INTERLINKED FIRMS
AND THE CONSEQUENCES OF PIECEMEAL REGULATION[*]

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Abstract

Industrial regulations are typically designed with a particular policy objective and set of firms in mind. When input-output linkages connect firms across sectors, such "piecemeal" regulations may worsen externalities elsewhere in the economy. Using daily administrative and survey data, we show that in Peru's industrial fishing sector, the world's largest, air pollution from downstream (fishmeal) manufacturing plants caused 55,000 additional respiratory hospital admissions per year as a consequence of the introduction of individual property rights (over fish) upstream. By removing suppliers' incentive to "race" for the resource and enabling market share to move from inefficient to efficient firms, the reform spread production out across time, as predicted by a conceptual framework of vertically connected sectors. We show that longer periods of moderate air polluting production are worse for health than shorter periods of higher intensity exposure. Our findings demonstrate the risks of piecemeal regulatory design in interlinked economies.

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1 Introduction

Firms that generate externalities do not exist in isolation; they interact with other firms through vertical and horizontal interlinkages in the economy. Those other firms may themselves generate externalities, possibly in a different domain. For example, loggers cut down forests and threaten biodiversity while the paper mills they supply pollute the local environment; oil and gas companies emit greenhouse gases while lax safety at the operators they employ put marine life at risk. Yet in practice, regulations are typically designed from a partial equilibrium perspective, with a particular set of firms in mind. If the targeted firms' response affects the extent of externalities generated elsewhere in the economy, such "piecemeal" regulatory design may help account for the frequent and often dramatic regulatory failures we observe (Lipsey and Lancaster, 1956), especially in countries with limited regulatory capacity (Laffont, 2005).[1]

The suboptimality of piecemeal regulatory design was shown theoretically in the 1950s (Lipsey and Lancaster, 1956), but empirical evidence on the welfare costs is lacking.[2] This paper provides a clean empirical demonstration of costly piecemeal regulatory design in an interlinked economy and the potential magnitude of the costs. We do so in the context of one of Latin America's biggest industries – fishmeal production in Peru[3] – which features two textbook externalities: overextraction by upstream suppliers (fishing boats) and air pollution from downstream manufacturers (fishmeal plants). We study the 2009 introduction of individual property rights over fish, an "optimal" policy for preventing overextraction,[4].

We show that the introduction of individual property rights upstream, while successful in stemming overextraction, dramatically increased the health impact of air pollution from downstream plants. In documenting the mechanism through which downstream spillover effects arose, we also provide a new finding that underscores the surprising consequences of the *time profile* of production in the presence of externalities: health deteriorated when a given amount of air polluting production downstream was dispersed over time. This, in turn, occurred because upstream boats responded to the reform by spreading their supply out in time. These contributions both have important implications for the regulation of firms and sectors that operate as part of a larger network.

To explore the costs of piecemeal regulatory design, the paper proceeds as follows. We: (a) estimate the health effect of downstream production that was ignored by the architects of the 2009 "individual, tradeable quota" (ITQ) upstream reform using a difference in differences approach comparing near-fishmeal-plants (hereafter "Near plant") locations and further-away (hereafter "control") locations during and outside of the production seasons. (b) Estimate the health impact of the 2009 reform using a difference in difference approach comparing Near plant and control locations pre- and post-reform. (c) Present a conceptual framework of, and document, the upstream and downstream industrial response to the ITQ reform, which serves as a starting point for (d) investigating the mechanism behind exacerbation of downstream externalities post-reform. To do so we view the reform as an exogenous shift in a particular dimension of fishmeal pro-

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[1] Regulatory failures are common in modern, interlinked economies: recent high profile examples include the 2014 and 2013 Indonesia forest fires (see e.g. The Guardian, 2014), the 2010 Deepwater Horizon oil spill (see e.g. BOEMRE/U.S. Coast Guard Joint Investigation Team, 2011), and the 2006 Ivory Coast toxic waste dump (BBC News, 2010).

[2] As put by Bento et al. (2014), "In the presence of unpriced externalities or other pre-existing distortions, policies levied to correct an externality can exacerbate or alleviate these other distortions in related markets. A priori, theory cannot shed light on the relative importance of the primary welfare effect of the policy – defined by the welfare gain from correcting the externality addressed by the policy – and the interaction effects – defined as the welfare effect that results from the interaction of the new policy with other unpriced externalities." (Bento et al., 2014, p. 2). We cannot do justice to the theoretical literature on regulatory design in the presence of multiple externalities here – see e.g. Bennear and Stavins (2007) and references therein.

[3] Fishmeal is a brown powder made by burning or steaming fish, and often used as animal feed. Peru's fishmeal industry accounts for around 3 percent of the country's GDP (De La Puente et al., 2011) and is the biggest industrial fishing sector in the world (Paredes and Gutierrez, 2008).

[4] See e.g. Boyce (2004, p.1): "In fishery management, an optimal instrument, individual transferable quotas (ITQs), exists".

duction: it led fishing boats and therefore most manufacturing plants to spread out production across time post-reform. We also exploit the framework's predictions on the local industry characteristics that should predict variation in how individuals' exposure to production changed post-reform and use triple difference strategies to investigate. Finally, (e) we argue that the health impact of fishmeal plants, and the exacerbation of these externalities when production was spread out across time, is due to air pollution generated in the production process, and investigate this hypothesis using a subset of the sample for which air pollution data is available.

The 2009 ITQ reform in Peru is an ideal setting for investigating the consequences of piecemeal regulatory design for several reasons. First, while a handful of influential existing empirical papers explore unforeseen effects of regulations imposed on a given set of firms (e.g. due to plant substitution between different pollutants or effects on market power),[5] we focus instead on a sequential production chain with two sets of firms that generate distinct externalities and a clear link between upstream and downstream firms. (Plants process the fish immediately after it has been offloaded as fishmeal is more valuable when made from fresh fish). This allows a clean separation between the targets of the regulation and the identified unexpected consequences, while highlighting the extent to which input-output linkages in the economy can propagate the impact of "regulatory shocks" into spheres of the economy in which the consequences may be detrimental. In this sense we follow the literature that examines how shocks transmit through the network of an economy.[6]

Second, individual property rights is the most commonly recommended regulatory system for natural resource sectors, including oil and gas, forestry, fisheries and mining (Ostrom, Janssen and Anderies, 2007). Since natural resources are an example of intermediate goods that are typically processed by downstream final good producers, their regulation may affect the impact on welfare of downstream externalities. The findings in this paper show that regulators face a trade-off: individual property rights help to eliminate the "race" for the resource, but tend to spread downstream production – and hence the associated externalities – out over time, which matters for welfare. There are many other examples of common regulatory systems that will tend to spread downstream production out over time.[7] Focusing on a particular downstream industry allows us a precise understanding of its vertical interlinkages, but fishmeal production shares many characteristics – and externalities – with other manufacturing industries.

Third, while recent studies have begun to emphasize the ubiquity and greater challenges of regulating industrial externalities in developing countries, the existing literature has largely focused on rich countries.[8]

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[5] Sigman (1996); Greenstone (2003); Gibson (2015) explore plant substitution between regulated and unregulated pollutants. Becker and Henderson (2000) find that, in the U.S., environmental regulations favoring small firms led to a shift in industry structure towards single-plant firms, which in turns contributed to environmental degradation. Ryan (2012) and Fowlie, Reguant and Ryan (2014) find that allocative inefficiencies due to changes in market power in the U.S. cement market counteract the social benefits of carbon abatement regulations. Note that because our focus is on interactions between externalities that arise through firms' interlinkages, we do not go into the literature on individuals substituting across regulated versus unregulated appliances and transport modes here.

[6] See e.g. Long and Plosser (1983); Horvath (1998); Jones (2011); Foerster, Sarte and Watson (2011); Acemoglu et al. (2012); Barrot and Sauvagnat (2015); Pomeranz (forthcoming).

[7] For example, Cap and Trade (CAT), some forms of entry barriers, and possibly temporary bans on production due to maximum pollution concentration restrictions. This paper's evidence on unintended consequences of Coasian regulations due to their impact on the distribution of production across time complements the evidence in Fowlie (2010)'s influential study on unintended consequences of CAT programs due to their impact on the geographical distribution of production.

[8] See, among others, Hanna and Oliva (2014); Ebenstein (2012); Chen et al. (2013); Rau, Reyes and Urzua (2013); von der Goltz and Barnwal (2014); Greenstone and Hanna (2014) on the often extremely high pollutant concentrations in developing countries. Several innovative recent papers also illustrate the need to take regulatory capacity and the prevailing incentive structures into account when designing regulation (Laffont, 2005; Estache and Wren-Lewis, 2009; Burgess et al., 2012; Duflo et al., 2013, 2014; Jia, 2014; Greenstone and Jack, 2015). The primary focus in the literature on how to design regulation of industrial externalities has been on rich countries and comparing (i) the magnitude of decreases in the targeted type of externalities (e.g. pollution or overextraction of a resource – see Costello, Gaines and Lynham (2008) for convincing evidence in the case of ITQs for open access resources) to (ii) the economic costs of compliance (see e.g. Gray and Shadbegian, 1993; Greenstone, 2002; List et al., 2003; Greenstone, List and Syverson, 2012; Natividad, 2014).

The task differs for regulators in developing countries in part due to the range and magnitude of interacting externalities they face (Greenstone and Jack, 2015). The reasons why regulatory design typically happens piecemeal – for example, non-coordination between regulating agencies or sequential political regimes with distinct objectives, unobservability of some interlinkages or externalities, and the complexity of optimizing regulations "in equilibrium" – also apply to a greater extent to the developing world. While piecemeal regulation likely leads to significant welfare losses in all countries, we thus focus on the type of context in which the possibility of such losses and the challenges in addressing the problem are of greatest concern.

Fourth, the Peruvian setting allows us to exploit sharp variation in downstream production due to government-imposed, irregularly timed, semi-annual production ban periods,[9] and in the introduction of ITQs upstream. Among developing countries, Peru also has exceptional data coverage. We link uniquely detailed hospital admissions records, repeated cross sections of household health and labor market surveys, administrative data on all production of fishmeal at the day×plant level, and ground-station measurements of air pollutant (PM^{10}, $PM^{2.5}$, NO_2 and SO_2) concentrations.

We begin by documenting the downstream health externality that was ignored by the ITQ reform's architects (The Ecologist, 2008). Difference in difference estimates comparing Near plant and control locations during production and ban periods show that plant production in the last 30 or 90 days increases respiratory (and total) hospital admissions, reported health issues and medical expenditures among adults, and reported health issues and coughs among children. The estimated health effects survive extensive robustness checks, and are not driven by changes in incomes or labor markets during production periods.

To identify how firms' response to the 2009 regulatory reform affected the downstream plants' impact on health, we compare Near plant and control locations before and after the reform came into effect. We find that the plants' production was dramatically more harmful to adult and child health post-reform, for example causing 55,000 additional respiratory hospital admissions per year. The estimated reform effects survive extensive robustness checks,[10] are not driven by changes in incomes or labor markets or confined to those who work in the sector, and are consistent in magnitude with the estimated health effects of plant production.

To begin investigating the mechanism underlying the downstream health impact of the 2009 reform, we first present a two-sector conceptual framework. The framework predicts that exposure to fishmeal manufacturing will spread out in time when individual property rights over fish are introduced upstream, as boats' incentive to rapidly capture as much as possible of the "total allowable catch" (TAC) is removed, less efficient plants decrease production or exit the industry, and more efficient plants spread their production across time. These predictions find support in the data. While there was a small decrease in the total *amount* of fishmeal produced post-reform, the average individual in our sample was exposed to 53 percent more *days* of production per year post reform.[11]

Following the conceptual framework and the observed industrial response to the introduction of individual property rights over fish, we hypothesize that plants' impact on health worsened primarily due to the change in the time profile of production. To test this hypothesis, we first instrument for days of production with the reform, and find that days produced is indeed an important determinant of the extent to which a given

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[9] Boats were not allowed to fish during periods when the fish reproduce.

[10] We show direct evidence supporting the identifying assumption of no differential trends in fishmeal locations, and that the estimates are robust to including location-specific trend terms and to varying the time window compared before/after the reform. We also show that the estimated health and reform effects are not driven by pollution from the fishing boats.

[11] Boats in the North/Central region spread out fishing in time as the ITQ reform came into effect. (Boats in the previously unregulated southern region fished for fewer days of the year after the reform due to the introduction of ban periods there in conjunction with the reform.) Fishmeal production days increased in the North/Central region and in locations with efficient plants. Production days decreased in the South and in locations with inefficient plants.

amount of production harms individuals' health. Geographical heterogeneity in the estimated reform effects further supports the time profile hypothesis. Where the extension across time of production was more extreme – the north (97 percent increase) and locations with efficient plants (134 percent increase) – the exacerbation of the industry's impact on health post-reform was significantly worse. But where fishmeal production days decreased with the reform – e.g. the smaller southern region (46 percent decrease) – the estimates of the effect on health are insignificant or significantly *positive* (favorable).

Convincing empirical evidence on the potential for, and possible magnitude of, a worsening of externalities elsewhere in the economy due to the introduction of piecemeal regulation is the primary objective of this paper. But the mechanism driving such adverse effects in the case analyzed is important for the specific but common scenario of natural resource suppliers supplying downstream manufacturers, and potentially any regulation that impacts the time profile of pollution. Why is plant production harmful to individuals' health, and why is the impact greater when production is spread out over time? We address this question in the final part of the paper using data on the sub-sample of individuals and hospitals in the Lima region, where ground-station measurements of air pollutants are available. We show that plants' impact on health, and the increased impact post-reform, is due to air pollution emitted in the production process. Our results suggest that increases in the duration of exposure to pollution are harmful to health, even when accompanied by proportional decreases in the intensity of exposure. Cost/benefit calculations that are suggestive but conservative indicate that the monetized cost of the reform's impact on health is of the same order of magnitude as the increase in sector profits due to the decrease in overextraction.

While the harmful effects of air pollution on adult and child (especially respiratory and pulmonary) health outcomes are convincingly documented in the existing literature,[12] this finding to our knowledge represents the first causal evidence on the health consequences of *simultaneous* changes in duration and intensity of exposure to air pollution (see e.g. Pope III et al., 2011) – a trade-off faced by policymakers whenever regulations that affect the time profile of production can be used. The finding is consistent with extensive existing evidence from economics and, especially, epidemiology on respectively (a) concavity in dose response at the levels of pollution seen in developing countries (Chay and Greenstone, 2003; Krewski et al., 2009; Crouse et al., 2012; Clay, Lewis and Severnini, 2015; Hanlon, 2015; Pope III et al., 2015), and (b) the importance of concurrent exposure and the duration of exposure (Pope III et al., 2011; Beverland et al., 2012; Chen et al., 2013; Anderson, 2015; Barron and Torero, 2015).[13] Exploring the generality of our findings on the shape of the health production function is an important direction for future research.

We conclude (a) that the cost of the exacerbation of "interlinked externalities" elsewhere in the economy that are ignored when (otherwise successful) regulatory reforms are designed can be of first order magnitude; and (b) that the health impact of air polluting plant production appears to be worse if spread out in time,

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[12] See e.g Brook RD et al. (2010); Moretti and Neidell (2011); Schlenker and Walker (forthcoming); Chen et al. (2013); Currie et al. (2014) on adult health and Chay and Greenstone (2003); Case, Fertig and Paxson (2005); Chay and Greenstone (2005); World Health Organization (2006); Jayachandran (2006); Currie and Almond (2011); Currie and Walker (2011); Gutierrez (2013); Roy et al. (2012); Currie et al. (2014, 2015); Isen, Rossin-Slater and Walker (forthcoming) on child health.

