishing for fishmeal in the period 1 January 2004 to 30 July 2010. This period is particularly appropriate for the empirical design for two reasons. First, the government-determined formula for individual fishing quota allocations was based on the operation of firms from 2004 to 2007 and I am able to observe the same information as policy makers and firms before the shock to study of quotas and productivity. Second, the period 20 April 2009 to 30 July 2010 includes three complete anchovy fishing seasons subsequent to the enactment of the quota regime; it is thus possible to draw inference by observing detailed data on a relatively long post-reform period.

Table 1 details summary statistics at the ship and firm level. Panel A describes the hold capacity and age of each asset and the composition of assets of all firms. Panel B details operational characteristics of all ships and firms.

2 Industry Trends Around the Quota Reform

The introduction of individual fishing quotas represents a specific regulatory change within an existent regulatory framework in place. Before analyzing the causal impact of quotas on within-firm productivity and market prices, I describe aggregate trends over time.

First, it is illustrative to see the aggregate evolution of total output per unit of capital and prices. Panel A of Figure 2 displays an aggregate ratio defined as the total allowed catch of anchovy divided by total installed extraction capacity, which is equal to the sum of hold capacity of distinct ships active in a season. As expected in an industry environment with a capital stock fixed by regulation, this aggregate ratio essentially co-moves with total allowed catch. After the enactment of the quota regime, beginning in Season 1, output per unit of capital significantly increases, indicating that the industry overall is extracting more fish with a smaller number of ships. While the main analysis of the paper in subsequent sections focuses on within-firm production microdata and employs controls for the intensity of capital use, this glance at industry capital utilization is a useful starting point.

In addition, Panel B of Figure 2 details the evolution of anchovy prices per season. The price of a ton of anchovy is expressed in U.S. dollars and is defined as the quantity-weighted average price using data on over 20,000 transactions of a large processing firm. Considering that anchovy is a single species with uniform characteristics, a quantity-weighted price series seems adequate for the analysis.[8] In the coarsest level of aggregation at the season level, displayed in Figure 2, prices dramatically increase after the enactment of quotas, reaching levels above 300% with respect to the season of transition. However, the total allowed catch levels during the quota regime are not unusually lower than those before the quota regime, suggesting that mechanisms other than aggregate supply explain the enormous price increase.

Figure 3 describes the evolution of key operational dimensions of industrial fishing. Panel I shows that ship exit at the end of Season 0 dramatically increases, and Panel II indicates that the industry installed capacity suddenly contracts when the quota regime is enacted. Consistent with the goal of reducing installed capacity and overall fishing pressure through the introduction of individual fishing quotas, these patterns suggest relatively quick results of the policy reform.

A different margin of adjustment for total fishing pressure is the intensity with which ships conduct fishing operations. Panel III of Figure 3 shows that the total number of trips increases sharply with the introduction of quotas, but it reverts to pre-reform levels after three seasons. Similarly, as shown in Panel IV of Figure 3, the average number of trips per ship increases sharply at the onset of quotas yet reverts to lower levels three seasons into the new regime. Taken together, the installed capacity and asset utilization patterns of the first four panels suggest that a productivity framework must directly consider these factors when explaining fish output before and after the introduction of individual quotas.

While the average number of trips conducted by each ship is informative of a margin of adjustment, it is also important to analyze within-season timing decisions. Two ships may

[8] Qualitative evidence suggests that anchovy could be heterogeneous in its freshness when arriving to port (e.g., `http://www.pcfisu.org/marine-programme/case-studies/peruvian-anchovy-fishery`, accessed May 21, 2013), but no systematic information is available on these product characteristics and their impact on prices.

significantly increase the number of trips they make, but one ship may cluster its trips more tightly towards the beginning of the season while the other may spread its fishing effort over a longer season. Panel V of Figure 3 reveals that the weighted length of fishing seasons (calculated as the dot product of industry daily catches in tons and ordinal day numbers within a season divided by the season's industry catches) significantly increases after quotas are enacted. With a longer season duration and an unchanged total allowable catch in the quota regime, it is therefore natural that the daily quantity of anchovy supplied to plants on a given day is smaller. Panel VI of Figure 3 confirms that this is the case: a drastic contraction of daily anchovy supply is observed after quotas are enacted.

Operational changes in fish extraction can affect the behavior of firms in a manner consistent with efficiency gains. Although within-firm data beyond production inputs and outputs are generally unavailable, two data series may capture firm behavior directly affected by the reduction of racing behavior: fishing infractions and banking delinquencies. Panel VII of Figure 3 shows that the total number of fishing infractions across the industry essentially comes down to zero after quotas are enacted; regardless of whether infractions are reduced because of exit of misbehaving ships or improvement of remaining ships, the pattern is consistent with broad gains for the industry correlated with the introduction of quotas. Panel VIII of Figure 3 shows that the incidence of bank delinquencies of fishing firms (based on a sample that pools all firms dealing with fish either as an input or output) continues to decrease during the quota regime.

The focus of this paper is on the within-asset, within-firm productivity impact of quotas. As quotas determine the maximum amount of output (as a percentage of the total allowable catch) that ships and firms can exploit, it is illustrative to see the relationship of fishing output and quota allocations in a single plot. Figure 4 shows the initially allocated quotas and subsequent output using one observation per ship (Panel A) or one observation per firm (Panel B). The population plotted includes all ships and all firms that received quotas by the law, regardless of whether they later operated all their quota allocation, or some of their quota allocation, or none of their quota allocation after the regime started. As expected, the relationship between allocations and total output is positive. Also, consistent with Panel I of Figure 3, quotas are transferred away from exiting ships, thus creating a mass of points a zero in Panel A of Figure 4. By contrast, when considering reallocations within and across firms in Panel B of Figure 4, the relationship becomes intuitively closer to a 1-to-1 mapping of output and quota allocations while also showing the path pursued by large firms that acquired ships (quotas) from others.

Overall, these patterns suggest that the enactment of individual fishing quotas precedes sweeping changes in the industry. Some of these dimensions will be directly built into the empirical framework below, and some will serve as supplementary evidence for the interpretation of the results. More broadly, this characterization of the industry suggests that the quota reform was a shock to the supply-side of the anchovy fishing sector. The goal of this study is to assess whether and why this regime affected within-firm productivity and market prices.

3 Productivity Before and After the Quota Reform

Prior research on the performance implications of individual fishing quotas has focused on comparisons before and after the advent of a quota regime (Grafton, Squires, and Fox 2000, Brandt 2007). My empirical design, detailed in Section 4 below, exploits unique features of the setting to estimate the causal impact of a quota regime on within-firm productivity and prices. Before introducing the empirical design, I present an initial set of productivity regressions and graphs with before-and-after comparisons as a baseline to assess the benefits of the quasi-experimental approach employed in this study.

Table 2 reports descriptive productivity regressions. The dependent variable is the logarithm of anchovy catches in tons; the input factors are ship capacity in cubic meters multiplied by the number of trips made by the ship in each season, also in logs.

Two features of the productivity estimation employed throughout the paper should be noted. First, the fixed component of capital, i.e., ship hold capacity, will be subsumed in the ship fixed effects. The productivity regression should thus be interpreted as within-ship increases in input for a fixed amount of installed capacity (i.e., ship hold) and a varying level of utilization of that equipment captured by the number of trips made by the ship during the season. Capital equipment in this industry is quite old (with a ship age average of 23.6 years), suggesting that the economic value of a ship is the license attached to it for anchovy extraction.

Second, the lay system of pay in fishing — the practice of paying captains and crews exclusively based on total catch rather than on a combination of fixed and variable wages (McConnell and Price 2006) — applies to the Peruvian fishing context. Although I do not observe labor use or labor costs for each firm in the industry, the lay system assuages concerns about a missing factor in productivity estimation here. I therefore assume Leontief separation for the labor component of the production function.[9] For robustness, Section 4.3 describes an alternative design using granular data from a multi-ship firm in which more detailed production inputs including labor are observable.

In this before-and-after description, the explanatory variables of interest are dummies for each season after the enactment of quotas, that is, Season 1, Season 2, and Season 3. (The omitted variable is Season -10). To gauge the statistical significance of productivity differences after the new regime, coefficients are compared using Wald tests.

The before-and-after comparison at the ship-season level in Table 2 suggests that ships only slowly become more productive in the quota regime. Specifically, the first column reports a pooled OLS model without ship fixed effects indicating that only in Season 3 does the enactment of quotas lead to higher productivity with respect to Season -1. The second model includes ship fixed effects, thus focusing on productivity changes within each asset; because a ship's hold capacity is time invariant by regulation, ship fixed effects absorb the partial coefficient on ship capacity, thus leaving as the key production input the number of trips. The results displayed in the second column of Table 2 suggest that the quota regime takes three seasons to generate higher productivity; by contrast, Season 1 and Season 2 have lower point estimates than Season -1. Similarly, the third model of Table 2 restricts the estimation sample to only those ships that

[9]See Wolff et al. (2013) for a rare case of direct observability of fishermen identities in productivity estimation.

were present in the industry before the quota regime and continued operating during all three seasons of the new regime; after this restriction of the sample abstracting away from changes in the extensive margin, the pattern of slow productivity improvement appears to be unchanged.

To supplement the productivity comparison for each ship over different seasons, the right-hand-side columns of Table 2 report regressions at the firm-season level following analogous specifications to those of the of ship-season regressions. Overall, the more aggregate models yield essentially the same results as before: only after three seasons of the quota regime do firms seem to enjoy higher productivity.

While illustrative, before-and-after comparisons can only be seen as limited description, as they are subject to the criticism that confounding factors may be driving the observed patterns, even if the quota natural experiment is genuinely exogenous. Thus, below I introduce two approaches that exploit the differential aspects of the quota regime for identification.

4 Empirical Specification

Two classes of regression models help uncover the causal impact of individual fishing quotas on productivity. These models are based on two alternative counterfactuals. First, I employ a difference-in-differences approach exploiting data on the South region of the Peruvian coastline as a control sample. Due to pre-existing legal differences, the Peruvian government mandated a separate quota system to be started with a delay in the South with respect to the North-Center, the focus of my analysis. Second, I make use of the exact fishing quota allocations for each ship to absorb the more general shock at the level of each ship. I describe each approach next.

4.1 Difference-in-differences estimation

The quota reform of interest here was mandated by the government for all firms and ships operating in the North-Center region of Peru. The enforcement of the individual fishing quota system for the North-Center started on 20 April 2009 and it was subsequently followed by the enactment of a parallel quota system in the South region (i.e., latitudes south of 16^{O} S) but only after 7 July 2009, thus leaving a simultaneous period of differing regulatory regimes in the same country amounting to nearly a full fishing season (labeled here as Season 1). Hence, the first specification uses data aggregated at the ship-season-region level to estimate:

$$y_{i,t,g} = \alpha + \beta_0 * k_{i,t,g} + \beta_1 * Post_t * North_g + \theta * North_g + \delta_i + \gamma_t + \epsilon_{i,t,g} \quad (1)$$

where $y_{i,t,g}$ is the log of fish output for ship i during season t operating in region g, defined as either the North-Center or the South; $k_{i,t,g}$ is the number of trips made by the ship in the region during that season multiplied by the ship's hold capacity in cubic meters, all expressed in logarithms; $North_g$ is a dummy for the North-Center region; δ_i is a set of ship fixed effects; γ_t are season dummies; and $\epsilon_{i,t,g}$ is the error term.