[13] Note that we use the term "health production function" to mean the three-dimensional relationship relating health at a given point in time to both the duration of exposure to air pollution and the intensity of exposure, though the existing literature typically analyzes the two underlying relationships (duration and dose response) separately. Pope III et al. (2015) summarize the epidemiological evidence on dose (concentration) response: "recent research suggests that the C-R [concentration response] function [between $PM^{2.5}$ and health risk] is likely to be supralinear (concave) for wide ranges" (Pope III et al., 2015, p. 516). The fishmeal locations in our sample are well into the higher ranges of PM concentration for which Pope III et al. (2015) argue that concavity in concentration response is increasingly uncontroversial (though many epidemiologists argue that concentration response may be concave also at lower concentrations (Crouse et al., 2012; Krewski et al., 2009)). Pope III et al. (2011) summarize the epidemiological evidence on duration response for cardiovascular mortality risk of air pollution and conclude that "the evidence suggests that...longer duration exposure has larger, more persistent cumulative effects than short-term exposure, but the highest marginal effects occur with relatively short-term exposures most proximal in time" (Pope III et al., 2011, p. 1).

which may alter the cost-benefit calculus for individual property rights and other regulatory regimes that affect the time profile of production in interlinked polluting industries downstream.

The paper is organized as follows. In Section 2 we discuss background on the setting, why fishmeal production may affect health, and the 2009 ITQ reform. In Section 3 we present the data. In Section 4 we explain our empirical strategy and provide evidence on plants' impact on health and how the ITQ reform affected this externality. Section 5 analyzes, theoretically and empirically, the industry's responses to the 2009 ITQ reform, and Section 6 tests the time profile hypothesis. In Section 7 we investigate *why* the time profile of production might matter for health. Section 8 discusses the total costs and benefits of the reform and regulatory design, and Section 9 concludes.

2 Background

2.1 Two interlinked sectors, downstream production, and health

The industrial fishing boats supplying Peru's fishmeal plants account for around 10 percent of global fish capture (Paredes and Gutierrez, 2008). The fishmeal plants, all located at ports, are present in around 22 towns with a suitable port and produce about a third of the global supply of fishmeal. Both the industrial fishing sector and the fishmeal sector are very capital intensive. Paredes and Gutierrez (2008) estimate that there were only about 26,500 jobs in the two sectors as a whole in 2008: 1,194 active industrial fishing boats employed around 17 workers each on average, and 110 fishmeal plants employed around 60 workers each on average (see Christensen et al., 2014; Paredes and Gutierrez, 2008). Five percent of our adult sample in fishmeal locations reports to work in the "fishing" sector. Because jobs in industrial fishing and fishmeal production are quite stable – many fishmeal firms keep the (relatively high-skill) plant workers on payroll outside of the production season[14] – there is little seasonal work migration, as discussed in more detail in Sub-section 4.2

Fishmeal is more valuable when made from fresh fish. Most fishing boats therefore go out for at most one day at a time, and plants process the fish immediately after it has been offloaded, leading to a direct link between plant production and supply of fish. The fish is transported from the boat into the plant through a conveyor belt. After cleaning, the fish is dried and converted into fishmeal by either exposure to direct heat or steaming. Fishmeal is storable for 6 – 12 months (but fishmeal companies report that they rarely store for long).

Air pollution may occur in the form of chemical pollutants (such as carbon dioxide (CO_2) and nitrogen dioxide (NO_2)) from the plants' heavy use of fossil fuels, in the form of noxious gases (e.g. sulfur dioxide (SO_2) and hydrogen sulfide (H_2S)) released as fish decompose, and in the form of microscopic natural particles (PM^{10} or $PM^{2.5}$) released during the drying and burning processes. Case studies have found high levels of air pollution near fishmeal plants during production periods, as discussed in detail in the appendix.[15] As also discussed at greater length in the appendix, air pollution in the form of particulate matter, chemical pollutants and gases associated with fishmeal production has been shown to cause a range of health problems in adults and children, especially respiratory disease episodes.

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[14] In a country-wide survey of workers in the sector conducted by the consulting firm APOYO in May 2007, 87 percent report having worked for the same company or fishing boat owner throughout their career, on average for about 14 years (APOYO, 2008). 40 percent report not working at all outside of the production seasons; a large proportion of the remainder work as artisan fishermen intermittently.

[15] In developed countries, filters and scrubbers are usually required by law and reduce emissions from manufacturing plants; in Peru, the regulatory authorities have unsuccessfully attempted to force the powerful fishmeal industry to install such technologies (De La Puente et al., 2011).

2.2 Regulations and the 2009 upstream reform

The regulations imposed on the Peruvian industrial fishing/fishmeal industry are aimed at preserving fish stocks while maintaining industry profitability. In the North/Central marine ecosystem (down to the $-16\,^{\circ}$S parallel), irregularly timed, semi-annual fishing/production bans were in place during the Peruvian anchoveta's reproductive periods throughout the years covered in our data. In addition, before the 2009 reform, industrial boats in the North/Central region operated under a sector-wide "Total Allowable Catch" (TAC) set at the beginning of each season. In the smaller southern marine ecosystem, fishing was allowed throughout the year and no aggregate quota was in place before the 2009 ITQ reform.[16]

In 2008, officials estimated excess capacity in the combined sector (the industrial fleet and fishmeal plants) of 35–45 percent and declining fish stocks (Tveteras et al., 2011). The goverment announced a new law introducing a system of individual, transferable quotas (ITQs) for industrial fishing boats on June 30^{th}, 2008. An extensive media search reveals no mention of the downstream plants' impact on health in the deliberations leading up to the law, though clear indications of such externalities had received considerable attention in the Peruvian and foreign media for years and must have been known to Peruvian regulators.[17] The ITQ law came into effect in the North/Central region on April 20^{th}, 2009 and in the South on July 7^{th}, 2009. In the South, the new ITQ system also meant that a quota and fishing ban periods were introduced for the first time.

Individual boat quotas were specified as a share of the regions's aggregate quota for the relevant season. The quota-share was based on historical catches and a boat's hull capacity. Within regions, the quotas could be transferred between boats, subject to certain rules.

3 Data

We combine five different types of data: hospital admissions records, individual- and household-level survey data, administrative regulatory data, administrative production and transaction registries, and data on pollution.

Hospital admissions records. Information on hospital admissions was provided by the Peruvian Ministry of Health and consists of counts of all patients admitted to any public health facility between 2007 and 2011. The data is at the facility×month level and gives information on the cause for admission (using the International Classification of Diseases (ICD) system).

Individual- and household-level survey data. The nationally representative Encuesta Nacional de Hogares (ENAHO) is the Peruvian version of the Living Standards Measurement Study (LSMS). Since 2004 surveying has taken place throughout the year, and the order in which sampling clusters are surveyed

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[16] This was due to fears that Chilean fishing activity would offset any environmental or industrial benefits of regulation.

[17] Travelers passing by fishmeal locations during production season can easily see and smell the severity of air pollution, an observation that helped motivate this paper. In a 2008 article, *The Ecologist* magazine reported that "When we visited one heavily afflicted community [in the fishmeal town of Chimbote], more than a dozen women and children gathered [...] to vent their anger at the fishmeal plants. They claim the plants that loom over their houses are responsible for asthma, bronchial and skin problems, particularly in children. 'We know the factories are responsible for these [problems], because when they operate the illnesses get worse', says one young woman [...] Another says when the plants are operating the pollution is so thick you cannot physically remain on the street. Footage [...] seen by *The Ecologist* illustrates typical conditions when fishmeal plants are operational: billowing black smoke drifts through the streets, obscuring vision and choking passers-by [...] Pupils at a Chimbote school [...] also complain of health problems. 'It causes fungal growths, breathlessness, we cannot breathe', says one boy." Such complaints were supported by case studies (e.g. Cerda and Aliaga, 1999), and local doctors (The Ecologist, 2008).

is randomly determined. A subset of clusters are re-surveyed every year and information on the "centro poblado" where each respondent is interviewed is recorded.[18] In our analysis, we use the GPS coordinates of the centro poblado's centroid. The survey focuses on labor market participation, income and expenditures, self-reported health outcomes, etc., as in other LSMSs.

We also use the nationally representative Encuesta Demografica y de Salud Familiar (ENDES), which is the Peruvian version of a Demographic and Health Survey (DHS). The sampling framework is similar to ENAHO. A subset of clusters are re-surveyed every year.[19] GPS coordinates for sample clusters are recorded. Women between 15 and 49 years old are interviewed, and information on the women themselves and their children (five years old and under) recorded. The survey is comparable to other DHS surveys, focusing on self-reported and measured health outcomes. For both surveys, we use the years 2007–2011.

Administrative regulatory data. We coded the dates of all fishing seasons from 2007 to 2011 and the size of each season's aggregate quota from the government gazette *El Peruano*.

Administrative production and transaction registries. The registry of all transactions between industrial fishing boats and fishmeal plants from 2007 to 2011 was provided by the Peruvian Ministry of Production.[20] All offloads by industrial boats are included, i.e., all (legal) input into fishmeal production. Information on the date of the transaction, and the boat, plant and amount of fish involved (though not the price), is included.

We also have access to the ministry's records of fishmeal plants' production/output, recorded at the monthly level, from 2007 to 2011.

Pollution data. Unlike for most developing countries, daily ground-station measurements of air pollutants are available for a significant period of time for Peru, though only for the area around the capital city. Information on the daily concentration, from 2007 to 2010, of four air pollutants at each of five stations in the Lima region was provided by the environmental division (DIGESA) of the Ministry of Health. The measured air pollutants – PM^{10}, $PM^{2.5}$, NO_2 and SO_2 – have been shown to correlate with factory production in many contexts and are commonly used in the health literature.

We construct five primary outcome variables, with a particular focus on the health issues that are most likely to be affected by short-term variation in air pollution from plant production (see e.g. Chen et al., 2013) – respiratory issues. The outcome "Respiratory Admissions" is a count at the hospital level of all admissions due to diseases of the respiratory system (ICD codes J00-J99). As no explicit question on respiratory issues is asked in the ENAHO survey, for adults we construct an outcome labeled "Any Health Issue" as the complement to "No health issue in the last month". We also use expenditure data to construct an estimate of the individual's total medical expenditures. For children, we use ENDES survey data to construct a measure of "Any Health Issue",[21] and also separately report the outcome of the child experiencing a cough.

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[18] Centros poblados are villages in rural areas and neighborhoods in urban areas. After the sample restrictions we impose, 2096 sampling clusters with on average 77 households each are present in our sample. 710 centros poblados are present, with on average 228 households each.

[19] From 2004 to 2007, a fixed set of clusters were used, the survey order of which was randomized (as was the trimester of surveying). The definition of clusters changed somewhat in 2008 when Peru's statistical bureau updated the sampling frame with the 2007 national census. Furthermore, 2008 was unusual in that fewer clusters were surveyed. From 2009 to 2011, the number of survey clusters was the same as in 2004-2007, and about half were part of a panel of clusters surveyed every year.

[20] This includes "within-firm" transactions. Some boats are owned by the firms that own the plants.

[21] This variable is equal to one if the surveyed parent reported that the child had experienced any of the health issues the survey covers in the last two weeks. The covered health issues are cough, fever, and diarrhea. These have all been linked to air pollution in the existing epidemiological literature (see e.g. Peters et al., 1997; Kaplan et al., 2010), although the evidence linking air pollution and cough is more extensive.

The survey based outcomes capture adverse health episodes of a wider range of severity than those leading to hospital admission.

4 Fishmeal Manufacturing's Impact on Health

4.1 Empirical strategy

The primary goal of this paper is to identify the impact of the introduction of a new regulatory system upstream—individual property rights—on the externalities generated by downstream plants, and the mechanism through which such spillover effects occur. There are three parts to our analysis. First we estimate how exposure to fishmeal production affects health. At this stage we are flexible in our specification of the extent of production activity: we show results from using both the amount produced and days of production within a given time window. We then go on to estimate the impact of the regulatory reform on health outcomes for those exposed to fishmeal production. We briefly lay out the approach we take in each of these steps here.

We consider the health outcomes y_{ijt} of an individual or hospital i in location j at time t. To estimate how exposure to fishmeal production affects health, we compare y_{ijt} for those located within a given radius of fishmeal plants,[22] $NearPlant_j = 1$, to those located further away, at times of varying production intensity in the cluster of plants closest to the individual or hospital in question $Production_{jt}$:

$$y_{ijt} = \alpha + \beta_1 Production_{jt} + \beta_2 NearPlant_j \times Production_{jt} + \beta_3 X_{ijt} + \gamma_{c(j)} + \delta_{m(t)} + \varepsilon_{ijt} \tag{1}$$

$$y_{ijt} = \alpha + \beta_1 Production_{jt} + \beta_2 NearPlant_j \times Production_{jt} + \beta_3 X_{jt} + \psi_i + \delta_t + \varepsilon_{ijt} \tag{2}$$

where t indicates a specific date for the individual level outcomes in (1) and a year×month for the hospital level outcomes in (2). X are covariates that include $NearPlant_j \times \theta_{n(t)}$, where $\theta_{n(t)}$ is a month fixed effect to control for possibly differential seasonality in $NearPlant_j$ locations. In (1) X also includes individual-level covariates.[23] $\gamma_{c(j)}$ is a centro poblado or district fixed effect, ψ_i a hospital fixed effect, and $\delta_{m(t)}/\delta_t$ a year×month fixed effect. We thus compare individuals/hospitals who are within the same town or district, but close to versus less close to fishmeal plants, during periods when production is higher versus lower. β_2 measures the marginal effect of additional production exposure. Standard errors are clustered at the centro poblado or district level.[24]

To explore how the 2009 ITQ reform affected health outcomes for those exposed to fishmeal production in reduced form, we compare individuals and hospitals in Near plant and control locations before and after

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[22] As we do not have GPS points for surveyed individuals' homes, nor shape files for the sampling clusters and centros poblados, we define the location of i as the centroid of j (the centro poblado (in ENAHO) or sampling cluster (in ENDES)) to which he/she belongs.

[23] The individual covariates are gender, age, mother tongue, years of education, and migration status for adults, and gender, age, mother's years of education, and the ENDES household asset index for children. These control for possible changes in the sample surveyed across time/space.

[24] While we use centro poblado fixed effects in regressions using ENAHO data, the lowest geographical unit we can condition on when using ENDES data is districts. The reason is that the ENDES sampling framework changed in 2008/2009. While district information is included in all rounds of ENDES, the data key necessary to link specific sampling clusters/centros poblados before and after 2008/2009 was not stored. Note that Peruvian districts are small; there are 1838 districts in the country.

the reform as follows:

$$y_{ijt} = \alpha + \beta_2 NearPlant_j * Reform_{jt} + \beta_3 X_{ijt} + \gamma_{c(j)} + \delta_{m(t)} + \varepsilon_{ijt} \qquad (3)$$

$$y_{ijt} = \alpha + \beta_2 NearPlant_j * Reform_{jt} + \beta_3 X_{jt} + \psi_i + \delta_t + \varepsilon_{ijt} \qquad (4)$$

$Reform_{jt}$ is a dummy variable equal to one after the reform took effect in the fishmeal port (cluster of plants) nearest to location j. In some specifications we additionally include centro poblade/district time trends or allow a $NearPlant$ specific trend.

How is the difference in difference specification on the reform in (3) and (4) related to that on exposure to production in (1) and (2)? As we show below, the reform led to a stark change in the fishmeal sector: fish capture and plant production were spread out in time. Suppose that this spread was the only or main mechanism through which the reform changed the fishmeal sector's impact on health. If so, (3) and (4) can be thought of as the reduced form corresponding to a hypothesis on the "structural" relationship between fishmeal plants' production and health. In particular, the hypothesis that the impact of production on health depends on the time profile of production—the number of days of exposure to production—holding constant the level of production. After we present the evidence from running (1)-(4), we test this hypothesis.

For outcomes drawn from surveys, in which we have precise village/cluster GPS data, we use five kilometers as the baseline "treatment" (Near plant) radius within which any health effects of fishmeal production are hypothesized to be greatest, based on the literature on air pollution (see e.g. Currie et al., 2015; Schlenker and Walker, forthcoming). For hospital admissions outcomes, we use 20 kilometers as the baseline treatment radius so as to include the facilities used by those living near fishmeal plants in the "treatment group."[25] Note that our specification is conservative in that we compare locations inside the treatment radius to locations outside the radius, allowing the "control locations" to also be affected by production in the nearest port. We simply allow production to have a differential effect in locations close to the fishmeal plants. As a robustness check, we also investigate how our estimates vary with the treatment radius used.

We initially consider two natural measures of fishmeal production: the number of days on which fishmeal production took place and log total input into fishmeal production reported in 10,000s of metric tons, in the previous X days in the port (i.e., cluster of plants) nearest to the individual or hospital (we use input rather than output to measure fishmeal production because we have data on input at the daily level and output only at the monthly level. As seen in Figure A.I, the output of fishmeal very closely tracks the input of fish). Our baseline lookback window—30 days—matches the way the ENAHO survey questions are asked. To capture health responses to more persistent exposure to production, we also show results for a 90 day window—approximately the longest period of continuous exposure observed in our data period—and also investigate how our estimates depend on the exact lookback window used. It is important to note that β_2 in (1) and (2) captures the health response to exposure to fishmeal production in the recent past – the marginal effect of an additional day or amount of production in the last 30 or 90 days. There may additionally be health consequences of long-term exposure to fishmeal production that we do not capture.

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[25] The geographical spread of health facilities is much greater than that of sampling clusters. In many fishmeal locations, the nearest hospital is more than 10 kilometers away.

Figure I is a map of Peru illustrating our identification strategy by showing five kilometer radii around fishmeal ports alongside ENAHO and ENDES sampling clusters. The assumption necessary for (1) and (2) to identify the impact of exposure to fishmeal production on health is that trends in health outcomes across periods with more versus less fishmeal production in the nearest cluster of plants would have been similar in Near plant and control locations in the absence of fishmeal production. In Table I we display the means and standard deviations of both health outcomes and covariates in Near plant and control locations during and outside of production periods. When the plants are not operating, respiratory hospital admissions and medical expenditures are higher in Near plant locations, whereas child health issues occur more frequently in control locations. Most household demographic characteristics are similar in Near plant and control locations, but education levels and assets are somewhat higher and the proportion of adults speaking an indigenous language is somewhat lower in Near plant locations. We include these variables as controls in all of our regressions. The numbers also indicate that there is little seasonal work migration to the fishmeal locations, probably because jobs in the industrial fishing sector are quite stable, as discussed above.

Similarly, the identifying assumption necessary for (3) and (4) to estimate the causal effect of the ITQ reform on health is that trends in health outcomes across the date when the reform took effect would have been similar in Near plant and control locations in the absence of the reform. Table II is identical to Table I, except that we now compare Near plant and control locations before and after the ITQ reform. Unsurprisingly, the differences in health outcomes and covariates between Near plant and control locations before the reform are similar to those for the non-production periods discussed in the previous paragraph.

Location fixed effects control for time invariant differences between Near plant and control locations, including the average level of air pollution. We include all covariates shown in Tables I and II for adults and children as controls when estimating (1), (2), (3), and (4) for adults and children respectively. In sub-sections 4.2 and 4.3 we investigate possible violations of the identifying assumptions in depth.

4.2 Results on fishmeal manufacturing and health

In addition to summary statistics, Table I shows the "raw" difference in differences, i.e., without any fixed effects or controls included, in health outcomes between Near plant and control locations during and outside of production periods. These are positive—indicating that health is relatively worse in Near plant locations during fishmeal production—and sizeable for all five categories of adverse health outcomes, and significant for respiratory hospital admissions and adult health issues.

Table III shows the effect of fishmeal production on adult and child health from estimating (1) and (2). We find that fishmeal production during the previous 30 or 90 days, whether measured as production days or total input into production, negatively affects adult and child health. A 50 percent increase in fishmeal production during the previous month leads to 1.6 (1 percent) more hospital admissions for respiratory diseases; a 0.77 percentage point (1.3 percent) higher incidence of "Any Health Issue" among adults; and a 3.8 percent increase in medical expenditures.[26] For these outcomes the estimated effects are similar when using a 90 day window. We also find that a 50 percent increase in fishmeal production during the last 90 days leads to a 1.7 percentage point (3.7 percent) increase in the incidence of "Any Health Issue" and a 1.6 percentage point (4.2 percent) increase in the incidence of having a cough among children ≤ 5. We do not find significant effects for children of production in a 30 day window. The reason may be that our statistical

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[26] As we estimate the effects of log production on health outcomes, we compute the effects shown here, the impact of a 50% change in production, as $\beta \times \ln(150/100)$. For medical expenditures, which is in logs, we report $e^{[ln(150/100) \times \beta]}$.

power to detect effects on child health is lower than for adult health due to much smaller sample sizes.[27] The last two panels of Table III show the estimated effect of days of production on health. The patterns are similar to those found in the top panels; for example, 10 additional days of production during the last 90 days increases the incidence of "Any Health Issue" by 8.9 percent for children ≤ 5. Overall, the results in Table III indicate that exposure to fishmeal production leads to worse health outcomes for both adults and children.

In the appendix we show that the results are robust to instrumenting for production and production days using non-ban days (Appendix Table A.I); to specifying hospital admissions in logs (Appendix Table A.II); to varying the treatment radius and look-back window used (Appendix Figure A.II);[28] to restricting the sample to the period prior to the ITQ reform (Appendix Table A.III);[29]and that a falsification exercise shows no significant effects on health outcomes that we would not expect to respond to plant production (Appendix Table A.IV). In Table I we see that average educational attainment, the proportion of immigrants, and the proportion speaking an indigenous language are lower in Near plant locations during the production periods. While these changes are unlikely to explain a deterioration in health outcomes, to be cautious we include all covariates shown in Table I as controls when estimating (1) and (2).

In the appendix we show that fishmeal production affects the health of whole communities (not just those who work in the sector, see Appendix Table A.V), and that the effect is not driven by labor market responses (average incomes and labor market outcomes are not significantly different during production periods, see Appendix Table A.VI). We also show that the adverse impact on health is not driven by ocean pollution or direct fish consumption (see Appendix Table A.VII). We return in Section 7 to the hypothesis that fishmeal production affects the health of the local population primarily through air pollution emitted by the manufacturing plants.

4.3 Results on the introduction of individual property rights upstream and health

Recall that the 2008 ITQ reform introduced individual property rights over the resource for the fishmeal plants' suppliers—industrial fishing boats—so as to de-incentivize boats racing to capture fish early in the season. In addition to summary statistics, Table II shows the raw difference in differences in health outcomes between Near plant and control locations before versus after the ITQ reform. These are positive and sizable for all five categories of adverse health outcomes—indicating that health is relatively worse in Near plant locations after the reform—and significant for respiratory hospital admissions, adult health issues, and medical expenditures.

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[27] The results indicate a decrease in hospital admissions (and in some specifications also weaker indications of improvement in child health) in non-fishmeal locations during the periods when production takes place. The explanation is most likely that differences in health between regions have changed over time in a way that happens to correlate with the extent of fishmeal production in the region. Such a pattern is not a concern for our estimates as it would lead us to understimate the impact of plant production on health.

[28] Note that we can also compare individuals/hospitals in fishmeal locations only to individuals/hospitals in locations that are contiguous to the fishmeal locations; this gives very similar results to those in Table III.

[29] Recall that we in (1) and (2) estimate the effect on health of a marginal increase in exposure to fishmeal production. As discussed in Sub-section 4.1, we are intentionally flexible in how we specify the extent of production activity at this stage: we simply wish to establish if there is an effect of plant production on health or not. (When we analyze if and why the impact on health changed after the reform, we will instead attempt to establish which specific dimensions of production that changed and thereby altered the impact on health). For this reason we find it most natural to include the whole sample period in Table III, which also helps to maintain power. Appendix Table A.III is provided for the reader who instead would prefer the impact on health to be estimated using only data from the pre-reform period. The estimates are similar to those in Table III, but less precisely estimated.

Table IV presents the results from estimating (3) and (4). The top panel is our preferred specification, in which we limit the sample to the last year before and first year after the reform. We see respiratory hospital admissions increase by 7.2 percent in Near plant locations, relative to control locations, after the reform. For adults, we see large and significant effects on health, with the likelihood of reporting a health issue increasing by over 10 percent, and medical expenditures by 23.9 percent, after the reform. We see even bigger effects for children, with the incidence of "Any Health Issue" increasing by 40 percent and coughs increasing by 39 percent.[30] We discuss the magnitude of the estimates below.

The other five panels of Table IV show results from robustness checks in which we control for $NearPlant$ specific time trends; control for centro poblado or district specific time trends; expand the sample to include data from the last two years before and first two years after the reform; restrict the sample to include data from only the first fishing season of the year[31] and restrict the sample to include only locations that are relatively near (within 50 kilometers of) fishmeal plants in the control group.[32] The significance and magnitude of the estimated coefficients is very similar to that found in the top panel throughout, with some changes for specific outcomes. Overall the results in the bottom five panels of Table IV provide strong support for the identifying assumptions for our estimation.

Finally, Figure II shows trends in health outcomes in Near plant and control locations before and after the reform took effect. We see similar trends in the two groups before the reform, again suggesting that the identifying assumption of parallel trends holds. The significant, differential increase in adverse health outcomes in fishmeal locations when the reform takes effect, estimated formally in Table IV,[33] is also apparent in Figure II, for all five health outcomes. We conclude that the estimated worsening of the downstream plants' impact on health after the 2009 ITQ reform is robust and likely reflects a causal relationship.

A possible concern is that the seriousness of health issues may have changed after the reform. While we ultimately cannot fully test for this possibility, it is important to keep in mind that (a) respiratory disease episodes have to be fairly serious to lead to a hospital admission (pre- or post-reform), and, perhaps more importantly, (b) the estimates for medical expenditures suggest that the total health costs to individuals increased significantly post-reform.

5 Plants' response to the introduction of individual property rights upstream

We now present a theoretical argument for how we should expect the introduction of individual property rights over intermediate goods to affect the spatial and temporal distribution of final good production. The purpose is two-fold. First, the framework informs which particular dimension(s) of fishmeal production we should expect to change *on average across locations* after the ITQ reform and therefore to potentially drive the increased impact on health. Second, the framework will ultimately help us *test* why the fishmeal industry's impact on health increased when individual property rights were introduced upstream. This is because it delivers predictions on which characteristics of the fishmeal industry *in a particular location* should predict a large or small local response. We present the basic framework and predictions of the model here;

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[30] The latter is imprecisely estimated and not significant in the main specification, but is significant in all the other specifications.

[31] We conduct this test to make sure that our results are not driven by the effect of El Niño in late 2009.

[32] The estimated reform effects are also robust to varying the "treatment radius" around ports used to define fishmeal locations.

[33] We do not have enough observations around the cut-off (the date then the reform took effect) to estimate the effect of the reform as in a regression discontinuity approach.

a full presentation is in the appendix.

The basic intuition of the model is as follows. An industry wide quota regime encourages boats to "race" for fish early in the season. The resulting high per-period fish capture early in the season decreases the price of fish and thereby allows less efficient fishmeal plants to survive. The introduction of individual quotas removes boats' incentive to fish intensely early in the season; now they instead minimize extraction costs, which requires spreading out fishing across time. This in turn increases the price of fish available for fishmeal production, forcing less efficient plants to reduce their production or exit the industry.

We now consider the industrial response to the 2009 ITQ reform in light of the model's predictions. Overall, the reform is widely seen as as a success. The downstream plants reported an increase in profits, and boats an improvement in the fish stock (International Sustainability Unit, 2011). Because the reform did not target total capture, the positive effect on fish stocks can be attributed mainly to changes in the *intensity* of fishing – capture of juvenile fish fell (Paredes and Gutierrez, 2008). In fact, most clusters of plants saw minor decreases in production after the reform came into effect, while two ports expanded considerably, as seen in Figure III. Still, on the whole fishmeal production fell on average post-reform, reflecting a combination of factors.[34]

Natividad (2014) documents a rise in the price of anchovy after the reform. In order to evaluate whether suppliers and plants responded to the new regulations along the lines of our theoretical predictions, we make use of administrative production registries. The most noteworthy change in the industry after the reform was in the time profile of production downstream. Consistent with our framework's predictions, the introduction of ITQs led to longer production seasons, as seen in Figure IV. Fish capture and therefore production of fishmeal spread out in time as boats' incentive to rapidly capture as much as possible of the TAC early in the season was removed. The sample-weighted across-port average increase in days of production post-reform was 26 days per year, or 53 percent. Production early in the season was considerably greater before the reform, but the decline in output over time was less steep after the reform.[35]

Figure V shows that the reform also led to consolidation in the industry. As seen in the top panel, the number of active plants began a steady decline in 2009. It thus appears that the increase in the price of fish after the ITQ reform came into effect led some plants to exit the market. The bottom panel of Figure V shows the intensive margin corresponding to the extensive margin in the top panel. Before the reform, the longest– and shortest– producing plants produced for about the same period of time. After the reform, bottom-quartile plants began to decrease or stop production mid-season, while top-quartile plants continued to produce. These findings are consistent with the framework above.

The top panel of Figure VI shows the average number of production days before and after the reform for efficient versus inefficient *ports*, noting that a plant's costs are partly determined by its location.[36] It is clear from the figure that plants in efficient ports greatly stretched out production across time after the reform, while plants in inefficient ports did so to a much lesser extent.

We conclude that, from the perspective of local communities, the two sectors' response to the 2009 ITQ

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[34] The total allowable catch continued to be set by the regulatory authorities after the reform, using the same criteria as before the reform – primarily estimates of fish stocks. Production was unusually low in 2010 due to El Niño. Consolidation in the industry, and how the boats and plants that exited or expanded production were selected, may also have affected total production.

[35] Note that the pause in fishing mid-season in the pre-reform regime was due to a regulatory rule that was removed with the ITQ reform. Before the reform, the seasonal TAC had two components; a total amount that could be fished before a specified "pause date" (this sub-quota was reached long before the pause date due to the race for fish), and a second amount that could be fished only after a specified "recommence" date. The removal of the pause rule contributed to production being spread out in time after the reform, along with the forces highlighted in our theoretical framework.

[36] We define efficiency formally below.

reform first and foremost led exposure to fishmeal manufacturing to be spread out in time. How should we expect such a change in the "temporal distribution" of the downstream industry's production to affect its impact on health? *If* – as we hypothesize, and test below – plants' impact on health is driven by air pollution, this will depend both on (a) plants' "pollution production function" and (b) the health production function. We are aware of no existing evidence on (a), but find it most plausible to generally expect the amount of pollution emitted at a given point in time to be either concave or linear in the level of plant production.

When it comes to the health production function, the existing literature generally analyzes the response to duration and dose separately. The few existing studies that overcome the formidable challenges of estimating the causal effect on health of *sustained* exposure to air pollution generally find much bigger effects on health (mortality and respiratory infections) than (the effects found elsewhere of) short-term exposure.[37] Moreover, Chay and Greenstone (2003) and Clay, Lewis and Severnini (2015) both find evidence consistent with concavity in the dose response function relating infant mortality to the intensity of air pollution, and Hanlon (2015) finds the same for all-ages mortality.[38] No existing research convincingly compares the health effects of a *given* amount of pollution when concentrated versus spread out in time (in their review of the literature, Pope III et al. (2011) flag that "there are likely important risk trade-offs between duration and intensity of exposure" (Pope III et al., 2011, p. 13)), despite their importance for policy making. Consider, for example, pollution regulation based on thresholds. If our hypothesis is true, perhaps it is not such a good idea to stop sources of pollution (eg. cars or factories) when the concentration hits certain levels, but rather try to concentrate the same amount of pollution in fewer days. Overall, the evidence from the economics literature is thus consistent with a health production function shape in which dispersing air pollution across time can exacerbate the impact on health.

6 Plants' Response to the Introduction of Individual Property Rights Upstream and their Impact on Health

The reform led to significant changes in suppliers' (boats') organization of production, which in turn led downstream production, on average across locations, to be spread out in time. Put loosely, individuals beforehand faced a "short, sharp" profile of production: a large amount of plant production concentrated in a relatively short period of time. Post-reform, individuals instead faced a "long, low" profile of production: the same amount of production distributed across a longer production season. We hypothesize that, within the range of port level production profiles observed during out data period in Peru, it is how many days production is spread out over that matter most for health, and that the reform's impact on health was therefore due to the move from "short, sharp" to "long, low" production. To investigate this hypothesis, we begin by estimating an adjusted version of (1) and (2) in which fishmeal production is no longer seen as a "black box". Instead we use the introduction of the reform as an exogenous shift in the number of days of production within the last 30 or 90 days for those in Near plant locations.

Before we present the results from this "structural" specification, it is important to note that we do not expect the exclusion restriction to hold in a literal sense. Relative to the change in the time profile of

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[37] Examples include Chen et al. (2013), Anderson (2015) and Barron and Torero (2015) (see also Isen, Rossin-Slater and Walker, forthcoming). The level of exposure differs considerably across these studies, but they all large effects of sustained exposure.