An innovation of this paper is to incorporate into the difference-in-differences approach of equation (1) a region-varying, time-varying control variable for resource abundance, an important control in the fisheries productivity literature (Squires 1992, Walden et al. 2012).[10]

The coefficient of interest is β_1, the interaction term for $North_g$ and a dummy for the post-period, defined as the period between the beginning of the enforcement of quotas in the North-Center and the beginning of the enforcement of quotas in the South. Standard errors are conservatively clustered at the level of each fishing season.

4.2 Variation in quota allocations

I observe the exact allocation of quotas made by the government as a share of the total allowable catch at the outset of the new system. Focusing exclusively on the North-Center region, I

[10] An even more detailed design would additionally control for the state of the environment (see Squires, Reid, and Jeon (2008) for a design centered on an innovation different from individual vessel quotas). Yet in my context that approach may not be fully warranted, as there is no consistent evidence that quota regimes significantly affect the biomass and ecological environment (Chu 2009, Essington 2010).

transform the industry-level shock into asset-specific shocks:

$$y_{i,t} = \alpha + \beta * k_{i,t} + \eta * Quota_{i,t} + \delta_i + \gamma_t + \mu_{i,t} \tag{2}$$

where $y_{i,t}$ is the output in logged tons of anchovy caught during season t by ship i; $k_{i,t}$ is the logged product of the ship's hold capacity and the number of trips carried out during the season; $Quota_{i,t}$ is the quota allocation for the ship in percentage points, and is equal to zero for periods before the enforcement of the new system; δ_i are ship fixed effects; γ_t are season fixed effects; and $\mu_{i,t}$ is the error term. Specification (2) is analogous to models analyzing the effect of subsidies on individual organizations (Goolsbee and Guryan 2006), though in my context quota allocations are more permanent. The coefficient of interest is η, which captures the direct impact of quota allocations on productivity after controlling for season dummies and ship fixed effects. Standard errors are clustered at the level of each fishing season.

Additionally, because I observe exactly the past ship-specific production figures as well as the formula that the government used when allocating quotas to ships, I am able to exploit this information in additional models explaining whether the surprising (i.e., residual of a non-linear model) component of the quota has any impact on future productivity. These additional models are useful to assuage concerns that the allocations granted by the government might be endogenously related to an unobserved driver of past extraction volumes (e.g., Reguant and Ellerman 2008, Fowlie and Perloff 2013).

Both equation (1) and equation (2) provide causal estimates of the impact of a quota regime on productivity at the level of each ship, yet compared with the difference-in-differences approach in (1), specification (2) is preferred for several reasons. First, by focusing the analysis on the North-Center region, more post-regulation periods can be studied (i.e., Season 2 and Season 3), thus gauging the evolution of productivity after the dramatic shift in industry conditions brought about by the reform. Second, by exploiting detailed information on the exact allocation of quotas to each ship, the causal impact of quotas can be more sharply distinguished from concurrent events potentially driving changes in productivity across geographic regions through channels other than the allocation of quotas over anchovy. The counterfactual of a ship's quota allocation in equation (2) is the same ship without an allocation before the quota regime as well as other ships' different quota allocations during the quota regime. Third, the study of individual ship allocations enables a more nuanced characterization of the reallocation of such quotas within and across firm boundaries, as ship quotas were meant to be fungible across ships in order to encourage industrywide reallocation.

4.3 More granular specification of productivity

I supplement the productivity specification (2) with a more granular analysis of data on a single firm's production factors in anchovy fishing operations. Specifically, for each trip of each ship of this firm, I observe information on trip duration, the number of crew members on board, and the usage of materials. With this information, I check whether the main results of the paper change when estimating a more refined measure of total factor productivity for this firm's ships.

5 The Impact of Quotas on Productivity

5.1 Difference-in-differences models using South region as a counterfactual

Table 3 displays the results of the difference-in-differences design specified in equation (1). Observations for the tests are at the ship-season-region (left-hand side) or at the firm-season-region level (right-hand side). Because the South remained without quotas for only one season after the enactment of quotas in the North-Center, the sample for the tests includes only data on the seasons running through Season 1, thus excluding information on Season 2 or Season 3. All models include season dummies and region dummies, and standard errors are clustered at the season level. The coefficient of interest is on the interaction of *North* and *Season 1*.

The productivity analysis at the ship-season level in Table 3 reveals that the quota regime did not lead to an increase in productivity in the short run (i.e., one season). The first model includes ship fixed effects to focus on within-asset productivity changes due to the quota regime. These ship fixed effects absorb ship hold capacity, which is time invariant for each ship by regulation, thus employing the number of trips as the varying production input. The results displayed in the first column of Table 3 suggest that the quota regime has a negative and significant impact equivalent to a 24% reduction in productivity.

This within-asset difference-in-differences estimation can be applied to more narrowly defined samples. Specifically, it is useful to restrict the sample to only ships present both before and after the quota regime was enacted, to avoid concerns about a selection bias introduced by changes in the extensive margin of what ships are participating in the new regime. (As detailed earlier, the regime was mandatory for all ships). The second model of Table 3 displays these results, indicating that the impact of quotas is still negative, though slightly smaller than in the unrestricted sample; thus, the obvious changes in the extensive margin prompted by the quota regime do not have much bearing on the within-ship outcomes. The third model further restricts the sample for the difference-in-differences analysis to those North-Center ships that actively fished in the South region before the quota system was enacted in the North-Center. Importantly, measuring the impact of quotas in this narrow sample is not subject to the criticism that ships may be drastically changing their geographic preferences following new regulation. The third column of Table 3 suggests that the impact of quotas is negative and statistically significant. Finally, it is also useful to relax the assumption that the number of trips (input) factor of the productivity models enters the regression exogenously. A two-stage least squares (2SLS) design instruments for the number of trips in the first stage using three environmental factors: stock abundance, average superficial sea temperature, and average anomaly of superficial sea temperatures. The results of this 2SLS approach are displayed in the fourth column of Table 3, indicating that even after considering the potential endogeneity of the number of trips, the causal impact of the quota regime is not a increase of productivity in quantities. Thus, all the within-ship analysis using the South as a counterfactual points to the absence of positive effects of quotas on productivity.

Table 3 also presents difference-in-differences models at the firm-season-region level. The advantage of this firm (vs. ship) aggregation is that it captures the net effect of the quota regime after factoring in within-firm reallocation. Because firms can reallocate their original ship quota allocations across their fleets, this analysis offers a complementary perspective not available in prior work (e.g., Walden et al. 2012). Importantly, to the extent that firms may flexibly vary their number of ships over time through acquisitions, selloffs, or closure, the key production input considered in the productivity regressions is the logged firm-level sum of ship capacity and number of trips, which remains informative even after the inclusion of firm fixed effects.

The within-firm difference-in-differences models on the right-hand side columns of Table 3 confirm that the enactment of quotas does not lead to productivity gains. Specifically, firm fixed effects models in the unrestricted sample (fifth column) as well as in the restricted sample of continuing firms (sixth column) and continuing firms that had already fished in the South (seventh column) all show negative or insignificant values on the coefficient capturing the causal impact of the quota regime on productivity. Moreover, a 2SLS design instrumenting for the number of trips multiplied by the fishing capacity stock of each firm using three environmental factors (i.e., stock abundance, average superficial sea temperature, and average anomaly of superficial sea temperatures) is shown in the eight column of Table 3, indicating no positive impact of the quota regime on productivity in quantities. These results suggest that the net short-term impact of the new regime is not beneficial on average, even after allowing for within-firm reallocation efforts under the new industry structure.

5.1.1 Probing the South region as an appropriate counterfactual

For identification, equation (1) exploits both the exogenous advent of the quota regime in the North-Center compared with the South as well as a refined region-varying, time-varying control variable for resource abundance. Yet this empirical strategy relies on the assumption that the South region is a proper counterfactual to analyze the quota regime. Two arguments help probe this assumption further. First, the marine biology literature has largely viewed anchovy as biologically identical across the two regions studied (Xu et al. 2013), thus offering a natural counterfactual that does not depend on my coding assumptions. Second, further refinements in the difference-in-differences design displayed in Table 3, untabulated here for brevity, indicate that when focusing on the ports closest to the dividing line between North-Center and South, or by conducting a coarsened exact matching of ports by fish volume caught prior to the quota regime, the results remain essentially the same. Note that I do not assume that North-Center and South were identical in fishing behavior before the shock. In fact, the North-Center and South regions had different pre-existing regulatory frameworks. Thus, the concern that the quota treatment in the North-Center might be confounded with an omitted variable arising exactly at the moment of the quota law is assuaged by the pre-existing administrative differences.

5.2 Exploiting variation in quota allocations across ships

The empirical results thus far have focused on changes across subsequent regimes to draw inference about the impact of individual quotas on productivity. I now make use of an additional feature of the quota reform, the availability of information on the exact quota allocation to each ship, to assess the absorbed impact of quotas on productivity, as detailed in equation (2). Because quota allocations vary across assets even if they show very similar physical characteristics, specification (2) is particularly useful to identify the causal influence of quotas on productivity.

How much did quota allocations impact within-asset and within-firm productivity? Table 4 reports productivity regressions both at the ship-season level and at the firm-season level using all seasons before and after the enactment of quotas. The explanatory variable of interest is the allocation of quotas expressed in percentage points. In the within-ship analysis, this variable is defined as the exact quota received by the ship when the new regime was announced. By contrast, in the within-firm analysis, the quota is defined as the sum of the focal firm's ship quotas including all ships that were operating when the new regime was announced, regardless of whether some of those ships were subsequently closed after the new regime started.

The results at the ship-season level suggest that quota allocations did not improve productivity. The first model of Table 4 shows a statistically insignificant coefficient on ship quota, contrary to the presumption that a ship with larger allocation would benefit more from the new quota regime in terms of productivity.

The second model of Table 4 introduces a decomposition of the quota allocation into its predicted and unpredicted portions. To see this test in context, a concern in estimating the direct effect of quota allocations on future productivity is that the government's allocation of quotas is based on the past output of the ship, and it may thus be endogenously linked to an unobserved driver of past productivity. I observe exactly the non-linear formula used by the government, equivalent to a weighted average of the maximum yearly share of industry catches taken over four years and the last year's share of industry hold capacity. In an untabulated ship-level regression, I predict each ship's quota allocation using as an explanatory variable the ship's productivity residual for the whole period considered by the government in calculating quota allocations as well as all the elements considered by the government's formula and quadratic terms for the kinks generated by the max function of yearly catch shares employed by the government. Based on this untabulated regression, I create the predicted component of the quota (i.e., the regression fit) and an unpredicted component (i.e., its residuals) for the period after the quota regime is enacted, and zero for the periods before the quota regime. The unpredicted component of the quota should therefore affect future outcomes merely due to the government rule rather than through the underlying factors driving the predicted component of the quota. As seen in the second model of Table 4, however, neither component has a statistically significant influence on productivity during the quota regime.

The third column of Table 4 interacts ship quota with season dummies to capture the marginal effect of quota allocations as the new regime progresses; the coefficients on these interaction variables are negative and significant, suggesting that the influence of quota allocations on productivity does not improve over time.

Table 4 also displays results at the more aggregate level of firm-season observations.

Because firms can reallocate their original ship quota allocations across their fleets, the firmwide level of analysis is particularly helpful. Interestingly, the results in the fourth, fifth, and sixth columns of Table 4 essentially mirror those obtained in the ship-season level analysis, suggesting that no net productivity benefit of quota allocations is obtained on average.

Should the impact of quotas be expected to be linear, as assumed in equation (2)? When relaxing that assumption through various untabulated polynomial specifications, the results of Table 4 are maintained. Moreover, a fractional polynomial fit of productivity on quota allocations, omitted here for brevity, shows a flat relationship of slope zero.

Note that the models of Table 4 employ the original allocations of quotas, as they were exogenously announced in the quota law. In untabulated models that instead use the post-transfer quotas at the ship level or at the firm level, the results remain essentially the same.

The lack of positive productivity implications of quotas reported in Table 4 appears to be robust across different measurement windows, levels of aggregation, and specifications. There are also several reasons why the definition of productivity employed in equation (1) is adequate in this context. First, productivity is defined throughout the paper using physical quantities after controlling for key production inputs captured flexibly by capital utilization, time effects, and asset-level time-invariant unobservables, thus offering some empirical advantages (e.g., Foster, Haltiwanger, and Syverson 2008, Syverson 2011). Second, the technical definition of output per input employed in the analysis is also in harmony with the definition of efficiency used by the government and industry participants, as noted in my fieldwork.

For robustness, in untabulated robustness models using proprietary information on a large fishing firm's detailed production inputs (e.g., labor, time of usage of each ship on the sea, materials) I replicated the estimation of Table 4, finding no impact of quota allocations on a more refined measure of total factor productivity. To illustrate, Figure 5 plots productivity residuals employed in the main models as well as alternative definitions of productivity in the case of the large firm. The pattern of insignificant improvements after the quota regime appears robust across measures.

5.3 Heterogeneous impact of quotas across firms

Table 5 extends the productivity analysis of Table 4 to assess which firms may benefit the most from quota allocations. Specifically, firm-season level models are expanded by introducing different dimensions of firms' operations as interactions capturing different firm characteristics that may enhance the impact of quotas on productivity. The analysis is conducted at the firm-season level here in order to allow for cross-asset, within-firm reallocation of quotas.[11]

The first model of Table 5 uses the number of ships as an interaction term for the firm-level quota. (All interaction variables are lagged one season and standardized to have a mean of zero and standard deviation of one). The coefficient on this interaction term is statistically insignificant. Larger firms do not appear to benefit more from quota allocations.

A different channel potentially affecting the productivity consequences of quotas is the dispersion of past productivity across the assets of a firm. Possessing a collection of ships of heterogenous efficiency, a firm receiving quotas on future catches could conceive better deployment and reallocation plans. However, the second model of Table 5 does not find empirical support for this channel; the coefficient on the interaction of firm quota and the variance of productivity for the firms' ships is statistically insignificant.

The dispersion of firm operations may alternatively be due to structural or contractual linkages reflected in their geographic extraction routines. At two ends of the spectrum can be found one firm with narrowly focused fishing operations delivering its fish to a single port location and another firm with broad deployment practices covering a wide area of the coastline when delivering its fish. Thus, interacting the variance of latitudes during a fishing season for each firm with its newly granted fishing quota would help assess whether reallocation leads to higher benefits for the more dispersed firms. The third model of Table 5 confirms that this is the case, indicating that a 0.6% increment in productivity is due to quota allocations for firms with a one standard deviation higher geographic dispersion.

[11] Alternatively, I also aggregated observations at the firm-regime level, thus pooling all periods before and after the quotas into two observations for each firm, finding largely the same results as the ones reported here.

An alternative channel for within-firm reallocation is the disciplining of operators' behavior. In a racing regime without quotas, it may have been difficult for firm owners and managers to credibly enforce orderly practices among their ship operators, as the incentives to extract fish may obviate the benefits of enforcing more discipline. By contrast, the advent of quota allocations gives firms more power to select from their pool of assets and operators those more aligned with orderly behavior in the long term. The fourth model of Table 5 interacts firm quota with the number of ship infractions attributable to operators' behavior. The positive and significant coefficient is equivalent to a 1.3% increase in productivity for firms with a one standard deviation higher number of fishing infractions, suggesting that disciplining is an important channel for the impact of quota allocations.

Is higher productivity a desirable outcome for all firms? Though the core performance outcome is productivity in fish extraction operations, it is also possible that some firms see a tradeoff between higher extraction productivity and higher anchovy quality. Specifically, to preserve the catch at lower temperatures, ships require refrigeration technologies that reduce their hold capacity if activated. Institutional evidence suggests that fish stored at lower temperatures after being caught commands a higher price and yields higher fishmeal quality. The fifth column of Table 5 interacts firm quota with the fraction of the firm's ships that are equipped with refrigeration technology. Firms with one standard deviation higher refrigeration capabilities achieve 0.8% lower productivity, suggesting that some firms may relinquish quantity gains during the quota regime if their assets are technologically capable to maintain fish in better conditions.

Overall, the channels analyzed in Table 5 provide a nuanced depiction of how and why quotas may lead to productivity gains through within-firm reallocation strategies. Because some of these mechanisms may be working concurrently, the last column of Table 5 introduces all interactions in the same model, indicating that firms with lower productivity dispersion and higher geographic dispersion are the ones that benefit the most from the enactment of quotas.

6 The Impact of Quotas on Market Prices

Anchovy is the single fish species authorized by government for fishmeal production. The introduction of individual fishing quotas may thus have had an impact on anchovy market prices even if within-firm productivity in quantities did not significantly improve. In this section, I exploit granular price information on different geographic markets along the coastline to assess the influence of quotas on market prices.

6.1 Graphical evidence

I start by plotting daily prices and daily quantities in Figure 6. (The periods in between seasons have no data points, as there are no market transactions.) These series reveal a striking pattern of significantly lower daily supply and significantly higher daily prices coinciding with the enactment of individual fishing quotas. It is therefore the functioning of the daily supply of anchovy that offers the most promising area to investigate the impact of quotas.

Figure 7 shows additional pricing information for the period of interest. Specifically, I combine the time series of prices in each geographic market with the cross-section of prices across geographic markets to gauge market structure changes after quotas are enacted. Hereafter, a market is defined as a set of fishing ports geographically proximate to one another and geographically distant from ports of other markets. (See Figure 1 for a stylized version of the coastline). I use the exact location of each fishing port and geographic coastline characteristics to assign ports to different markets.

The quota regime may enact lower price dispersion across markets if the price required by sellers becomes less sensitive to geographic location due to the elimination of racing. Panels I and II of Figure 7 display the daily cross-market variation of prices for different seasons around the quota reform. Panel I shows that the daily cross-sectional standard deviation of prices across geographic markets moves towards zero after the quota regime is in place. Panel II deflates the standard deviation series using the mean daily price, thus obtaining the daily coefficient of variation. After the quota regime is enacted, this measure of cross-sectional variation of prices is strikingly lower than before. These patterns suggest a dramatic shift in firm behavior that makes prices much less sensitive to idiosyncratic differences across geographies.

But can the price increase be attributed to a supply shift without considering potential demand factors? So far the analysis of prices has been limited to local anchovy markets. Panels III and IV of Figure 7 broaden the analysis to consider the monthly anchovy price time series, after controlling for the global price of fishmeal (Panel III) or, alternatively, after controlling for the global price of rapeseed oil and soybean prices, the two closest substitutes for fishmeal in global markets (Panel IV). Even after controlling for these demand factors, the price of anchovy appears to be significantly higher during the quota regime. The time evolution of price residuals displayed in these plots confirms that something other than a shift in global demand for animal feed is explaining the observed spike in anchovy prices during the quota regime.

6.2 Difference-in-differences analysis of prices using the South region as a counterfactual

The before-and-after evidence on anchovy prices presented in Section 6.1 can be supplemented with a difference-in-differences analysis exploiting the South region as a counterfactual. The caveat for this analysis is that, differently from within-firm productivity, market price equalization across regions may influence anchovy prices in the South even if the South still operates under a racing regime during the first season of the North-Center quota regime. Nonetheless, this supplementary regression-based evidence can be useful to assuage the concern that an event other than the quota reform may be driving anchovy prices.

Table 6 displays the results of the difference-in-differences design. Observations are at the market-day level. As in prior analyses, prices are quantity-weighted using price and quantity information on granular transactions provided by a single firm based on all its ports, which are classified into different markets for the analysis. The markets where this firm operates represent more than 50% of the historical market volume of anchovy across the industry and account for more than 50% of the distinct geographic markets of the industry, with the exact number of markets employed here omitted for confidentiality. The coefficient of interest is on the interaction of North-Center region, that is, a dummy for all markets north of parallel 16^{O}S, and a dummy for Season 1, that is, the first season under the quota regime in the North-Center region.

The results in Table 6 suggest that the quota regime significantly increases anchovy market prices during the first season of the regime under various specifications. The first model of Table 6 does not include market fixed effects or season dummies; the coefficient of interest is positive and significant, indicating a 52.5% increase in prices due to the anchovy quota in the North-Center. The second model introduces season dummies and yields a positive and significant coefficient equivalent to a 17% increase in anchovy prices due to the quota. The third model of Table 6 further extends the specification to include market fixed effects, which subsume the North-Center region dummy, and yields a positive and significant difference-in-differences estimate of 19% in price increases attributable to the anchovy quota regime.

6.3 Regression analysis of prices in North-Center local markets

Having found a robust causal impact of the quota regime on anchovy market prices, in Table 7 I explore whether some features of a local market's structure influence anchovy prices differently before and after the quota regime. For this analysis, I restrict the sample to markets in the North-Center region. All models include market fixed effects to control for time-invariant unobservable factors particular to each market. Additionally, all models include year-week dummies to account for more general factors affecting the price of anchovy across all geographies, as the main focus of the analysis is on understanding whether the shock matters differently for prices depending on different market structures, which is a question about the interaction of market characteristics and time after the shock. The coefficients of interest are those capturing a market characteristic interacted with *post*, a dummy equal to one for Seasons 1, 2, and 3, that is, the periods after quotas were enacted.[12] I focus exclusively on markets for which the price data were available.

A first market feature observed with daily frequency is anchovy buyers' concentration index. A buyer, in the case of this sector, is a firm that operates at least one plant. If on a given day there are few buyers making most of the fish purchases in a market, then this market is expected to show different prices from those of a market with atomized buyers. As shown in the first column of Table 7, the enactment of fish extraction quotas has a statistically meaningful effect on concentrated markets, leading to a higher price of anchovy than in the absence of quotas. At the average level of Herfindahl concentration, the quota regime implies a differential increase of 1.2% in prices with respect to the same market structure before quotas. This result is consistent with a reduced bargaining power of buyers with respect to sellers enacted by the quota regime.

A second market characteristic that may be informative is the relative abundance of sellers with respect to buyers on the market. This is modeled as the ratio of the number of distinct ships divided by the number of distinct plants transacting on a given day. A market with a high number of ships for each available plant is expected to face more queuing and related operational concerns than a market with relatively few ships for each given plant. The second model of Table 7 indicates that quotas impact prices positively in markets with higher ratios of ships per plant. At the average level of the ratio of ships per plant, the advent of quotas indicates a increase in prices of 2% with respect to the same level of ships per plant before the new regime. The results also corroborate the interpretation of the first model that bargaining power is shifted from buyers to sellers after quotas are mandated.