[38] It is reasonable to expect a similarly shaped production function for respiratory diseases and other diseases that are affected by air pollution and (eventually affect mortality) (see e.g. Pope III et al., 2011).

production, however, other changes in the production environment post-reform were either minor or arguably unable to explain a deterioration in health. First note that total production *decreased* after the reform so the observed impact of the reform cannot be explained by an overall increase in production. To address the possibility that the impact is due to a shift in production across ports, Table V shows results from regressions that are identical to those in the first panel of Table IV, except that we now include various measures of port level production. Controlling for production in the last 30 days, the last 90 days, or the season has a negligible effect on the size and significance of the estimated impact of the reform on health. These results suggest that, regardless of how it is specified, reallocation of market share across ports cannot explain the estimated reform effect. [39]

Second, while Appendix Table A.VI shows that average incomes and labor market outcomes are not significantly different during fishmeal production periods, it is nevertheless possible that the impact of the reform on health was due to changes in labor markets post-reform. As seen in Table VI, however, the reform increased the probability of having a job for fishing workers, but had no significant effects in the sample as a whole. We thus rule out the possibility that the aggregate health effect is explained by income effects or labor market responses to the reform. Third, in Appendix Table A.VIII, we show that the adverse health impact of the reform estimated in the full sample is not driven by impacts on fishing workers' health. Finally, it is also clear that the impact of the reform on health is not explained by pollution from the fishing boats,[40] nor by production expanding into periods of the year in which the impact of air pollution differs.[41]

The results from instrumenting for the time profile of production using $Reform \times NearPlant$ are presented in Table VII. The top panel shows the results of first stage regressions of days of production on $Reform \times NearPlant$. For adults and hospitals near plants, there is a strong relationship between the reform and production days in the last 30 or 90 days. On average those in the hospital sample faced just under four additional days of production in the last 30 days, and about 8.5 additional days of production in the last 90 days, while those in the adult sample saw just over five additional production days in the last 30 days, and about 9.5 additional production days in the last 90 days. In our sample of children, the first stage is less clear. The bottom panels show the results of the second stage, the impact of production days in the last 30 or 90 days—instrumented by $Reform \times NearPlant$—on health. In our hospital and adult samples, the effects of these additional days of production on health are positive (adverse) and significant in both the 30 and 90 day windows. Taking the results from our "structural" specification at face value thus suggests that the reform impacted health by increasing production days. Further, the magnitude of the IV results is significantly larger than those estimated in Table III. This points towards possible non-linearities in the relationship between health and exposure to production: additional days of production impact health to a greater degree than the average day. We find no significant results for children in these specifications, which is unsurprising given the weakness of our first stage in the child sample.

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[39] The estimated reform effects are also robust to excluding the two ports that saw an increase in total, yearly production after the reform.

[40] The boats spend little time in the ports with their engines on and thus probably do not contribute noticeably to the worse health of those who live near the plants/ports, relative to others, during production. Additionally, however, there was a considerable decrease in port queuing times post-reform (as expected (International Sustainability Unit, 2011)), indicating that post-reform changes in pollution from boats should, if anything, counteract the adverse reform effects we identify.

[41] While ex ante unlikely due to the fact that production takes place during two different periods of the year, both of which expanded across time after the reform and corresponded with worsening health outcomes, we formally investigate this possibility as follows. We construct a "New Period" variable equal to one for those periods of the year in which non-negligible production took place after the reform but not before. We then estimate specifications (1) and (2), additionally interacting "Fishmeal production × Near Plant" with "New Period" and using only post-reform data. We do not find worse health effects post-reform of fishmeal production during the "new" production periods relative to the periods on which production took place also before the reform.

The results in Table VII are consistent with the hypothesis that the introduction of individual property rights upstream exacerbated plants' impact on health by increasing the number of days of production in Near port areas. To provide further evidence on this possibility, we exploit the fact that the average change in the time profile of production seen in Figure IV masks considerable heterogeneity across locations. We ask whether the impact of the reform on health is worse in the areas that see greater increases in production days post-reform. The first source of variation in the effect of the reform on the time profile of production we exploit is regulatory: the reform effectively differed in the North/Central region and the South. The second source of such variation we exploit is based on a prediction of the framework presented above: areas with different production costs should see different changes in the time profile of production post-reform.

The North/Central region covers the large majority of the country (as seen in the map in Figure I). For this reason the theoretical framework above was built to match the regulatory system in place in the North/Central region before (and after) the reform, and we expect the full-sample industrial response to the reform to largely reflect what occurred there. Indeed, fishmeal locations in the North/Central region saw a striking 97 percent (sample-weighted) increase in the average number of days of plant production per year, as predicted by the model and illustrated in Figure VI.Conversely, in the smaller southern region, fishing and fishmeal production instead became more concentrated in time – a 48 percent decrease in the average number of days produced per year – with the introduction of fishing ban periods there in conjunction with the ITQ reform.

The top panel of Table VIII shows results from a difference in differences in differences specification in which we interact the double difference term in specification (3) with an indicator for the household residing in the North/Central region. For respiratory hospital admissions and medical expenditures, the estimated coefficient on "Post-reform×Near Plant" is negative (beneficial) and significant for the South, and positive (adverse) and significant for the North/Central region. We similarly see a differential increase in "Any Health Issue" in the North/Central region (although the coefficient on "Post-reform×Near Plant" is positive also for the South).[42] Overall, the results in Table VIII, with a deterioration in health in the North/Central region after the reform and signs of improvement in the South, support the hypothesis that the introduction of ITQs upstream exacerbated the downstream industry's impact on health by changing the time profile of production.

In a third and complementary test of the time-profile-of-production hypothesis, we exploit another key prediction of our model, namely that inefficient plants should exit or reduce production after the reform and efficient plants should expand. To relate changes in plants' production to health effects of the reform estimated at the location level, we need a proxy for plants' costs at the location level. We take advantage of the fact that we observe both input of fish and output of fishmeal and construct pre-reform, plant-level "efficiency" (output/input ratio) and associate each fishmeal location with the maximum efficiency observed among plants in the location before the reform.[43] As shown in Figure VI, days of production increased by 134 percent in more efficient locations and increased by only 46 percent in less efficient locations when the ITQ reform took effect.

The bottom panel of Table VIII shows results from a difference in differences in differences specification in which we interact the double difference term in specification (3) with port level efficiency. The adverse health effects of the reform for adults are concentrated in locations with efficient plants; beneficial, though

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[42] Child outcomes are not included in Table VIII because we have insufficient observations in ENDES to estimate standard errors in difference in differences in differences specifications.

[43] This maximum is based on the overall input/output ratio in the year 2008. For ports with only one plant, it is simply the 2008 input/output ratio for that plant. This measure serves as a proxy for the limits on efficiency imposed by the geography of that port, and hence provides a measure of the port specific component of costs.

insignificant, health effects are seen for adults in locations with inefficient plants. Similarly, we see a large (but imprecisely estimated) increase in respiratory hospital admissions in locations with more efficient plants, but not in locations with less efficient plants.

The majority of locations with efficient plants are located in the North/Central region. Note, however, that efficiency predicts both the response in days produced and in the health consequences of the reform also *within* the North/Central region as seen in Appendix Table A.IX. Further, the strikingly different effects of the reform on health outcomes in the North/Central region and the South, and in locations with efficient versus inefficient plants, are not driven by differential effects on incomes or labor market outcomes, nor on fishing workers' health.[44] We conclude that the concentration of adverse health effects in fishmeal locations where production days increased after the introduction of individual property rights upstream supports the hypothesis that the downstream plants' exacerbated impact on health post-reform was due to changes in the time profile of production.

In sum, the battery of tests presented in this section are strongly supportive of the view that Peruvian fishmeal plants' impact on health increased after the introduction of property rights among their suppliers because the regulatory change affected the plants' time profile of production due to the interlinkage between the two sectors. While the across-location movements in plants' market share after the reform intensify location level changes in the time profile of production and thus help us test our hypothesized explanation for the deterioration in health post-reform, most fishmeal locations saw negligible changes in the *level* of production post-reform, as seen in Figure III. On average the ITQ reform can thus be thought of as spreading out downstream production over time without changing the total amount of production. Our findings indicate that such a dispersion worsens the impact of polluting plant production on health.[45]

7 Why Plants' Response to the Introduction of Individual Property Rights Upstream Matters for Health

7.1 Fishmeal production, air pollution, and health

We have shown that exposure to fishmeal production is harmful to individuals' health; that the impact on health increases after the upstream ITQ reform; and that the reason is that plant production spreads out over time when suppliers no longer face incentives to "race" for the resource early in the season. We hypothesize that air pollution generated by the plants during the production process explains these three sets of findings. To investigate this hypothesis, we first return to the flexible specification of production in (1) and (2).

We start, in Appendix Table A.X by disaggregating respiratory hospital admissions into ICD subcategories. Doing so shows that the overall effect on health is driven primarily by a higher incidence of "Acute Upper Respiratory Infections" during production periods, consistent with air pollution as the underlying mechanism.[46]

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[44] Appendix Table A.VIII shows that there is no significant differential effect across regions or high versus low cost ports on either health or labor market outcomes for those who work in the fishing industry.

[45] The port-level average change in the time profile of fishmeal production after the reform is affected "directly" by boats spreading out fishing in time to a much greater extent than by the movements in market share. As seen in Figure III, only two ports saw a non-negligible increase in the level of production after the reform, six saw a considerable decrease, while almost all ports (in the North/Central region) saw a significant increase in days produced after the reform. We estimate very similar reform effects if we limit the sample to those 15 ports that saw a negligible change in the level of production after the reform, but lose significance because 2/3 of the sample live near the ports that saw bigger changes in levels of production.

[46] Using specifications identical to those in Table III with different subcategories of respiratory admissions as dependent

To investigate more directly, we estimate (i) the effect of fishmeal production on air pollution, and (ii) the effect of plant-generated air pollution on adult and child health. This can be done for the part of our sample that live in the Lima region (27 percent), where, as discussed above, daily data on ground-level concentration of four air pollutants – PM^{10}, $PM^{2.5}$, NO_2 and SO_2 – from five measuring stations is available. For each date we construct the average concentration of each of the measured air pollutants during the last 30 days in the port/cluster of plants closest to Lima as an average over the pollutant concentration at each of the five measuring stations weighted by inverse distance between the station and cluster of plants as in Schlenker and Walker (forthcoming)[47] We then run a location-level regression with year×month fixed effects in which we regress the average pollutant level in the Lima area during the 30 days prior to the date in question on fishmeal production by the six plants that are located at the port that is closest to the five stations – Callao – during the same 30 days. As seen in the top panel of Table IX, we find that fishmeal production is significantly positively correlated with all four air pollutants. A 50 percent increase in production in the last 30 days increases PM^{10} by just under 1 percent, $PM^{2.5}$ by 1.3 percent, NO_2 by 0.5 percent, and SO_2 by 1.1 percent.[48] Figure VII directly plots the data on air pollution concentration levels on a given day against the level of fishmeal production on that day, controlling for month fixed effects. The relationship between the two time series is clearly increasing and appears approximately linear.

In the bottom panel of Table IX, we merge the air pollution data with outcome data for the respondents and hospitals in the Lima area. We regress respiratory hospital admissions and adult health outcomes on the 30 day average level of an air pollutant, separately for each of the four pollutants, and instrument each by fishmeal production.[49] We present these IV regressions to illustrate the magnitude of the component of fishmeal production's impact on health that may arise through air pollution, acknowledging that the exclusion restriction is likely violated.[50] While distinguishing the relative contributions of different air pollutants is not the goal of this exercise, it is important to note that PM is regarded by many as a general indicator of air pollution, receiving contributions from fossil fuel burning, industrial processes, and other underlying sources (see e.g. Greenstone and Hanna, 2014). Restricting attention to the PM regressions thus provides a (very) conservative interpretation of the impact of pollution generated by fishmeal production estimated in Table IX.[51]

The results in Table IX show that a one standard deviation (10 $\mu g/m^3$) increase in PM^{10}, as instrumented by fishmeal production, gives an increase in respiratory admissions of 1.3 percent (0.7 percent). A one standard deviation (10 $\mu g/m^3$) increase in $PM^{2.5}$ gives an increase in respiratory admissions of 3.2 percent (2.7 percent). A one standard deviation (10 $\mu g/m^3$) increase in NO_2 gives an increase in respiratory admissions of 6.6 percent (11.2 percent). Finally, a one standard deviation (10 $\mu g/m^3$) increase in SO_2 gives an increase in respiratory admissions of 13.4 percent (16.2 percent). All pollutants, as instrumented by fishmeal production,

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variables, we find a coefficient on "Fishmeal Production in Last 30 Days x Near Port" of 3.192 for "Acute Upper Respiratory Infections." The estimated effect is significant at the 5 percent level, and suggests that the subcategory explains about 80 percent of the total effect on respiratory admissions.

[47] This is done after using the empirical distribution at other stations to impute missing values of a given pollutant at a given station, also following Schlenker and Walker (forthcoming). Note that using a single station and imputing missing values using this technique gives similar results (see Appendix Table A.XI), as does using the mean, max or median across stations.

[48] Once again, given that we estimate the effect of log fishmeal production on pollutants, we display the impact of a 50% change in fishmeal production as $\beta \times \ln(150/100)$.

[49] Child health outcomes are not included because the ENDES data does not have sufficient treatment observations in the vicinity of Callao to estimate standard errors.

[50] PM^{10}, $PM^{2.5}$, NO_2 and SO_2 have all been linked with adverse health outcomes in the existing literature. The exclusion restriction is violated in each of these regressions in the sense that fishmeal production likely affects health also through (at least) three other air pollutants. For a similar approach, see e.g. Malamud and Pop-Eleches (2011).

[51] The correlation between PM^{10} and $PM^{2.5}$, NO_2 and SO_2 is 0.83, 0.39 and 0.37, respectively. The correlation between $PM^{2.5}$ and NO_2 and SO_2 is 0.37 and 0.48 respectively.

also significantly increase "Any Health Issue". These effect sizes are comparable to those that have been found in epidemiological studies relating health outcomes to air pollution.[52] Note that while the fact that some of the pollutants produced are so fine as to penetrate homes (e.g. $PM^{2.5}$) complicates "avoidance behavior", any such behavioral response to the pollution generated by plant production would lead us to underestimate the direct health effects of production.[53]

In sum, the evidence presented in this sub-section is strongly supportive of air pollution emitted by plants being the primary mechanism through which fishmeal production affects adult and child health.[54] In the next section we explore why the impact of plant-generated air pollution on health is increased when production is spread out over time.

7.2 The time profile of production and the impact of air pollution on health

There are two obvious possible reasons why spreading out manufacturing over time could worsen its impact on health: that the total amount of air pollution generated in the "long, low" production scenario is greater than that in the "short, sharp" scenario, and/or that prolonged exposure to low levels of air pollution is worse for health than short-term exposure to higher pollution levels.

All four measured air pollutants decreased in concentration post-reform in the Lima area,[55]. We should not overinterpret this evidence – other factors may also have contributed to changes in air pollution in the Lima area after the point in time when the reform was introduced – but it is difficult to reconcile with a hypothesis in which an increase in overall pollution levels explains the exacerbated impact of downstream plants on health post-reform.

We posit that the primary explanation for why "long, low" plant production is worse for health than "short, sharp" lies in the shape of the health production function, or more specifically, the three-dimensional relationship relating health at a given point in time to both the duration of exposure to air pollution and the intensity of exposure. Though the existing literature typically analyzes the two underlying relationships (duration and dose response) separately, there is in fact a considerable body of evidence in the epidemiological literature indicating that air pollution in high-concentration contexts may have worse health consequences if dispersed over time. Pope III et al. (2015) summarize the evidence on dose (concentration) response: "recent research suggests that the C-R [concentration response] function [between $PM^{2.5}$ and mortality risk] is likely to be supralinear (concave) for wide ranges" (Pope III et al., 2015, p. 516). The authors point out that air pollution in low and middle income countries is frequently in the (higher) part of the concentration range where concavity in dose response is now uncontroversial – as are the fishmeal locations in our sample (though

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[52] In their review of the (primarily correlational) epidemiological literature on particulate matter and health outcomes, Anderson, Thundiyil and Stolbach (2012) cite studies that for example associate a 10 $\mu g/m^3$ (14.8 $\mu g/m^3$) increase in PM^{10} with a 2.28 percent (3.37 percent) increase in respiratory hospital admissions, and a 10 $\mu g/m^3$ increase in $PM^{2.5}$ with a 2.07 percent increase in respiratory admissions. Our estimated effect sizes thus appear plausible in light of the epidemiological literature, though is of course important to keep in mind that the IV results presented here may overestimate the health effect of *each specific* air pollutant by "loading" the health effect of the other air pollutants onto the one in question. Restricting attention to the PM results avoids this possibility, but likely yields an underestimate of the total component of the impact on health that is driven by air pollution.