Finally, differential pricing may also be observed in markets more heavily populated by firms participating at both ends of the anchovy market through vertical integration. A market with higher prevalence of vertical transfers within firm boundaries (i.e., a seller transferring anchovy to a downstream plant affiliated through ownership) could be viewed as either leaning towards foreclosure or leaning towards efficiency gains (e.g., Hortaçsu and Syverson 2007). Plants (i.e.,

[12] A descriptive analysis fitting regressions using only the pre-quota periods to see how market features correlate with prices would be less informative, as those pre-quota reduced-form regressions would lack exogenous variation to assess how market structure affects prices.

buyers) should be expected to foreclose ships (i.e., sellers) through their advantageous control of docking stations and the timing pressure of ships to maximize the weight of the catch, which naturally diminishes if wait time is prolonged. The third model of Table 7 uses the share of a market's total transactions on a given day that occurs within firm boundaries as an interaction with the post-quota dummy, finding a negative and significant coefficient on this interaction term. At the average level of market share represented by vertical transfers on a market, the quota regime decrease prices in 2.6%. This pattern suggests that foreclosure of ships' landings through plants' vertical integration was not a force driving prices downwards before the quota regime, consistent with evidence from other domains (e.g., Hortaçsu and Syverson 2007). Conversely, an efficiency explanation for vertical structure during the quota regime (i.e., when prices are high) is plausible. In contrast to buyer concentration and seller-buyer numerical imbalance, vertical structure seems to counteract the sharp price increase through market substitution once bargaining power has significantly shifted to the upstream segment of the industry.

These results on how the shock affects prices differently across different market structures should be taken as suggestive. The massive nature of the quota regime shifting prices may have thus altered market structure in a way that could raise valid concerns about the endogeneity of market proxies in Table 7. To go one step further, I instrumented for buyers' Herfindahl using data from the local bank credit market and creating a bank clients' Herfindahl measure as an instrument, finding in untabulated results that the relation between market structure, anchovy prices, and the shock remained similar after accounting for such kind of endogeneity.

While each of the market characteristics analyzed above offers a nuanced perspective to how anchovy markets operate, it is possible that all market structure dimensions operate concurrently rather than in isolation. The last column of Table 7 places all these market features in the same model, finding essentially the same results. The enactment of quotas reduces the market power effects of buyer concentration, assuages queuing concerns, and leads vertically integrated firms to seek efficiencies and substitute for the market. Even though all these patterns are statistically significant in all tests, their economic importance in explaining price differentials across markets appears small compared with the very large increase of prices measured in Figure 6 over the time series. Note that market fixed effects and year-week fixed effects control for many alternative factors, helping focus only on the moderating effect of the quota regime on how market characteristics correlate with price differentials.

7 Discussion

The evidence reported in Sections 5 and 6 suggests that (i) individual fishing quotas do not improve extraction firms' productivity in quantities, and (ii) individual fishing quotas significantly increase anchovy market prices. At first glance, these results would appear to be consistent with a rent transfer mechanism. Specifically, the reduction of racing behavior typical of the commons problem leads to a contraction in daily supply that significantly increases anchovy prices, thus benefitting extraction firms through higher revenues for the same output and same operational efficiency as before the regime. Before inferring that extraction firms benefitted purely from rent transfers, it may be worthwhile to incorporate additional information on the impact of the quota regime and to review the antitrust environment surrounding the reform.

The data for this complementary analysis are less granular than in the main regression analysis. Contrasting with the precision of information on quantities and prices, there is little visibility of other important dimensions of operations and usage of anchovy. Nonetheless, this supplementary evidence may still be useful to interpret the results.

First, Panel VII of Figure 3 shows a decrease in fishing infractions during the quota regime, suggesting that the industry become less irregular in its operations. Extraction companies thus start following norms more dutifully, freeing up regulatory resources and benefitting the marine environment through a less disruptive activity. This suppression of a negative trait of fish extraction could be viewed as an incorporation of social costs into the private profit-maximizing function of extraction firms after the quota regime is enacted, a desirable outcome of the new regime that is not fully captured in quantities and prices.

Second, Panel VIII of Figure 3 displays a trend towards lower banking delinquency of firms in the broadly defined fishing sector. The data are aggregated at the level of all firms in the fishing sector, not only extraction firms, thus giving a broad characterization of all the fishing sector's debt repayment behavior. The sustained path of lower delinquency suggest a more orderly planning of cash flows, possibly due to less racing behavior, better fishing season planning, and an overall improvement in the management of the natural resource.

Third, Figure 8 shows an increase in the share of fishmeal output that is of premium quality. Note that the quality of fishmeal is precisely determined according to industry standards in the global market. As shown in Figure 8, there is an appreciable increase in the share of fishmeal of premium quality, a shift that is not purely explained by the global prices of premium fishmeal vs. standard fishmeal also plotted in Figure 8. Absent exact data on the quality conditions of fresh anchovy during each fishing trip, the aggregate pattern of higher quality fishmeal suggests that the quality of anchovy delivered to plants significantly improved.

Finally, a search of the antitrust authority's filings for the years 2008–2010 yielded no single complaint in relation to the fishing industry in general, nor anchovy prices after the quota regime in particular. Anecdotal evidence from fieldwork also suggests that anchovy operations did not raise concerns among antitrust authorities around the time of the quota reform.

Overall, this supplementary evidence helps paint a consistent picture of an efficiency-gains logic. The causal evidence of flat within-firm productivity and substantially higher prices could then be interpreted as a positive outcome of a radical reform in the industry through a reduction in excess supply and more orderly operations. Fewer operational infractions, higher product quality, and lower banking delinquency observed during the quota regime are patterns consistent with an efficiency-gains explanation. At the very least, the evidence suggests that pure rent transfers from downstream processing companies to upstream extraction companies are not the only explanation for the impact of quotas on market structure.

8 Conclusion

In this paper, I analyze a reform that introduced individual fishing quotas for Peruvian anchovy to assess the causal impact of production quotas on productivity and prices. Quotas have long occupied economists broadly interested in market structure and firm behavior, but there has been little connection between ongoing research in industrial organization and a large body of work analyzing various property rights instruments in the economics of fisheries. Unique features of the fishing data allow me to create counterfactuals to study the causal impact of the quota reform in a reduced-form fashion. I find that quotas do not increase within-asset or within-firm productivity in quantities. Instead, a 200% increase in anchovy prices benefits extraction firms through higher revenues, consistent with more orderly industry operations reducing excess supply and an increase in bargaining power of extraction firms with respect to fish-processing firms enacted by the quota regime. Several market characteristics across geographies differentially affect market prices after the quota regime. Patterns of fewer operational infractions, higher product quality, and a lower banking delinquency observed during the quota regime supplement the productivity and pricing evidence to suggest the existence of efficiency gains rather than purely rent transfers.

Individual quotas have been viewed as one of the few available mechanisms to prevent the collapse of fisheries around the world. The findings of this paper suggest that quota regimes enact radical industry changes that are a primary concern to industrial economists, policy makers, businesses, and society in general. A deeper understanding of the market impact of environmental policies is likely to have substantial welfare implications.

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Figure 1: Anchovy Landing Ports on the Peruvian Coastline

This figure presents a stylized map of the Peruvian coastline where each dot is one of the top-20 anchovy ports. The length of each horizontal bar represents average annual anchovy landings (in weight) at each port for periods before the quota regime was announced; top-10 ports are marked with a darker bar. The coastline is 1,500 miles long, all in the Southern Pacific.

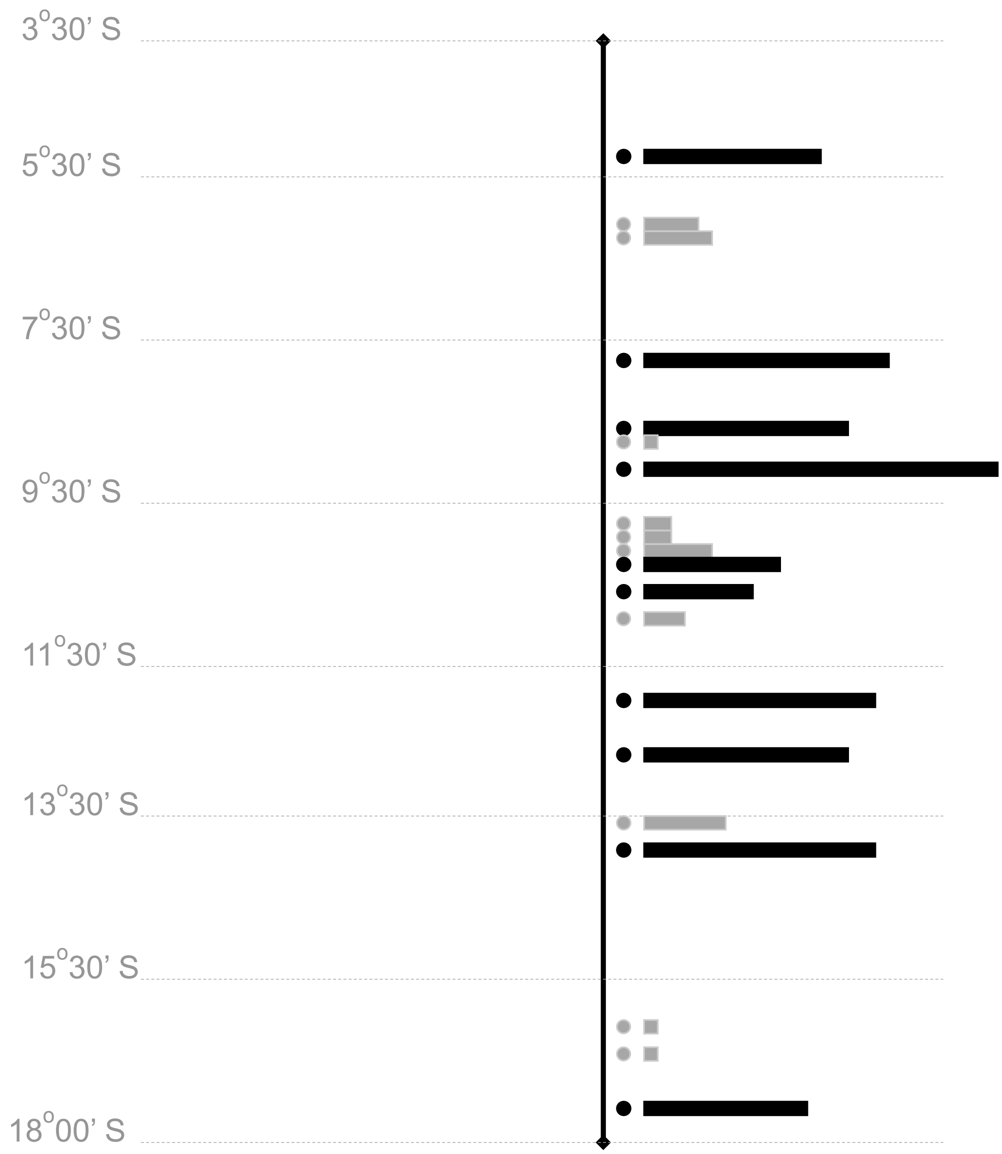
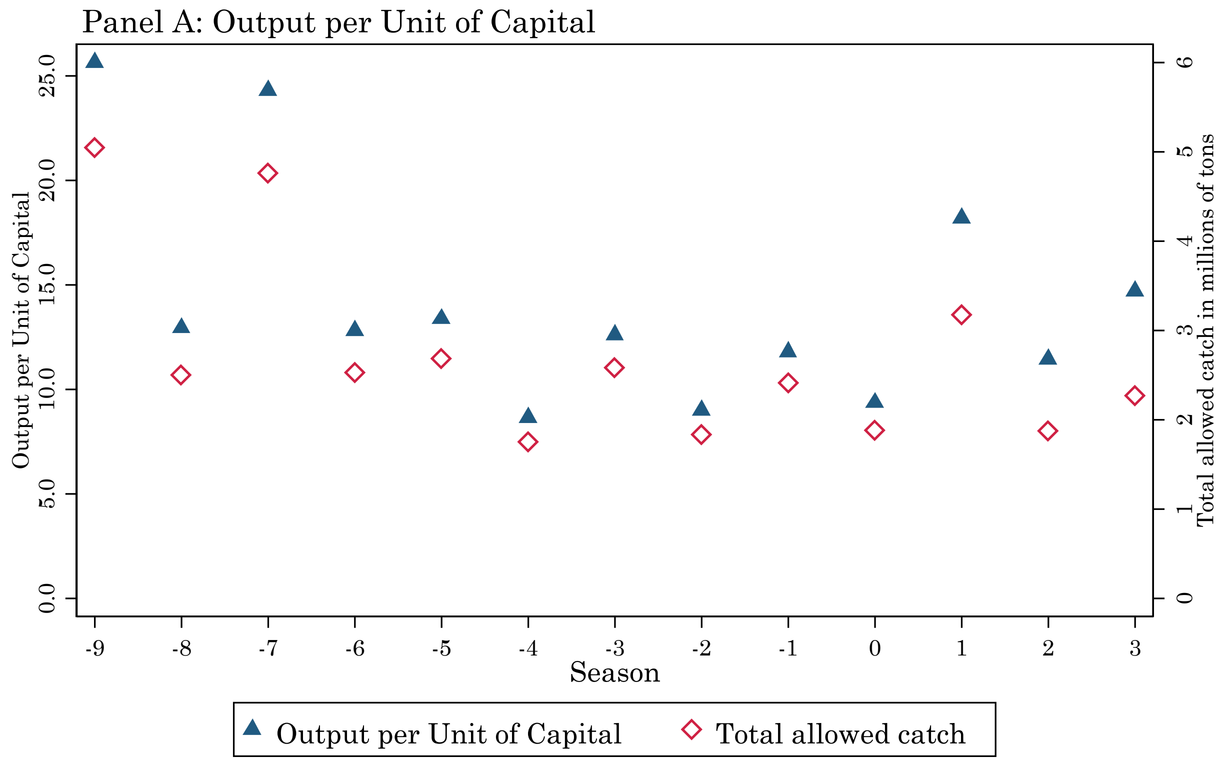


Figure 2: Total Allowed Catch, Output per Unit of Capital, and Prices

The quota regime was announced after the end of season −1 and was enforced starting at season 1. Output per unit of capital is defined as the total allowed catch divided by the hold capacity of all ships that had at least one active trip during each season. Anchovy prices are quantity-weighted.



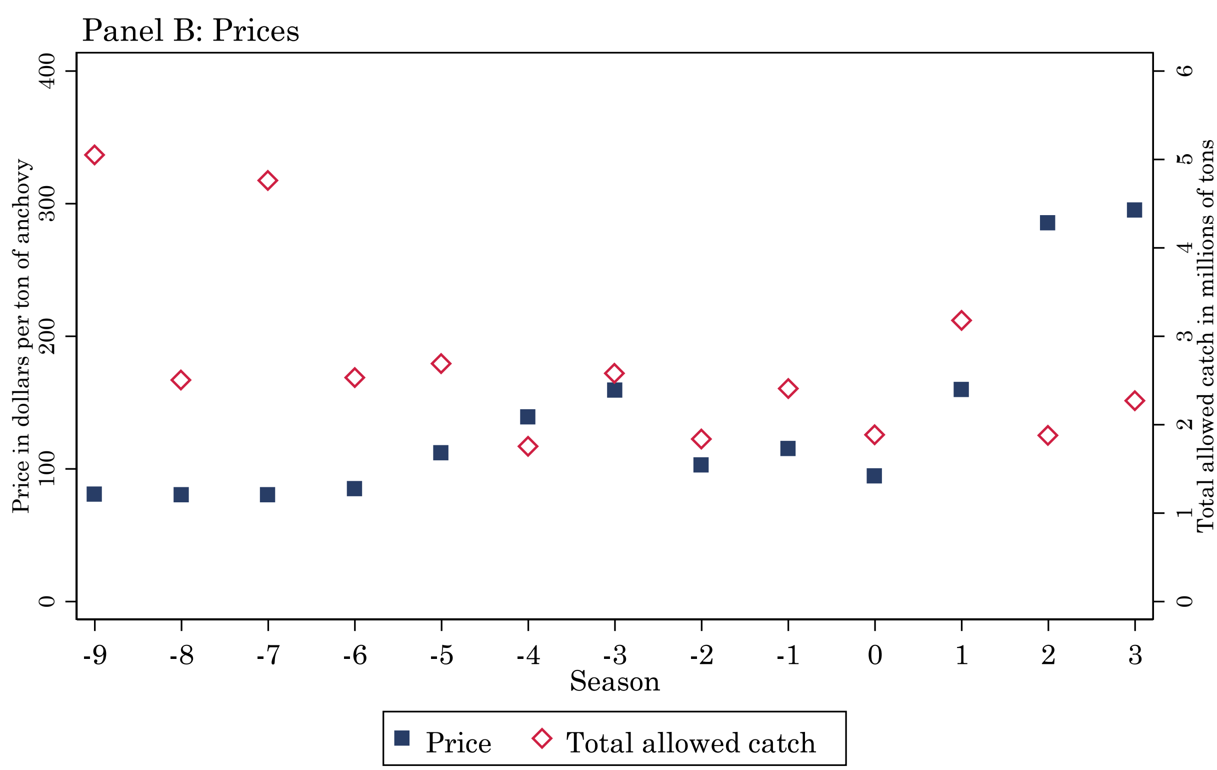


Figure 3: Industry Trends Before and After Quotas

Each panel displays information at the season level for all firms in the industry. The quota regime was announced after the end of season −1 and was enforced starting at season 1.

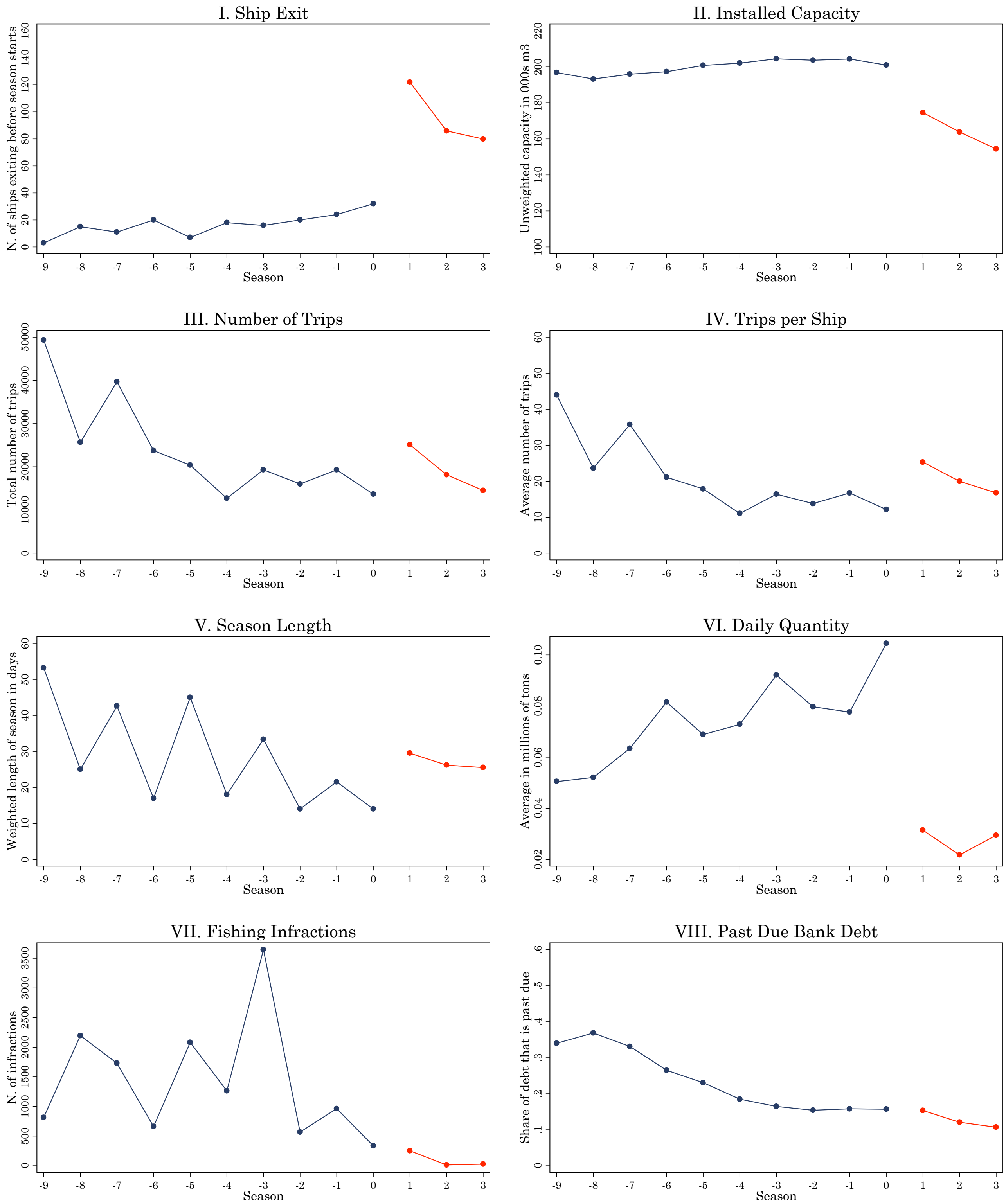
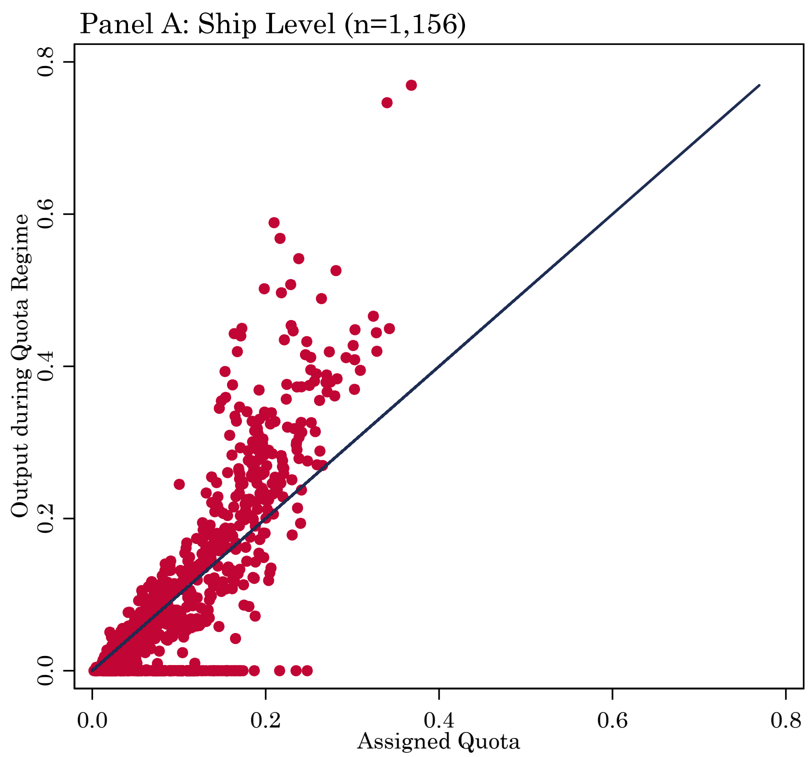


Figure 4: Allocated Quotas and Future Output at the Ship Level and Firm Level

This figure shows the allocated quotas (vertical axis) and future output (horizontal axis). The units are in percentage points of the total allowable catch (e.g., 0.6 = 0.6% of total allowable catch). Observations are all ships and their firms that received quotas by the quota law, regardless of whether they later on operated all quota allocations, some of their quota allocation, or none of their quota allocation after the regime started. The relation between allocation and output is displayed at the ship level (Panel I) and, by aggregation, at the firm level (Panel II). A 45-degree solid line is included in each plot.