[53] The final panel of Table V shows the effects of reform on health in Lima. The effects for hospital admissions and log medical expenditures are remarkably similar to our main effects, although neither are significant given the relatively small sample size.

[54] We additionally attempted to compare individuals and hospitals located downwind from the fishmeal plants to those located upwind. The estimated coefficient on "Fishmeal production × Near Plant × North of Plant" is positive in almost all specifications (indicating a more adverse health impact of fishmeal production north of the plants) and for some health outcomes also significant. While winds are reported to blow north most of the time along the coast of Peru, we do not have wind maps that would allow us to precisely define downwind/upwind locations and exploit time variation in wind directions.

[55] PM^{10}, $PM^{2.5}$, NO_2 and SO_2 decreased by in 5, 12, 43 and 18 percent in average concentration during the first year post-reform respectively.

many epidemiologists argue that concentration response may be concave also at lower concentrations (Crouse et al., 2012; Krewski et al., 2009)). The literature on cardiovascular disease risk of exposure to tobacco smoke similarly finds a concave dose response function (California Environmental Protection Agency, 1997; Law, Morris and Wald, 1997; Smith and Ogden, 1998; Smith, Fischer and Sears, 1999). Law et al. (1997) finds the same for lung cancer risks of tobacco. Note that there is considerable biological overlap between the types of health issues considered in this paper and those analyzed in the epidemiological literature summarized in this Sub-section. For example, Pope III et al. (2011) point out that cardiovascular and pulmonary ("of or affecting the lungs") diseases have "substantial common co-morbidity" and argue for conceptualizing a shared health production function for "cardiopulmonary" diseases.

Pope III et al. (2011) summarize the epidemiological evidence on duration response for cardiovascular mortality risk of air pollution and conclude that "the evidence suggests that...longer duration exposure has larger, more persistent cumulative effects than short-term exposure, but the highest marginal effects occur with relatively short-term exposures most proximal in time" (Pope III et al., 2011, p. 1). Beverland et al. (2012), for example, find that "short-term [black smoke] exposure-mortality associations were substantially lower than equivalent long-term associations".

This paper is the first to provide direct evidence on the three-dimensional relationship between health, dose, and duration of air pollution. We do so via the natural experiment represented by Peru's ITQ reform, in which the level of air pollution-generating activity remained essentially constant but was spread out over time. In Figure VIII we take advantage of the detailed information on cause of admission available in the hospital data, and the fact that, considering all ports and seasons observed in our datasets, we observe many different combinations of production levels and time profiles. We relate the total number of hospital admissions for a given cause in a location and production season to the number of days of production that season, controlling for the total amount of production. The figure shows two important results. First, the point estimates are positive for almost every hospital admission category, and significant also for about half. This highlights a central argument of the paper: the number of days of production is harmful to health, even after conditioning on the total (seasonal) level of production. Second, and perhaps more importantly, the disease categories that respond most to how spread out production is across time are exactly the ones we a priori expect to be most influenced by air pollution, such as respiratory issues, digestive issues, and skin issues. While ultimately suggestive, the evidence in Figure VIII is strongly indicative that a given amount of air pollution is more harmful to health if occurring at low concentrations for long periods of time, at least within the range observed in Peru.

8 Quantifying the Risks of Piecemeal Regulation

In this section we analyze what our estimates imply about the magnitude of the risks of piecemeal regulatory design by comparing the cost of the estimated worsening of downstream externalities to the benefit of the decrease in the targeted upstream externality. We have seen that the introduction of individual property rights upstream exacerbated downstream plants' impact on the health of the local population, but that fishmeal companies reported an increase in profits and their suppliers an increase in fish stocks post-reform.[56]

In the costs and benefits of the ITQ reform we include the (monetized) value of the deterioration in

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[56] The increase in fish stocks was likely due to lower juvenile fish capture after the reform, when boats no longer "raced" for fish early in the season. There were likely several reasons for the increase in profits. These include, for example, a decrease in overcapacity. See also Natividad (2014).

health and the increase in sector profits after the reform.[57] We obtained data on the profits of the fishmeal companies that are publicly listed from publicly available financial statements. Since not all companies are listed, we scale these up by extrapolating based on the share of production the publicly listed firms account for in each year to arrive at a yearly, sector-wide estimate. The resulting estimate of the increase in sector-wide profit in the first post-reform year is USD 219 million. (The details of the cost/benefit calculations are in the notes of Table X).

We consider only the increase in disease episodes associated with a respiratory hospital admission and medical expenditures in the total health costs of the reform.[58] We start with the 55,516 additional respiratory hospital admissions caused each year as estimated in Table IV. To quantify the cost of these respiratory disease episodes, we first convert to the equivalent number of "years lived with disability (YLDs)", using standard weights from the Global Burden of Disease Study 2010 (Murray, 2012; U.S. Environmental Protection Agency, 2010). Assuming conservatively that the estimated additional disease episodes did not result in increased mortality, our results imply that in the first post-reform year 5,681 disability-adjusted life year equivalents were lost due to the reform's impact on respiratory diseases. Finally, we use a conventional "value of statistical life (VSL)" method to monetize the DALYs lost.[59] As there are no existing convincing estimates of the VSL in Peru, we present estimates from using both the value estimated for Africans in Leon and Miguel (2015)—the only existing paper to estimate VSL in a developing country setting with revealed preference methods and using a sample fairly close to ours in average income levels—and the VSL for Americans estimated and used by the U.S. Environmental Protection Agency (Murray, 2012; U.S. Environmental Protection Agency, 2010). To scale these VSL estimates, we use the GNI per capita in Sub-Saharan Africa, the U.S., and Peru with the commonly used elasticity recommended by Hall and Jones (2007). The per-year costs of the 2009 ITQ reform due to its impact on respiratory disease episodes estimated using this methodology is between USD 297 million (with the Leon and Miguel (2015) VSL) and USD 128 million (with the EPA VSL). To this we add the additional medical expenditures caused to finally arrive at a total, yearly health cost of the reform of USD 174-343 million.[60]

Comparing these cost estimates to the estimated yearly benefits of the reform to the industry of USD 219 million, it appears that the costs of the 2009 introduction of individual property rights among industrial fishing boats in Peru, due to the unintended add-on effect on downstream plants' impact on health, are of the same order of magnitude as the benefits of the reform. While our calculation probably underestimates the total health costs, as we include only the impacts on respiratory diseases, the methodology used to monetize health costs rests on strong assumptions. Our goal is not to conclusively say whether the costs of the reform exceeded the benefits, but simply to illustrate that the unexpected health impacts of the reform are a first order concern.

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[57] Local incomes are not considered in our cost/benefit calculations as we find no significant effect of the reform on average incomes.

[58] We do not count the health issues measured in the ENAHO and ENDES surveys because it is difficult to estimate the monetary cost of "Any Health Issue", and because the extent to which the health issues reported in the surveys also led to hospital admissions and hence would be double counted if included is unclear.

[59] See e.g. Ashenfelter and Greenstone (2004); Ashenfelter (2006); Hall and Jones (2007); Greenstone, Ryan and Yankovich (2012); Leon and Miguel (2015).

[60] To consider also the reform's impact on fish stocks, we can potentially use government data on stocks to inform how far into the future we should "project" the additional, yearly profits and health costs due to the ITQ reform. There is suggestive evidence that the reform succeeded at slowing the decline in the fish stock. We expect the health costs to be more persistent than the increase in profits, and thus the net cost of the reform to grow over time. (For example, some of the increase in profits in the first year post-reform likely came from a one-time sale of excess plant capacity. Comparing 2011 to 2006, Paredes and Gutierrez (2008) estimate that sector-wide profits increased by USD 144 million.) But we prefer to be conservative and count only the per-year gap.

9 Conclusion

This paper considers the interplay of externalities generated in different parts of the economy due to the interlinkages between firms, and how regulation designed from a partial equilibrium perspective affects the total externalities generated in a production chain. We analyze how a Coasian solution – individual property rights – to overextraction among suppliers in one of the world's largest natural resource sectors affected the impact on health of the downstream manufacturing plants that process the resource.

Using hospital admissions records and survey data on individual health outcomes, and exploiting government-imposed, irregularly timed semi-annual production ban periods in a difference in differences approach, we first document that production by the downstream plants that convert fish from Peru's industrial fishing boats into fishmeal harms adult and child health. We then analyze how the impact on health changed with a 2009 reform that introduced individual, transferable quotas (ITQs) upstream so as to sustain fish stocks. We find that, on average across locations, plants' adverse impact on health increased substantially after the reform, leading to e.g. 55,000 additional respiratory hospital admissions per year and a total, yearly health cost of the reform exceeding USD 174 million.

While total downstream production fell slightly, the quotas removed boats' incentive to "race" for fish early in the season and led inefficient plants to decrease production or exit the market and efficient plants to expand production across time, as predicted by a two-sector model with heterogeneous plants. As a result, downstream production was spread out in time on average across locations. We show that the plants' exacerbated impact on health after the reform was due to this change in the time profile of production.

We use a sub-sample for which air pollution data is available to explore why "long, low" production is worse for health "short, sharp" exposure. We find suggestive evidence that the explanation lies in the shape of the health production function, i.e. that longer periods of exposure to moderate air pollution levels are worse for health than shorter periods of higher intensity exposure. While this paper is the first to consider the health consequences of simultaneous changes in duration and intensity of exposure to polluting plant production, our findings are thus in line with the existing epidemiological evidence, which points to concavity in dose response and importance of concurrent exposure and the duration of exposure to air pollution (Pope III et al., 2015; Pope III and Dockery, 2013; Crouse et al., 2012; Pope III et al., 2011; Krewski et al., 2009; California Environmental Protection Agency, 1997).

These results highlight that the exacerbation of externalities elsewhere in the economy that are ignored when regulatory reforms are designed can be very large, and that regulations' effect on the time profile of production – often ignored by researchers and regulators – can be crucial for industries' impact on welfare. In the particular and common case of natural resource suppliers supplying downstream manufacturing plants, policymakers face a trade-off. On the one hand, the objective of preventing depletion of the resource suggests "internalizing the externality" by giving upstream market participants individual property rights. Such Coasian solutions will tend to spread out production in time as the incentive to "race" for the resource is removed. On the other hand, the evidence in this paper suggests that the impact of pollution on health may be minimized by concentrating downstream production in time.[61] The case analyzed in this paper illustrates a general take-away: the importance of the method and "level" of regulation used to restrict each externality being optimally chosen *in equilibrium*, taking into account the input-output links that connect different firms in the economy.

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[61] Our findings do not speak to the relative merits of the many regulatory methods that can be used to restrict or influence the time profile of production.

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Tables and Figures

Figure I
Location of Fishmeal Ports and Sampling Clusters

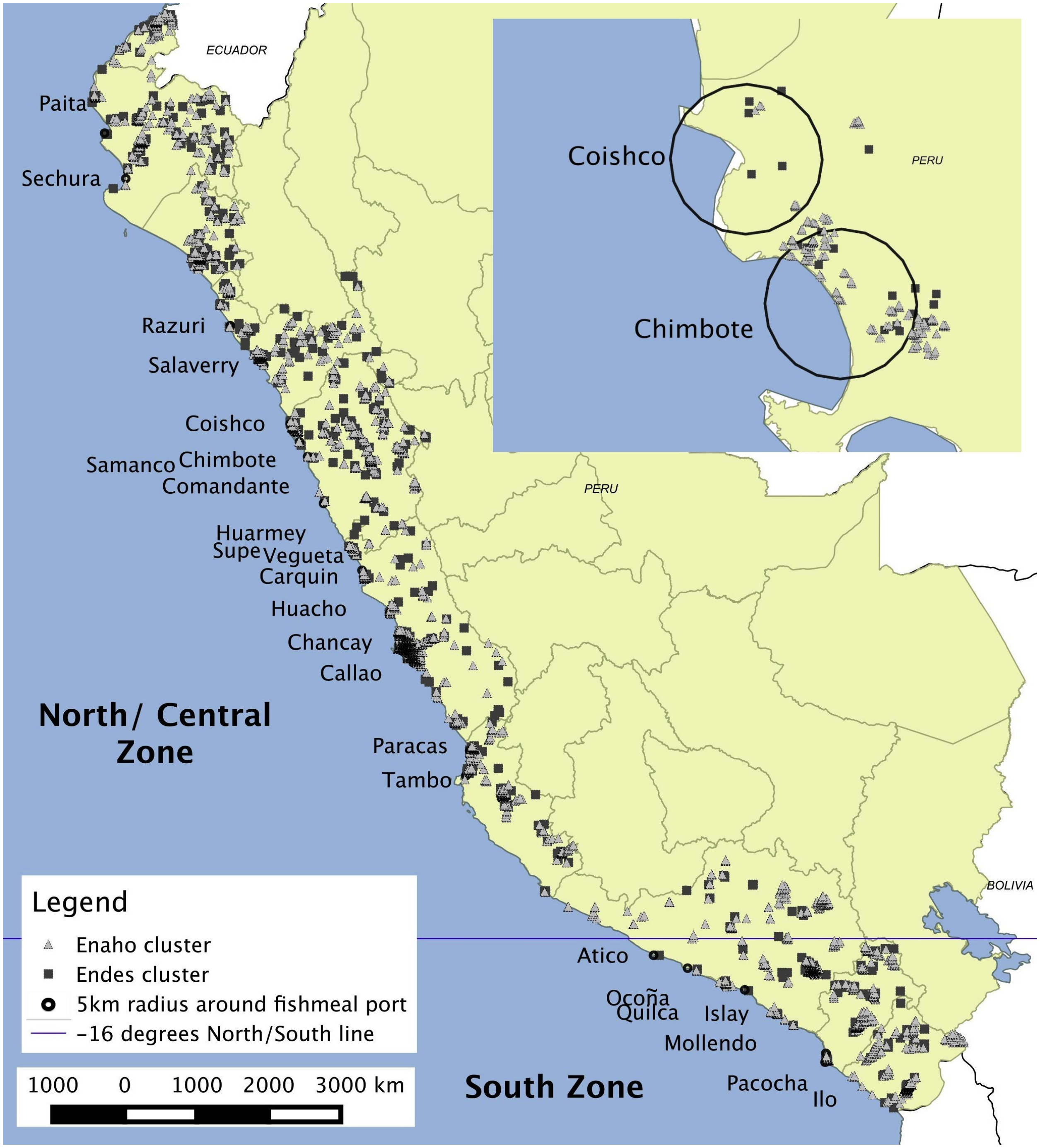
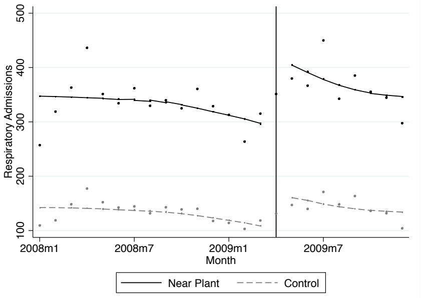
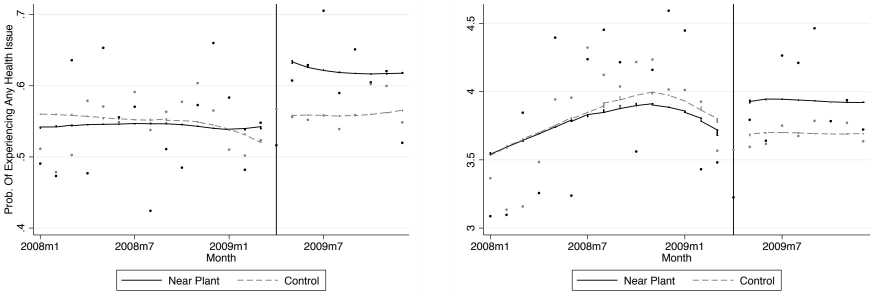


Figure II
Plotting Health Outcomes Across Time Pre- and Post-Reform

(a) Respiratory Admissions



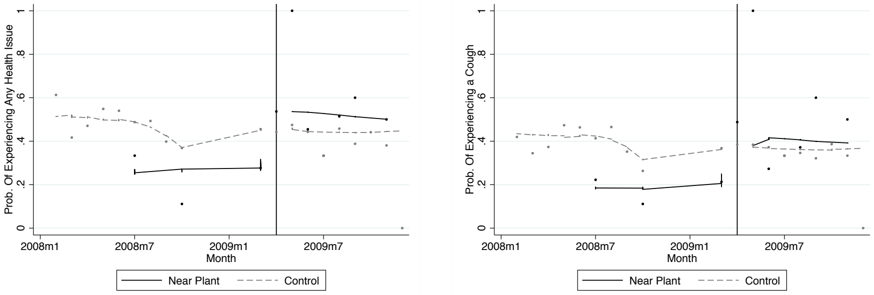
Adults



(b) Any Health Issue

(c) Log Medical Exp.