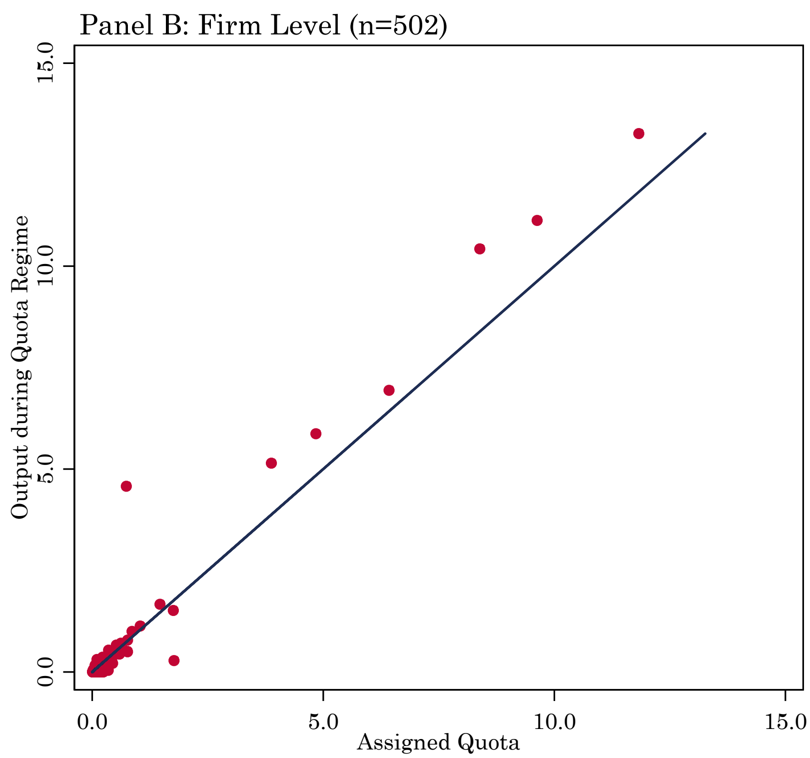


Figure 5: Productivity and Costs at a Large Firm

This figure displays productivity residuals of all ships of a large firm using three alternative ship fixed-effects productivity models. The baseline model uses number of trips as the single input, as employed throughout the paper. The alternative models use either the exact duration of each trip or the gallons of fuel consumed during trips. All regressions are of logarithms of physical quantities on logarithms of input quantities, estimated at the ship-season level; the residuals of these regressions are averaged at the season level in the plot.

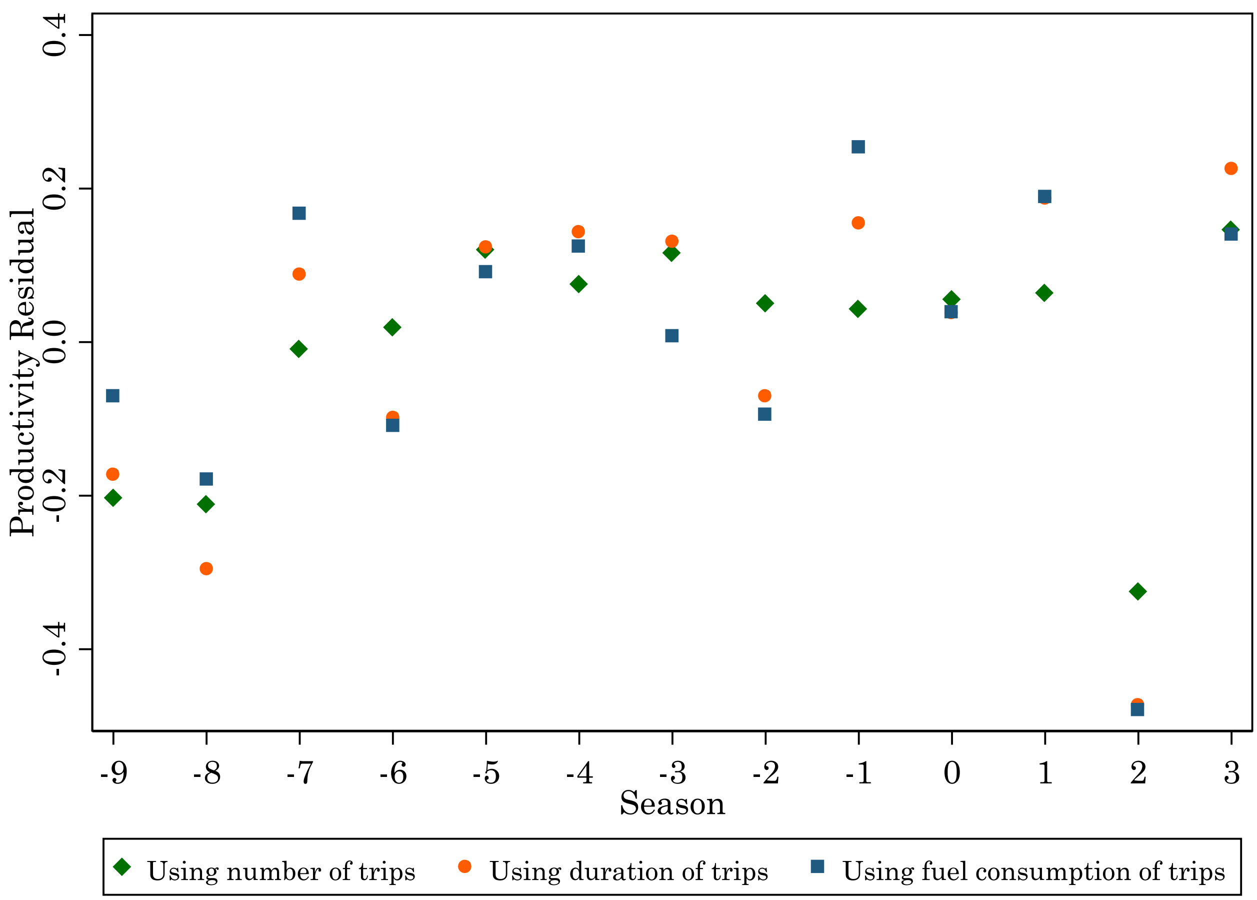


Figure 6: Daily Quantity Supplied and Daily Prices

Observations are at the daily level, pooling information across all anchovy supply transactions and all markets on the coastline. Prices per ton of anchovy are quantity-weighted and expressed in U.S. dollars. For clarity, only three seasons before the season of transition, the season of transition, and the three seasons of the quota regime are displayed. The vertical line represents 20 April 2009, that is, the beginning of enforcement of the quota regime.

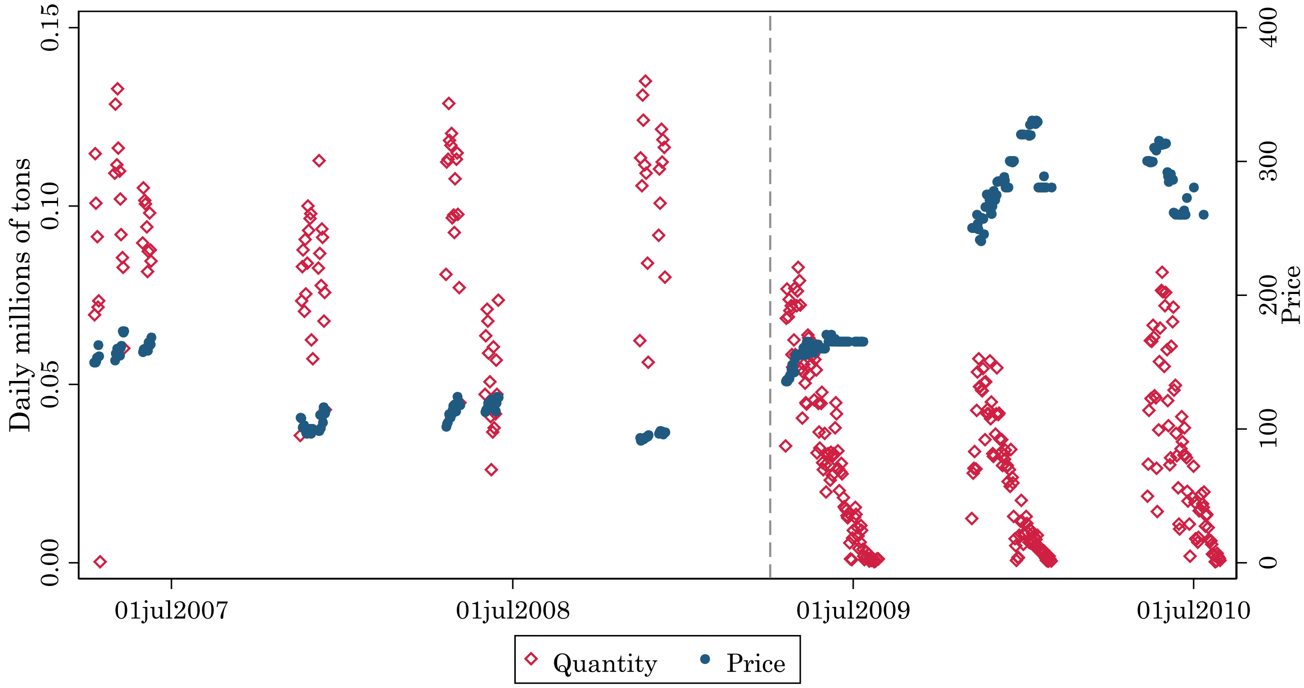


Figure 7: Price Variation across Markets and Comparison with Global Commodity Prices

All plots are based on quantity-weighted prices for a ton of anchovy in U.S. dollars. Plots I and II are based on price data across different markets, with each market defined as a set of geographically distinct ports. Plot III displays residuals of anchovy price regressed on global fishmeal price. Plot IV displays residuals of anchovy price regressed on global rapeseed oil price and global soybean meal price. All vertical lines represent 20 April 2009, that is, the beginning of enforcement of the quota regime.

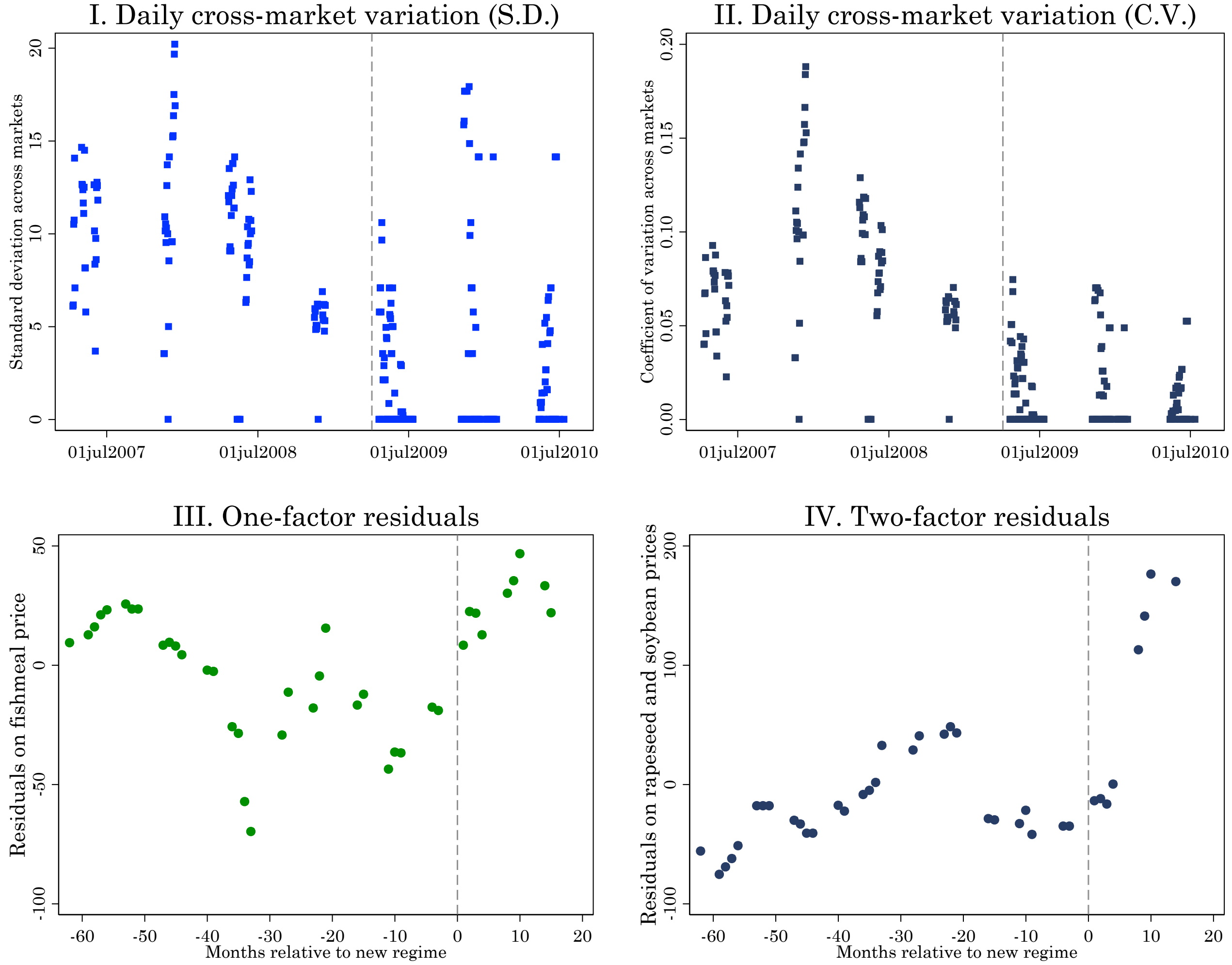


Figure 8: Quantity and Prices of Premium Quality Fishmeal

This figure employs information on the prices and quantities of premium quality fishmeal vs. standard quality fishmeal. The price series are obtained from the global commodity market. The quantity series represent the total production of fishmeal of each type in the country.

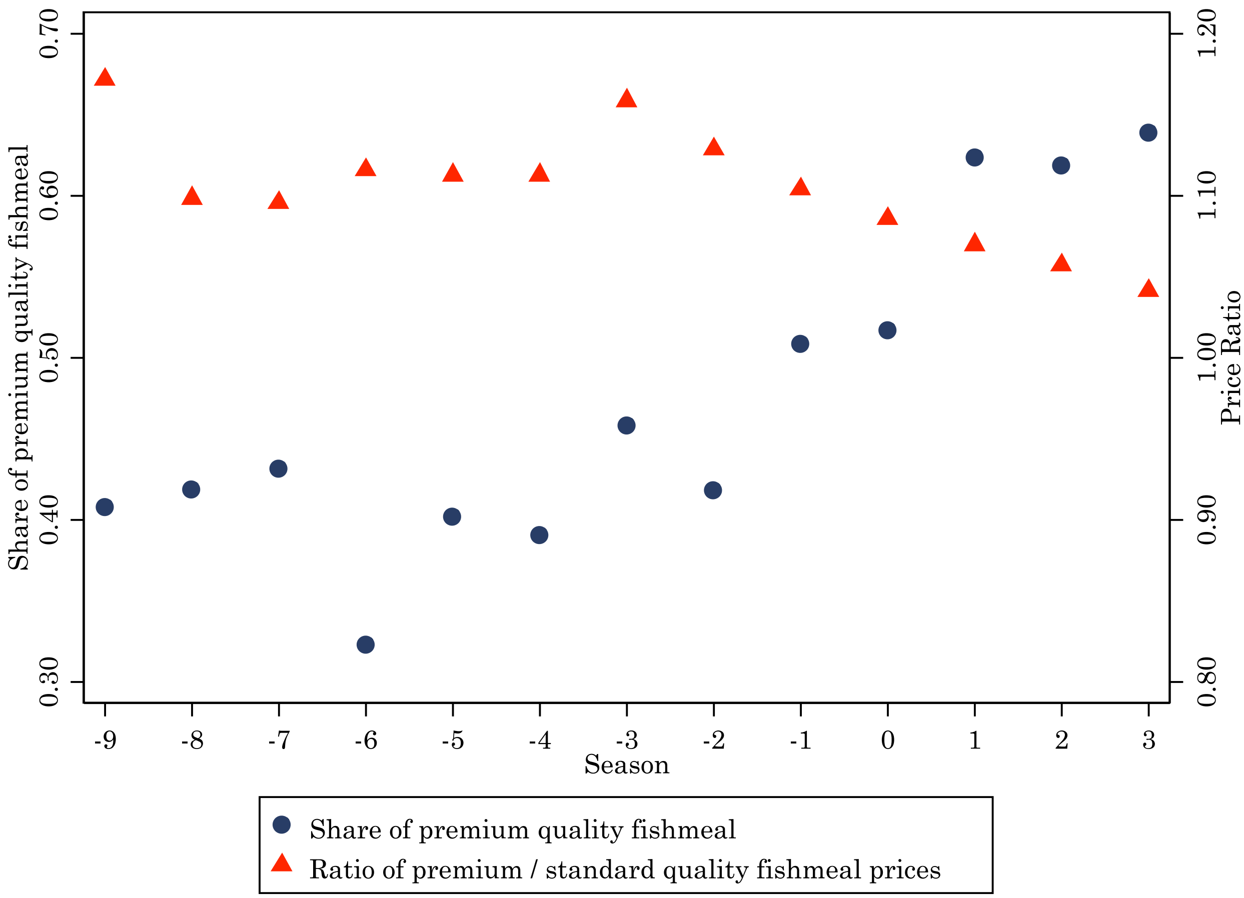


Table 1: Summary Statistics

The data cover the period 1 January 2004 to 30 July 2010 for all industrial fishing firms extracting fish (anchovy) for fishmeal in the Peruvian sea north of parallel 16^{o}S, i.e., the North-Center region. Panel A describes ship characteristics for all ships that received individual fishing quotas from the government. A cubic meter of ship hold is approximately equivalent to one ton (=1,000 kilograms) of anchovy. Panel B describes fishing operations for all seasons in the sample period for the ships and firms that remain throughout all three seasons after the enactment of the quota regime. Output is expressed in tons of anchovy. Ship quota is the percentage of the global industry quota for each season assigned by the government in 2008 for all periods going forward; for example, a ship assigned a 0.37% of the global industry quota has a ship quota of 0.37; before the first season of the quota regime (starting on 20 April 2009), the ship quota is zero for all ships. Panel B also reports firm-season variables based on the operations of the ships of each firm. Productivity dispersion is the variance of the productivity residual of a firm's ships for each season using a ship-season regression with ship fixed effects and season fixed effects. The geographical dispersion of a firm's ships is modeled as the variance of latitudes of landing ports. The number of infractions is based on the government's complete records of ship infractions during extraction operations. The refrigeration capabilities of a firm's ships is the fraction of ships of the firm that are equipped with refrigeration capabilities regardless of whether they are turned on or off. These firm-season characteristics are further standardized to have a mean of zero and a standard deviation of one in the empirical analysis, and they are always introduced lagged by one season with respect to the productivity inputs and outputs in the estimation.

Panel A: Ship and Firm Description

Variable	N. obs.	Mean	Median	Std.dev.	Min.	Max.
I. Ship level (n=1,105)						
Hold capacity in cubic meters						
All ships	1105	178.8	107.6	152.8	32.8	868.3
Steel ships	530	306.4	296.1	128.9	62.2	868.3
Wood ships	575	61.3	52.1	26.6	32.8	154.5
Ship age in years as of 2008	1105	23.6	19.0	12.9	2.0	54.0
II. Firm level (n=514)						
Number of ships per firm						
Steel-only firms	151	3.5	1.0	9.3	1.0	72.0
Wood-only firms	360	1.6	1.0	1.0	1.0	7.0
Both steel and wood firms	3	2.3	2.0	0.6	2.0	3.0
Hold capacity in cubic meters						
Steel-only firms	151	1087.2	252.0	3365.8	89.2	25945.1
Wood-only firms	360	101.1	80.3	75.6	32.9	448.7
Both steel and wood firms	3	358.5	345.7	117.4	248.0	481.7

Panel B: Fishing Operations

Variable	Mean	Median	Std.dev.	Min.	Max.
I. Ship-season level (n=10,379)					
Output (in 000 tons)	2.43	1.13	3.04	0.00	29.30
Number of trips	20.21	17.00	12.12	1.00	82.00
Ship quota	0.02	0.00	0.05	0.00	0.37
II. Firm-season level (n=4,269)					
Output (in 000 tons)	5.66	1.22	24.33	0.00	414.96
Firm capacity $\times$ n.trips (in 000 tons)	9.23	1.96	39.49	0.04	616.48
Firm quota	0.06	0.00	0.53	0.00	11.83
Number of ships	2.51	1.00	4.64	0.00	72.00
Productivity dispersion	0.02	0.00	0.06	0.00	1.51
Geographical dispersion	0.85	0.31	1.37	0.00	13.02
Number of infractions	2.43	0.00	9.08	0.00	202.00
Refrigeration capabilities	0.04	0.00	0.17	0.00	1.00

Table 2: Productivity Before and After Quotas

This table displays productivity regressions with season fixed effects. Observations are at the ship-season level (left-hand side columns) or at the firm-season level (right-hand side columns). Because the capacity of each ship is fixed by design, the key input factor is the number of trips in models introducing ship fixed effects. The excluded dummy is for Season -10. Standard errors are robust and clustered by season.

	Dependent Variable: **Log (Output)**					
	Ship-season analysis			Firm-season analysis		
Sample ships and firms:	All	All	Continuing	All	All	Continuing
	(2.1)	(2.2)	(2.3)	(2.4)	(2.5)	(2.6)
Log (ship capacity × n.trips)	0.996***					
	(0.01)					
Log (firm capacity × n.trips)				1.011***	1.077***	1.019***
				(0.01)	(0.04)	(0.03)
Log (n.trips)		1.111***	1.072***			
		(0.06)	(0.06)			
Season −3	0.949***	0.795***	0.792***	0.874***	0.767***	0.749***
	(0.01)	(0.08)	(0.07)	(0.01)	(0.06)	(0.04)
Season −2	0.890***	0.751***	0.743***	0.836***	0.734***	0.701***
	(0.01)	(0.07)	(0.06)	(0.01)	(0.05)	(0.03)
Season −1	0.909***	0.756***	0.746***	0.841***	0.727***	0.708***
	(0.01)	(0.08)	(0.07)	(0.01)	(0.06)	(0.04)
Season of Transition	0.988***	0.862***	0.856***	0.911***	0.815***	0.790***
	(0.01)	(0.06)	(0.06)	(0.01)	(0.05)	(0.03)
Season 1	0.896***	0.686***	0.704***	0.816***	0.681***	0.691***
	(0.02)	(0.10)	(0.10)	(0.01)	(0.07)	(0.05)
Season 2	0.656***	0.474***	0.480***	0.594***	0.476***	0.465***
	(0.02)	(0.09)	(0.09)	(0.01)	(0.06)	(0.04)
Season 3	1.039***	0.881***	0.886***	0.999***	0.901***	0.870***
	(0.01)	(0.08)	(0.07)	(0.01)	(0.05)	(0.03)
Seasons −4 to −9 dummies	Yes	Yes	Yes	Yes	Yes	Yes
Fixed effects	No	Ship	Ship	No	Firm	Firm
Wald test p-value (Season 3 vs. Season −1)	0.00	0.00	0.00	0.00	0.00	0.00
R^2	0.95	0.97	0.97	0.96	0.98	0.98
Sample size	15047	15047	10514	7088	7088	4379
Number of clusters (seasons)	14	14	14	14	14	14

***, **,* significant at the 1%, 5% and 10% level. Standard errors are heteroskedasticity-robust and clustered at the season level.