Children ≤ 5



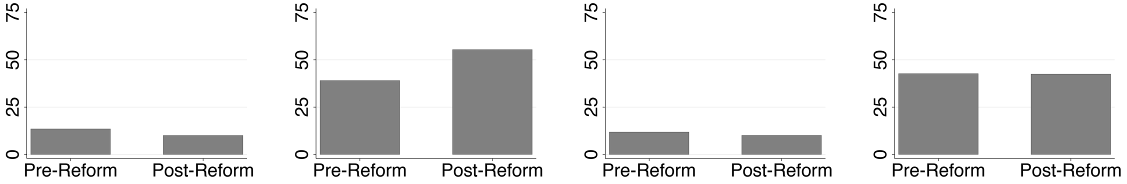
(d) Any Health Issue

(e) Cough

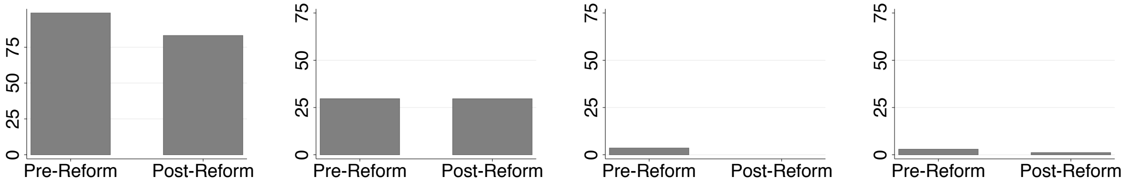
Scatter plots and lowess smoothing of health outcomes across months. Black lines and dots are based on data for those living near plants, gray lines and dots are based on data for all others. Dots are monthly mean levels for each group. Adult data includes those over 13 years of age living in costal regions sampled in ENAHO (2008-2009), child data includes those under 6 years old living in coastal regions sampled in ENDES (2008-2009). Note that no clusters in ENDES sampled in the early part of 2008 were near a plant. Noisier graphs for child outcomes are in general due to smaller sample sizes for children. Smoothed separately before and after the start of the reform in the north region (April 2009). The small South region is omitted due to a later reform starting date and different regulatory change.

Figure III
Port-Level Fishmeal Production Pre- and Post-Reform

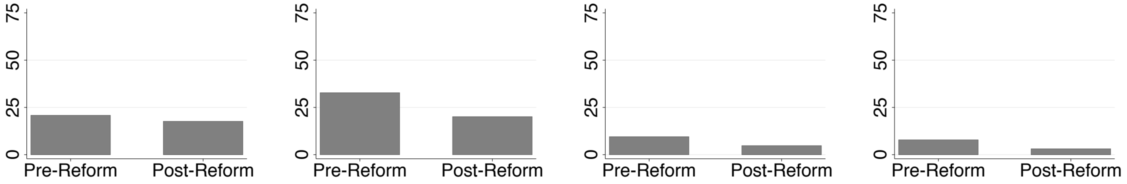
(a) Atico (b) Callao (c) Carquin (d) Chancay



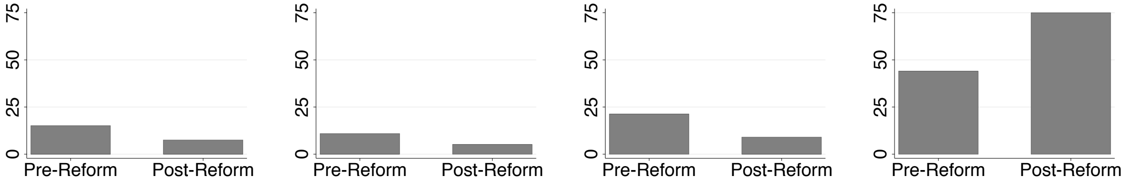
(e) Chimbote (f) Coishco (g) Comandante Noel (h) Huacho



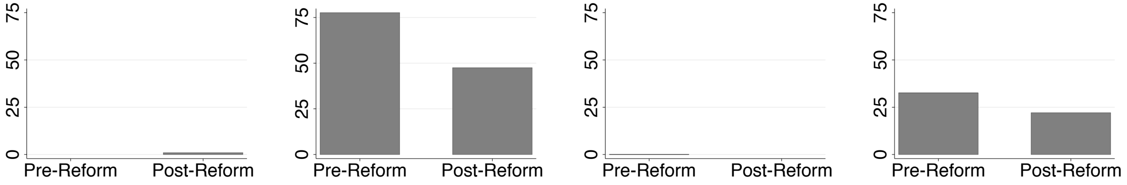
(i) Huarmey (j) Ilo (k) Islay (l) Mollendo



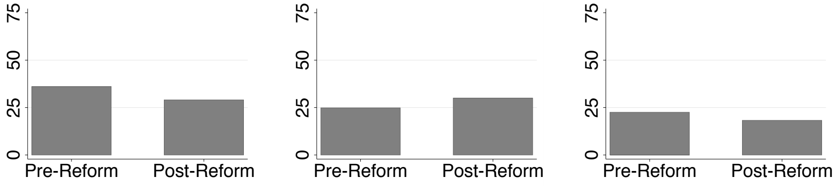
(m) Ocoña (n) Pacocha (o) Paita (p) Paracas



(q) Quilca (r) Razuri (s) Salaverry (t) Sechura

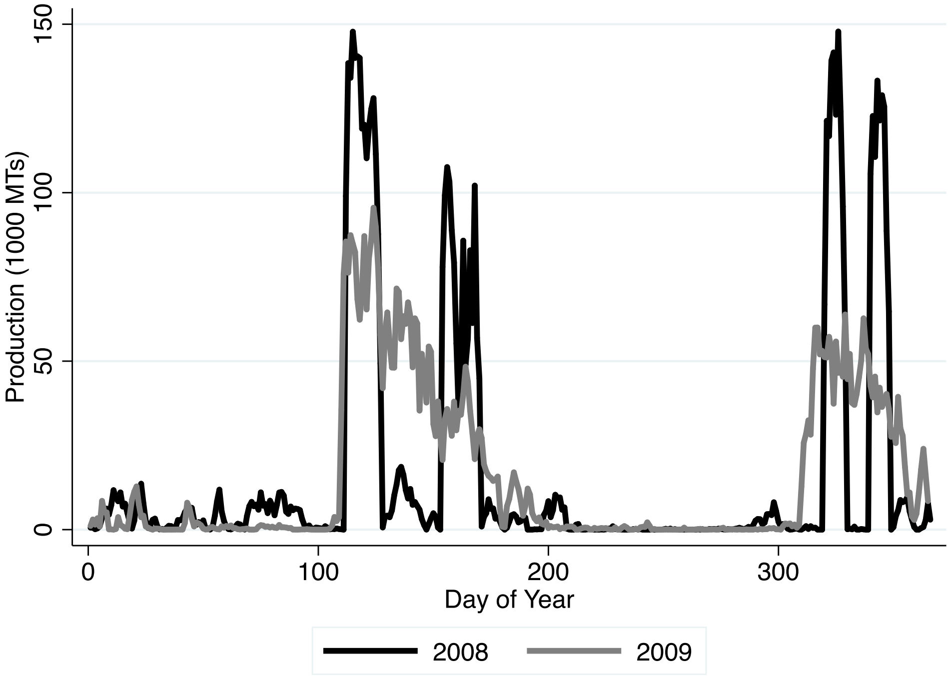


(u) Supe (v) Tambo de Mora (w) Vegueta



Average yearly production levels by port in 1000s of metric tons, pre-and post-reform. There was no production in Quilca pre-reform.

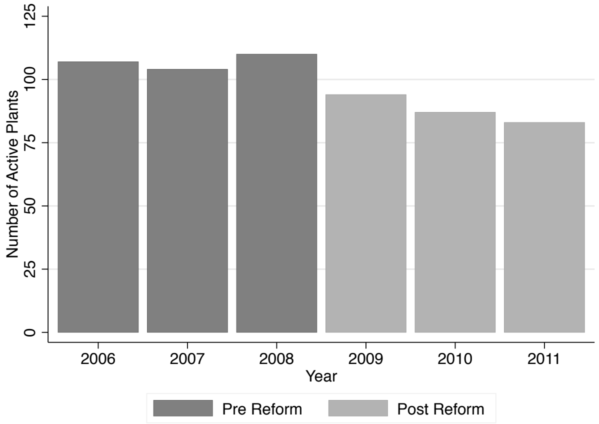
Figure IV
Time Profile of Fishmeal Production



Comparisons of production (measured as fish inputs) in 1000s of metric tons in 2008 and 2009. Before the reform, the seasonal regulation (TAC) had two components; a total amount that could be fished before a specified "pause date" (note that this sub-quota was reached long before the pause date due to the race for fish) and a second amount that could be fished only after a specified "recommence" date. The removal of the pause rule contributed to production being spread out in time after the reform, along with the forces highlighted in our theoretical framework.

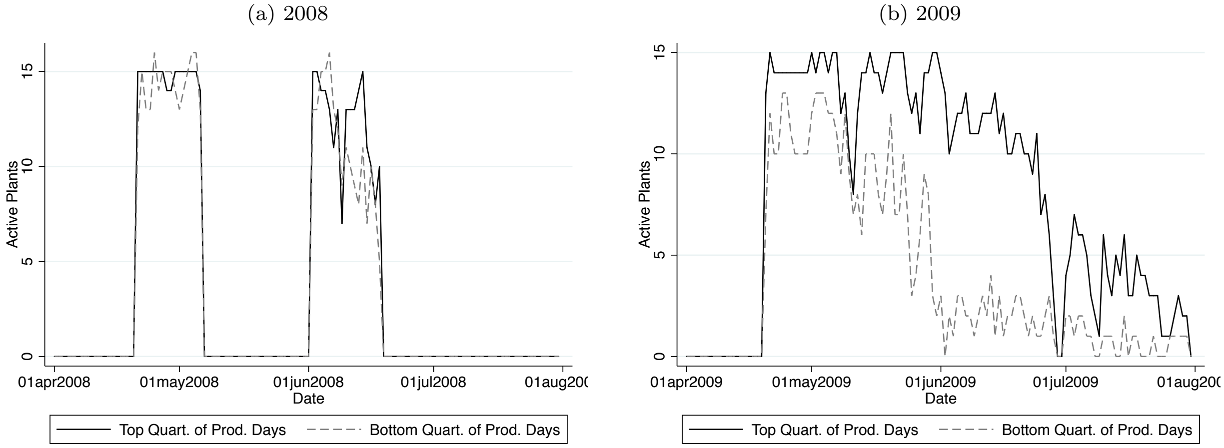
Figure V
Plant Activity Pre- and Post-Reform

Number of Active Plants Across Years



Number of Active Plants During the Season: Top vs. Bottom Quartiles of 2009 Production Days

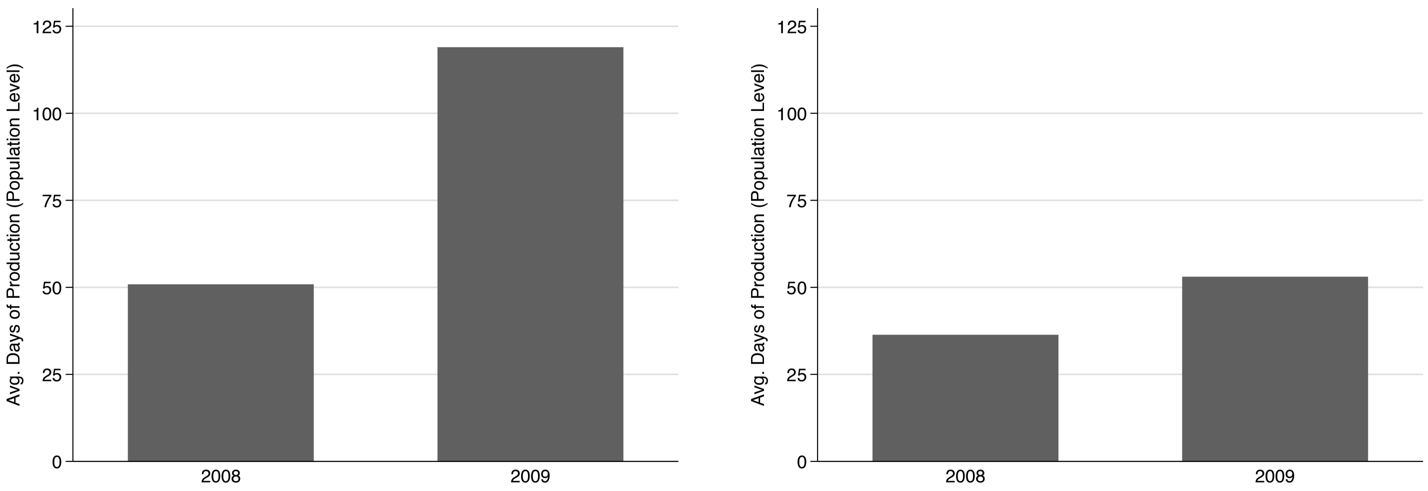
Active Plants


(a) 2008 (b) 2009

Top figure plots total number of active plants by year, where a plant is considered active if it purchases fish input any day of the year. The lower figures plot the number of active plants during the first production seasons in 2008 and 2009. The solid line in each shows plants in the top quartile of production days in 2009, while the dashed line shows plants in the bottom quartile of production days in 2009.