Table 3: The Impact of Quotas on Productivity Using the South Region as a Counterfactual

This table displays productivity regressions expanding the sample with data analogous to the one described in Table 1 but drawing from the South region (i.e., latitudes south of parallel 16^{o}S) to analyze the differential effect of the quota regime during the only season in which the North-Center had quota enacted by the South did not. Observations are at the ship-season-region level (left-hand side columns) or at the firm-season-region level (right-hand side columns). The coefficient of interest in this difference-in-differences design is on the interaction of a dummy for the North-Center region and a dummy for Season +1. The second and sixth models restrict the sample to ships or firms operating in the industry both at some point before the announcement of the quota regime and also staying through the quota period. The third and seventh models further restrict the sample to ships or firms that had operated in the South region before the quota regime was announced. The fourth and eight models instrument for the number of trips using three environmental factors: stock abundance, average superficial sea temperature, and average anomaly of superficial sea temperatures. Standard errors are robust and clustered by season.

Dependent Variable: **Log (Output)**

	Ship-season-region analysis				Firm-season-region analysis			
Sample ships and firms:	All	Continuing	Continuing & Pre-South	Continuing & Pre-South 2SLS	All	Continuing	Continuing & Pre-South	Continuing & Pre-South 2SLS
	(3.1)	(3.2)	(3.3)	(3.4)	(3.5)	(3.6)	(3.7)	(3.8)
North-Center × Season 1	−0.236**	−0.214**	−0.222**	−0.381	−0.191**	−0.109	−0.109	−0.058
	(0.09)	(0.09)	(0.09)	(0.35)	(0.06)	(0.06)	(0.07)	(0.17)
North-Center	0.847***	0.836***	0.889***	0.563***	0.679***	0.595***	0.639***	0.531***
	(0.21)	(0.21)	(0.21)	(0.12)	(0.15)	(0.12)	(0.12)	(0.09)
Log (capacity × n.trips)					1.122***	1.092***	1.097***	1.073***
					(0.03)	(0.02)	(0.02)	(0.13)
Log (n.trips)	1.180***	1.168***	1.180***	1.346***				
	(0.04)	(0.04)	(0.03)	(0.29)				
$\text{Stock}_{t,g}$	−0.034	−0.031	−0.040		−0.024	−0.011	−0.017	
	(0.03)	(0.03)	(0.03)		(0.02)	(0.02)	(0.02)	
Season dummies	Yes	Yes	Yes		Yes	Yes	Yes	Yes
Fixed effects	Ship	Ship	Ship		Firm	Firm	Firm	Firm
R^2	0.95	0.95	0.94	0.93	0.97	0.97	0.97	0.97
Sample size	16780	13704	8872	8872	8073	6016	3709	3709
Number of clusters (seasons)	12	12	12	12	12	12	12	12

***, **,* significant at the 1%, 5% and 10% level. Standard errors are heteroskedasticity-robust and clustered at the season level.

Table 4: The Impact of Quota Allocations on Productivity

This table displays productivity regressions introducing quota allocations as the explanatory variable of interest. Observations are at the ship-season level (left-hand side columns) or at the firm-season level (right-hand side columns). Only ships and firms that continue throughout all three seasons of the quota regime are included in the sample. In the firm-season analysis, ship quotas are summed at the firm level. Before the first season of the quota regime, ship quotas are zero for all ships. The second and fifth models decompose ship quota or firm quota into two summands: the predicted portion of a ship's quota using the productivity residual from a 2004–2007 (i.e., pre-regime) regression as the explanatory variable in an ancillary regression, and the unpredicted portion of a ship's quota as the difference between the quota allocation and the predicted portion. In the firm-season analysis, the predicted portion of quotas are summed over all ships of a firm, and so is the unpredicted portion of quotas. The third and sixth models interact ship or firm quotas with dummies for the second and third season in the quota regime. Standard errors are robust and clustered by season.

	Dependent Variable: **Log (Output)**					
	Ship-season analysis			Firm-season analysis		
	(4.1)	(4.2)	(4.3)	(4.4)	(4.5)	(4.6)
Ship quota	−0.233		0.202			
	(0.31)		(0.20)			
Firm quota				−0.008		−0.001
				(0.01)		(0.00)
Predicted portion of quota		−0.244			−0.008	
		(0.31)			(0.01)	
Unpredicted portion of quota		0.648			−0.098	
		(1.20)			(0.23)	
Quota × Season 2			−0.326***			−0.002***
			(0.02)			(0.00)
Quota × Season 3			−0.984***			−0.017***
			(0.10)			(0.00)
Log (n.trips)	1.073***	1.072***	1.075***			
	(0.06)	(0.06)	(0.06)			
Log (capacity × n.trips)				1.015***	1.018***	1.018***
				(0.03)	(0.03)	(0.03)
Season dummies	Yes	Yes	Yes	Yes	Yes	Yes
Fixed effects	Ship	Ship	Ship	Firm	Firm	Firm
R^2	0.97	0.97	0.97	0.98	0.98	0.98
Sample size	10379	10379	10379	4269	4269	4269
Number of clusters (seasons)	14	14	14	14	14	14

***, **,* significant at the 1%, 5% and 10% level. Standard errors are heteroskedasticity-robust and clustered at the season level.

Table 5: Differential Effects of Firm-Level Quotas on Productivity

This table analyzes mechanisms explaining the productivity impact of quota allocations. Observations are at the firm-season level. Only ships and firms that continue throughout all three seasons of the quota regime are included in the sample. The specification is as in model 4.4 of Table 4 but interacting firm quotas with other firm-season level variables that also enter each regression directly. These firm-season level variables are all lagged one season and standardized to have a mean value of zero and a standard deviation of one for ease of interpretation. Standard errors are robust and clustered by season.

	Dependent Variable: **Log (Output)**					
	(5.1)	(5.2)	(5.3)	(5.4)	(5.5)	(5.6)
Firm quota	−0.031	−0.004	−0.021	−0.010	0.005	−0.034
	(0.02)	(0.01)	(0.01)	(0.01)	(0.01)	(0.04)
Firm quota × number of ships	0.002					0.002
	(0.00)					(0.00)
Firm quota × productivity dispersion		−0.011				−0.022**
		(0.01)				(0.01)
Firm quota × geographic dispersion			0.006*			0.006*
			(0.00)			(0.00)
Firm quota × number of infractions				0.013**		0.006
				(0.00)		(0.00)
Firm quota × refrigeration capabilities					−0.008***	−0.001
					(0.00)	(0.01)
Number of ships	−0.005					−0.003
	(0.00)					(0.01)
Productivity dispersion		0.000				0.000
		(0.00)				(0.00)
Geographic dispersion			0.002			0.002
			(0.01)			(0.01)
Number of infractions				0.000		0.001
				(0.00)		(0.00)
Refrigeration capabilities					0.028*	0.027
					(0.01)	(0.02)
Log (capacity × n.trips)	1.019***	1.018***	1.018***	1.018***	1.018***	1.018***
	(0.04)	(0.03)	(0.03)	(0.03)	(0.03)	(0.04)
Season dummies	Yes	Yes	Yes	Yes	Yes	Yes
Firm fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
R^2	0.98	0.98	0.98	0.98	0.98	0.98
Sample size	4269	4269	4269	4269	4269	4269
Number of clusters (seasons)	14	14	14	14	14	14

***, **,* significant at the 1%, 5% and 10% level. Standard errors are heteroskedasticity-robust and clustered at the season level.

Table 6: The Impact of Quotas on Market Prices Using the South Region as a Counterfactual

This table analyzes the impact of the quota regime in the North-Center region using the South region as a counterfactual. Observations are at the market-day level. A market is defined as a set of geographically distinct ports. A region (i.e., North-Center vs. South) is a split of the coastline according to regulation. Note that "market" is not the same as "region" as markets are much smaller. There are multiple markets in the sample, with the exact number suppressed for confidentiality, as the daily market price information was provided by a large firm operating in those markets. Only seasons up to Season 1 are included in the sample, as after Season 1, the South region implemented a parallel quota regime.

	Dependent Variable: **Log (Price)**		
	(6.1)	(6.2)	(6.3)
North-Center × Season 1	0.400***	0.194***	0.215***
	(0.10)	(0.03)	(0.03)
North-Center	0.349	−0.141	
	(0.23)	(0.08)	
Stock$_{t,g}$	−0.055*	0.012	0.012
	(0.03)	(0.01)	(0.01)
Market fixed effects	No	No	Yes
Season dummies	No	Yes	Yes
R^2	0.19	0.89	0.89
Sample size	2480	2480	2480
Number of clusters (seasons)	12	12	12

***, **,* significant at the 1%, 5% and 10% level.

Standard errors are heteroskedasticity-robust and clustered at the weekly level.

Table 7: The Impact of Quota Regime on Prices across Market Characteristics

This table analyzes the influence of market characteristics on anchovy prices before and after the quota regime was enacted. Observations are at the market-day level, using data exclusively on the North-Center region. Each market is defined as a set of geographically distinct ports; there are multiple markets in the sample, with the exact number suppressed for confidentiality, as the daily market price information was provided by a large firm operating in those markets. Post is a dummy equal to one for Seasons 1, 2, and 3; this variable is not independently identified given the introduction of year-week dummies, so it only enters the specification as an interaction. Information on the identity and vertical ownership status of all buyers of fish (i.e., plants) is available from the Ministry of Production. Buyers' Herfindahl is the concentration index of firms buying anchovy on a given day on the market. Ships per plant is the ratio of the number of distinct ships unloading anchovy on the market on a given day divided by the number of distinct plants buying anchovy that day on the market. Vertical transfer share is the fraction of all anchovy unloaded on the market that was transferred within firm boundaries (i.e., from a ship to its affiliated plant).

	Dependent Variable: **Log (Price)**			
	(7.1)	(7.2)	(7.3)	(7.4)
Buyers' Herfindahl × post	0.048**			0.059**
	(0.02)			(0.03)
Buyers' Herfindahl	0.023			0.030*
	(0.02)			(0.02)
Ships per plant × post		0.002**		0.002**
		(0.00)		(0.00)
Ships per plant		−0.000		−0.000
		(0.00)		(0.00)
Vertical transfer share × post			−0.080***	−0.062**
			(0.03)	(0.03)
Vertical transfer share			−0.005	−0.006
			(0.01)	(0.02)
Market fixed effects	Yes	Yes	Yes	Yes
Year-week dummies	Yes	Yes	Yes	Yes
R^2	0.99	0.99	0.99	0.99
Sample size	1728	1728	1728	1728
Number of clusters (weeks)	126	126	126	126

***, **,* significant at the 1%, 5% and 10% level.

Standard errors are heteroskedasticity-robust and clustered at the weekly level.