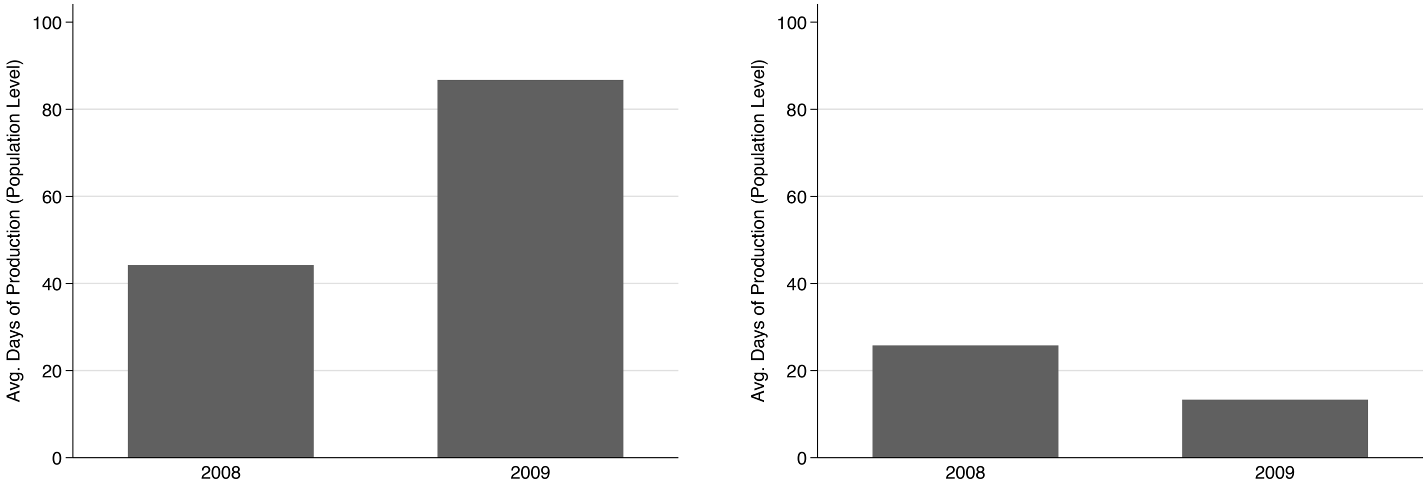
Figure VI

Average Port Level Days of Production by Efficiency: Pre-Reform vs. Post-Reform


(a) Ports in Top Quartile of Efficiency

(b) Ports in Bottom Quartile of Efficiency

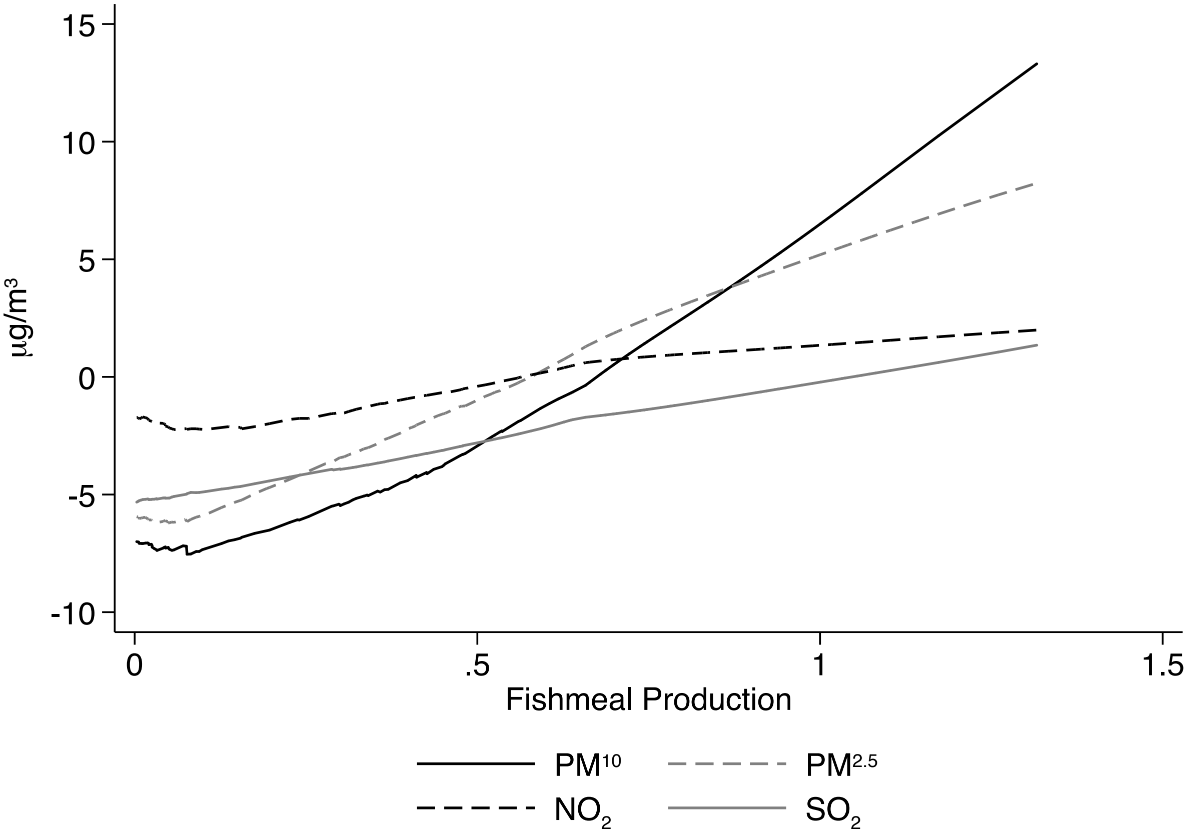
Average Port Level Days of Production by Region: Pre-Reform vs. Post-Reform


(a) North/Central Region

(b) South Region

Top figures show average yearly days of production at the port level (weighted by representation in our adult sample) pre-and post- reform, split by port level efficiency. Bottom figures show average yearly days of production at the port level (weighted by representation in our adult sample) pre-and post- reform in the North/Central and South regions. A production day is defined by > 1000 MTs of input at the port level. Efficiency is measured as the maximum port level yearly output/input ratio.

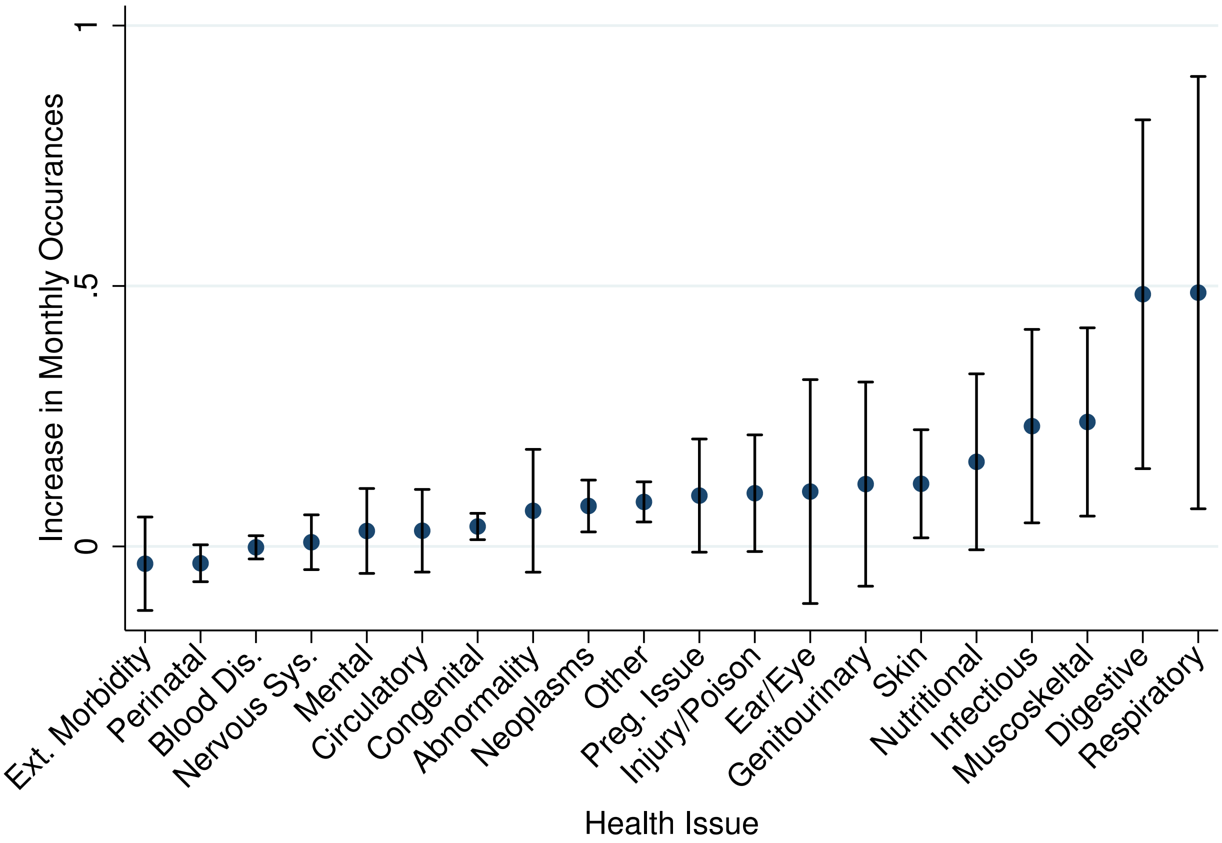
Figure VII
Daily Fishmeal Production and Air Pollution in Lima



Lowess smoothing of month demeaned pollutant levels (in $\mu g/m^3$) against daily fishmeal production in Callao (measured as inputs in 10,000s of MTs) for days with positive production. Pollutant levels at the port of Callao are calculated as the inverse distance weighted mean of 5 air quality measurement stations in Lima. Missing values at individual stations are imputed using the following method: (i) construct the empirical distributions for each of the five stations. (ii) On days that data is missing at a given station, find the value of the empirical distribution on that day for each of the other stations. (iii) Take the inverse distance weighted mean of those values. (iv) Replace the missing data with the concentration corresponding to the point in the empirical distribution found in (iii).

Figure VIII

Impact of Days of Fishing on Hospital Visits: Controlling for Production Level



Results from regressions of hospital visits at the season level for various health issues on total seasonal days of fishing and the total level of seasonal production, as well as hospital and season fixed effects. Coefficients on days of fishing are plotted with 95% confidence intervals. Standard errors are clustered at the hospital level. Only hospitals within 20km of ports are included.

Table I
Summary Statistics: Health Outcomes in Near Plant and Control Locations

	Health Outcomes								
	Near Plant				Control				
	No Prod.		Prod. Season		No Prod.		Prod. Season		
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Diff-in-Diff
Respiratory Admissions	317.8	331.9	334.9	348.9	129.7	173.4	132.7	183.0	14.1*** (4.49)
Any Health Issue (Adults)	0.58	0.49	0.62	0.49	0.59	0.49	0.59	0.49	0.041*** (3.99)
Log Medical Expend.	3.88	2.88	3.88	2.86	3.71	2.86	3.68	2.88	0.027 (0.45)
Any Health Issue (Children)	0.40	0.49	0.46	0.50	0.44	0.50	0.48	0.50	0.019 (0.54)
Cough	0.32	0.47	0.38	0.49	0.36	0.48	0.40	0.49	0.022 (0.64)
	Covariates								
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Diff-in-Diff
Age (Adults)	35.8	21.3	37.2	20.0	35.7	20.6	36.3	20.2	0.85* (2.08)
Age (Children)	2.44	1.42	2.54	1.42	2.50	1.43	2.50	1.43	0.095 (0.94)
Male (Adults)	0.49	0.50	0.48	0.50	0.49	0.50	0.48	0.50	0.00049 (0.05)
Male (Children)	0.52	0.50	0.52	0.50	0.51	0.50	0.50	0.50	0.0017 (0.05)
Years of Education (Adults)	9.87	4.21	9.69	4.29	9.21	4.60	9.47	4.48	-0.44*** (-4.59)
Mothers Years of Educ. (Children)	10.8	3.51	11.6	3.04	9.54	4.14	9.81	3.99	0.54 (1.89)
Current. Lives in Birth Prov. (Adults)	0.43	0.49	0.47	0.50	0.39	0.49	0.40	0.49	0.031** (2.99)
Indigenous Language (Adults)	0.078	0.27	0.11	0.31	0.13	0.34	0.13	0.34	0.038*** (5.32)
HH Asset Index (Children)	0.83	0.67	0.90	0.65	0.29	0.93	0.44	0.91	-0.080 (-1.24)
Observations (Adults)	5172		4563		93852		58225		
Observations (Children)	631		319		9203		4531		
Observations (Hospitals)	13563		8979		77463		41976		

Adult data from ENAHO (2007-2011), child data from ENDES (2007-2011) and hospital admissions from administrative data. Adults older than 13 and children under 6 living in coastal regions are included. All health outcomes excluding "Log Medical Expenditure" and counts of hospital admissions are binary. Medical expenditure is measured in Peruvian Soles. Production seasons are periods in which there has been a production day ($>$ 1000 MTs of input at the port level) in the last 30 days.

Table II
Summary Statistics: Health Outcomes Pre- and Post-Reform

	Health Outcomes								
	Near Plant				Control				
	Pre-Reform		Post-Reform		Pre-Reform		Post-Reform		
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Diff-in-Diff
Respiratory Admissions	327.5	352.5	322.3	327.2	136.5	183.6	124.7	169.4	6.70*
									(2.19)
Any Health Issue (Adults)	0.55	0.50	0.64	0.48	0.57	0.50	0.60	0.49	0.059***
									(5.73)
Log Medical Expend.	3.66	2.89	4.06	2.84	3.59	2.86	3.79	2.88	0.21***
									(3.52)
Any Health Issue (Children)	0.39	0.49	0.43	0.50	0.47	0.50	0.45	0.50	0.063
									(1.69)
Cough	0.32	0.47	0.35	0.48	0.39	0.49	0.37	0.48	0.056
									(1.52)
	Covariates								
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Diff-in-Diff
Age (Adults)	37.7	20.0	35.4	21.3	36.2	19.7	35.7	21.0	-1.72***
									(-4.19)
Age (Children)	2.39	1.40	2.50	1.43	2.51	1.44	2.49	1.43	0.13
									(1.19)
Male (Adults)	0.49	0.50	0.48	0.50	0.49	0.50	0.49	0.50	-0.011
									(-1.06)
Male (Children)	0.50	0.50	0.53	0.50	0.50	0.50	0.50	0.50	0.026
									(0.68)
Years of Education (Adults)	9.64	4.27	9.90	4.22	9.32	4.54	9.30	4.57	0.28**
									(2.94)
Mothers Years of Educ. (Children)	10.9	3.36	11.1	3.38	9.69	4.19	9.60	4.05	0.35
									(1.15)
Current. Lives in Birth Prov. (Adults)	0.45	0.50	0.45	0.50	0.40	0.49	0.38	0.49	0.014
									(1.35)
Indigenous Language (Adults)	0.099	0.30	0.088	0.28	0.13	0.34	0.13	0.34	-0.0083
									(-1.18)
HH Asset Index (Children)	1.00	0.68	0.80	0.64	0.60	0.90	0.21	0.91	0.19**
									(2.81)
Observations (Adults)	4388		5347		7013		9176		
Observations (Children)	255		695		4558		9176		
Observations (Hospitals)	10210		12332		55136		65773		

Adult data from ENAHO (2007-2011), child data from ENDES (2007-2011) and hospital admissions from administrative data. Adults older than 13 and children under 6 living in coastal regions are included. All health outcomes excluding "Log Medical Expenditure" and counts of hospital admissions are binary. Medical expenditure is measured in Peruvian Soles. Post-reform refers to the 2009 ITQ reform, which began on April 20th, 2009 in the North/Central region and July 7th, 2009 in the South.

Table III
Impact of Fishmeal Production on Health

	Hospitals	Adults		Children: ≤ 5	
	Respiratory Admissions	Any Health Issue	Log Medical Expenditure	Any Health Issue	Cough
Log Fishmeal Production in Last 30 Days					
Log Fishmeal Prod. in Last 30 Days	−2.340***	0.010***	0.006	0.002	0.000
	(0.555)	(0.003)	(0.014)	(0.009)	(0.010)
Log Fishmeal Prod. in Last 30 Days x Near Plant	3.952**	0.019***	0.092**	0.014	0.014
	(1.591)	(0.006)	(0.043)	(0.028)	(0.029)
Log Fishmeal Production in Last 90 Days					
Log Fishmeal Prod. in Last 90 Days	−1.800***	0.006**	0.017	−0.001	−0.005
	(0.483)	(0.003)	(0.014)	(0.007)	(0.007)
Log Fishmeal Prod. in Last 90 Days x Near Plant	4.374**	0.010*	0.073**	0.041***	0.039**
	(2.047)	(0.006)	(0.033)	(0.015)	(0.019)
Production Days in Last 30 Days					
Production Days in Last 30 Days	−0.268***	0.001***	0.001	0.000	0.000
	(0.066)	(0.000)	(0.002)	(0.001)	(0.001)
Production Days in Last 30 Days x Near Plant	0.228	0.003***	0.010**	0.000	0.000
	(0.174)	(0.001)	(0.005)	(0.003)	(0.003)
Production Days in Last 90 Days					
Production Days in Last 90 Days	−0.172***	0.000**	0.000	−0.000	−0.001**
	(0.038)	(0.000)	(0.001)	(0.000)	(0.000)
Production Days in Last 90 Days x Near Plant	0.219*	0.001**	0.006***	0.004***	0.003**
	(0.116)	(0.001)	(0.002)	(0.001)	(0.001)
Mean of Dep. Var.	161.6	0.59	3.71	0.45	0.37
N	141981	161773	161806	14684	14678
Hospital/Centro Poblado/District FEs	Yes	Yes	Yes	Yes	Yes
Month x Year FEs	Yes	Yes	Yes	Yes	Yes
Month x Near Plant FEs	Yes	Yes	Yes	Yes	Yes
HH Controls	No	Yes	Yes	Yes	Yes

OLS regressions. Hospital admissions measure total monthly admissions at the hospital level. Adult data includes those over 13 years of age living in costal regions sampled in ENAHO (2007-2011), child data includes those under 6 years old living in coastal regions sampled in ENDES (2007-2011). Last 30 or 90 days is calculated as last 1 or 3 months for hospital data. "Near Plant" is defined as 5 kilometers for survey data and 20 kilometers for hospital data. All specifications include a dummy variable for living near a plant. Adult regressions include controls for age, gender, native language and level of education. Child regressions include controls for age, gender, household assets and mother's level of education. Hospital, adult and child specifications include hospital, Centro Poblado and district fixed effects respectively, with standard errors clustered at the same level. A "Production Day" is defined by > 1000 MTs of input at the port level. Fishmeal production is based on daily inputs of fish, measured in 10,000s of MTs. "Respiratory Admissions" is a count, medical expenditure is measured in Peruvian Soles and all other dependent variables are binary. Mean of dep. var. gives unconditional mean for sample included in the corresponding regression. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table IV
Impact of Fishmeal Industry on Health Before and After 2009 ITQ Reform

	Hospitals	Adults		Children: ≤ 5	
	Respiratory Admissions	Any Health Issue	Log Medical Expenditure	Any Health Issue	Cough
	Baseline (2008-2009)				
Post-Reform x Near Plant	12.239**	0.059**	0.239*	0.184**	0.146
	(5.245)	(0.027)	(0.140)	(0.092)	(0.090)
Mean of Dep. Var.	170.5	0.57	3.70	0.45	0.37
N	57554	62158	62167	6602	6599
	Treatment/Control Specific Time Trends				
Post-Reform x Near Plant	19.483***	0.061*	0.198	0.241**	0.206*
	(6.364)	(0.033)	(0.174)	(0.116)	(0.121)
Mean of Dep. Var.	170.5	0.57	3.70	0.45	0.37
N	57554	62158	62167	6602	6599
	Centro Poblado Specific Time Trends				
Post-Reform x Near Plant	1.417	0.066***	0.243*	0.280***	0.346***
	(7.908)	(0.025)	(0.135)	(0.082)	(0.083)
Mean of Dep. Var.	133.2	0.57	3.70	0.43	0.36
N	48631	62158	62167	4785	4782
	Sample Explanded to 2007-2010				
Post-Reform x Near Plant	9.681*	0.056***	0.181**	0.099***	0.083**
	(5.408)	(0.018)	(0.084)	(0.036)	(0.038)
Mean of Dep. Var.	167.2	0.58	3.68	0.46	0.37
N	114755	125084	125106	11112	11107
	Sample Restricted to First Season of 2008 and 2009				
Post-Reform x Near Plant	17.136***	0.093***	0.317*	0.288***	0.260***
	(5.839)	(0.028)	(0.168)	(0.074)	(0.096)
Mean of Dep. Var.	188.7	0.57	3.73	0.46	0.38
N	28776	31504	31510	5059	5059
	Sample Restricted to Within 50 Kilometers of Port				
Post-Reform x Near Plant	10.319*	0.023	0.155	0.189**	0.167**
	(6.018)	(0.027)	(0.145)	(0.084)	(0.073)
Mean of Dep. Var.	279.8	0.55	3.99	0.46	0.39
N	18620	29042	29049	2450	2448
Hospital/Centro Poblado/District FEs	Yes	Yes	Yes	Yes	Yes
Month x Year FEs	Yes	Yes	Yes	Yes	Yes
Month x Near Plant FEs	Yes	Yes	Yes	Yes	Yes
HH Controls	No	Yes	Yes	Yes	Yes

OLS regressions. Hospital admissions measure total monthly admissions at the hospital level. Adult data includes those over 13 years of age living in costal regions sampled in ENAHO (2007-2010), child data includes those under 6 years old living in coastal regions sampled in ENDES (2007-2010). The reform began on April 20th, 2009 in the North/Central region and July 7th, 2009 in the South. All specifications include a dummy variable for living near a plant. Time trends refers to the inclusion of a treatment or Centro Poblado specific monthly linear trend. Adult regressions include controls for age, gender, native language and level of education. Child regressions include controls for age, gender, household assets and mother's level of education. Hospital, adult and child specifications include hospital, Centro Poblado and district fixed effects respectively, with standard errors clustered at the same level. "Respiratory Admissions" is a count, medical expenditure is measured in Peruvian Soles, all other dependent variables are binary. Mean of dep. var. gives unconditional mean for sample included in the corresponding regression. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table V
Impact of Fishmeal Industry on Health Before and After 2009 ITQ Reform – Controlling For Production

	Hospitals	Adults		Children: ≤ 5	
	Respiratory Admissions	Any Health Issue	Log Medical Expenditure	Any Health Issue	Cough
	Controlling for Log Production in Last 30 Days				
Post-Reform x Near Plant	11.389**	0.052**	0.223	0.188**	0.150*
	(5.302)	(0.026)	(0.144)	(0.081)	(0.087)
Mean of Dep. Var.	171.2	0.57	3.70	0.45	0.37
N	57035	62158	62167	6602	6599
	Controlling for Log Production in Last 90 Days				
Post-Reform x Near Plant	11.519**	0.052**	0.241*	0.222***	0.178**
	(5.357)	(0.025)	(0.140)	(0.063)	(0.080)
Mean of Dep. Var.	171.2	0.57	3.70	0.45	0.37
N	57035	62158	62167	6602	6599
	Controlling for Log Seasonal Production				
Post-Reform x Near Plant	7.880	0.059**	0.212	0.216***	0.172**
	(5.762)	(0.027)	(0.141)	(0.059)	(0.068)
Mean of Dep. Var.	171.2	0.57	3.70	0.45	0.37
N	57035	62158	62167	6602	6599
	Controlling for Levels of Seasonal Production				
Post-Reform x Near Plant	11.225**	0.061**	0.257*	0.192***	0.144**
	(5.512)	(0.027)	(0.141)	(0.056)	(0.059)
Mean of Dep. Var.	171.2	0.57	3.70	0.45	0.37
N	57035	62158	62167	6602	6599
	Sample Restricted to Lima				
Post-Reform x Near Plant	11.406	−0.010	0.238		
	(8.554)	(0.061)	(0.535)		
Mean of Dep. Var.	328.5	0.52	4.17		
N	10420	17227	17234		
Hospital/Centro Poblado/District FEs	Yes	Yes	Yes	Yes	Yes
Month x Year FEs	Yes	Yes	Yes	Yes	Yes
Month x Near Plant FEs	Yes	Yes	Yes	Yes	Yes
HH Controls	No	Yes	Yes	Yes	Yes

OLS regressions. Hospital admissions measure total monthly admissions at the hospital level. Adult data includes those over 13 years of age living in costal regions sampled in ENAHO (2007-2010), child data includes those under 6 years old living in coastal regions sampled in ENDES (2007-2010). The reform began on April 20th, 2009 in the North/Central region and July 7th, 2009 in the South. All specifications include a dummy variable for living near a plant. Time trends refers to the inclusion of a treatment or Centro Poblado specific monthly linear trend. Adult regressions include controls for age, gender, native language and level of education. Child regressions include controls for age, gender, household assets and mother's level of education. Hospital, adult and child specifications include hospital, Centro Poblado and district fixed effects respectively, with standard errors clustered at the same level. "Respiratory Admissions" is a count, medical expenditure is measured in Peruvian Soles, all other dependent variables are binary. Fishmeal production is based on daily inputs of fish, measured in 10,000s of MTs. Mean of dep. var. gives unconditional mean for sample included in the corresponding regression. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table VI
Impact of Fishmeal Industry on Labor Market Outcomes
Before and After 2009 ITQ Reform – By Job Category

	Panel A: All Adults			
	Has Any Job	Has 2nd Job	Total Labor Hours	Log. Total Income
Post-Reform x Near Plant	0.023	−0.001	−0.111	−0.675
	(0.020)	(0.015)	(0.110)	(0.973)
Mean of Dep. Var.	0.63	0.10	3.44	30.3
N	62104	62104	62104	62104
	Panel B: Non-Fishing Workers			
	Has Any Job	Has 2nd Job	Total Labor Hours	Log. Total Income
Post-Reform x Near Plant	0.022	−0.002	−0.110	−0.148
	(0.022)	(0.014)	(0.127)	(1.067)
Mean of Dep. Var.	0.62	0.10	3.40	30.0
N	60832	60832	60832	60832
	Panel C: Fishing Workers			
	Has Any Job	Has 2nd Job	Total Labor Hours	Log. Total Income
Post-Reform x Near Plant	0.097***	0.085	0.453	−3.334
	(0.036)	(0.090)	(0.330)	(6.480)
Mean of Dep. Var.	0.93	0.12	5.67	43.8
N	1272	1272	1272	1272
Hospital/Centro Poblado FEs	Yes	Yes	Yes	Yes
Month x Year FEs	Yes	Yes	Yes	Yes
Month x Near Plant FEs	Yes	Yes	Yes	Yes
HH Controls	Yes	Yes	Yes	Yes

OLS regressions. Data from ENAHO (2007-2011). Adults older than 13 living in coastal regions are included. All specifications include a dummy variable for living within 5 kilometers of a port and controls for age, gender, native language and level of education. Standard errors, clustered at the Centro Poblado level, are included in parentheses. A "Production Day" is defined by $>$ 1000 MTs of input at the port level. Fishmeal production is based on daily inputs of fish, measured in 10,000s of MTs. Total income is measured in Peruvian Soles. Mean of dep. var. gives unconditional mean for sample included in the corresponding regression. Labor categories are based on 3 digit job codes. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table VII

Impact of Fishmeal Production on Health - Production Instrumented by Reform – 2008 and 2009

	First Stage					
	Hospitals		Adults		Children: ≤ 5	
	Production Days In Last		Production Days In Last		Production Days In Last	
	30 Days	90 Days	30 Days	90 Days	30 Days	90 Days
Post-Reform x Near Plant	3.705^{***}	8.572^{***}	5.048^{***}	9.548^{***}	0.415	-2.385
	(0.108)	(0.267)	(1.174)	(2.842)	(0.516)	(4.792)
Mean of Dep. Var. (Near Plant)	5.06	14.4	5.83	14.4	1.87	12.3
N	57035	57035	62167	62167	6755	6755
Hospital/Centro Poblado/District FEs	Yes	Yes	Yes	Yes	Yes	Yes
Month x Year FEs	Yes	Yes	Yes	Yes	Yes	Yes
Month x Near Plant FEs	Yes	Yes	Yes	Yes	Yes	Yes
HH Controls	No	Yes	Yes	Yes	Yes	Yes
	Second Stage - Production in Last 30 Days					
	Hospitals	Adults		Children: ≤ 5		
	Respiratory Admissions	Any Health Issue	Log Medical Expenditure	Any Health Issue	Cough	
Production Days in Last 30 Days x Near Plant	3.061^{**}	0.011^{**}	0.051^{*}	0.602	0.489	
	(1.380)	(0.004)	(0.026)	(0.955)	(0.867)	
	Second Stage - Production in Last 90 Days					
	Hospitals	Adults		Children: ≤ 5		
	Respiratory Admissions	Any Health Issue	Log Medical Expenditure	Any Health Issue	Cough	
Production Days in Last 90 Days x Near Plant	1.349^{**}	0.006^{**}	0.027^{*}	-0.068	-0.054	
	(0.601)	(0.002)	(0.015)	(0.146)	(0.115)	
Mean of Dep. Var.	171.2	0.57	3.70	0.45	0.37	
N	57035	62154	62163	6600	6597	
Hospital/Centro Poblado/District FEs	Yes	Yes	Yes	Yes	Yes	
Month x Year FEs	Yes	Yes	Yes	Yes	Yes	
Month x Near Plant FEs	Yes	Yes	Yes	Yes	Yes	
HH Controls	No	Yes	Yes	Yes	Yes	

Hospital admissions measure total monthly admissions at the hospital level. Adult data includes those over 13 years of age living in costal regions sampled in ENAHO (2007-2011), child data includes those under 6 years old living in coastal regions sampled in ENDES (2007-2011). Last 30 or 90 days is calculated as last 1 or 3 months for hospital data. The top panel shows first stage regressions of production days in the last 30 or 90 days interacted with "Near Plant", on an indicator for the post reform period interacted with "Near Plant." The bottom panels show second stage IV regressions of health outcomes on production days interacted with "Near Plant" instrumented by the post reform period interacted with Near Plant." All specifications also include a dummy variable for "Near Plant," which is defined as 5 kilometers for survey data and 20 kilometers for hospital data. Adult regressions include controls for age, gender, native language and level of education. Child regressions include controls for age, gender, household assets and mother's level of education. Hospital, adult and child specifications include hospital, Centro Poblado and district fixed effects respectively, with standard errors clustered at the same level. A "Production Day" is defined by > 1000 MTs of input at the port level. "Respiratory Admissions" is a count, medical expenditure is measured in Peruvian Soles and all other dependent variables are binary. The reform began on April 20th, 2009 in the North/Central region and July 7th, 2009 in the South. Mean of dep. var. gives unconditional mean for sample included in the corresponding regression. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table VIII
Impact of Fishmeal Industry on Health Before and After 2009 ITQ Reform – North vs. South and Efficient vs. Inefficient Ports

	Hospitals	Adults	
	Respiratory Admissions	Any Health Issue	Log Medical Expenditure
	North vs. South		
Post-Reform x Near Plant	−15.472	−0.080	−0.315*
	(11.603)	(0.054)	(0.178)
North/Central Region x Post-Reform	−20.047***	0.040**	−0.263*
	(3.399)	(0.019)	(0.146)
North/Central Region x Post-Reform x Near Plant	31.151**	0.134**	0.547**
	(12.976)	(0.055)	(0.221)
p-value (Row 1+Row 3=0)	0.182	0.051	0.152
Mean of Dep. Var.	169.8	0.56	3.73
N	56570	58143	58152
	Efficient vs. Inefficient Ports		
Post-Reform x Near Plant	−2.135	−0.072	−0.330
	(22.528)	(0.055)	(0.350)
Pre-Reform Max. Efficiency x Post-Reform	−49.622***	−0.016	−1.333***
	(12.454)	(0.068)	(0.479)
Pre-Reform Max. Efficiency x Post-Reform x Near Plant	56.634	0.356***	1.802**
	(85.399)	(0.129)	(0.813)
p-value (Row 1+Row 3=0)	0.392	0.001	0.005
Mean of Dep. Var.	172.3	0.56	3.74
N	54323	57250	57259
Hospital/Centro Poblado FEs	Yes	Yes	Yes
Month x Year FEs	Yes	Yes	Yes
Month x Near Plant FEs	Yes	Yes	Yes
HH Controls	No	Yes	Yes

OLS regressions. Hospital admissions measure total monthly admissions at the hospital level, limited to 2008/2009. Adult data includes those over 13 years of age living in costal regions sampled in ENAHO (2008-2009). The reform began on April 20th, 2009 in the North/Central region and July 7th, 2009 in the South. All specifications include a dummy variable for living near a plant. Adult regressions include controls for age, gender, native language and level of education. Children are excluded due to a lack of observations in Southern ports. Hospital and adult specifications include hospital and Centro Poblado fixed effects respectively, with standard errors clustered at the same level. "Respiratory Admissions" is a count, medical expenditure is measured in Peruvian Soles, all other dependent variables are binary. The port of Ilo is excluded from both specifications due to production outside of designated seasons. Efficiency is determined by the maximum 2008 output/input ratio for any plant within the port. Efficiency is included as a continuous variable interacted with both living near a plant and post-reform. Mean of dep. var. gives unconditional mean for sample included in the corresponding regression. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table IX
Impact of Fishmeal Production on Health Through Air Pollution in Lima

	Port Level Correlation Between Fishmeal Production and Air Pollution			
	PM^{10}	PM$^{2.5}$	NO$_2$	SO$_2$
Log Fishmeal Prod. in Last 30 Days	1.631*** (0.284)	1.418*** (0.202)	0.328** (0.140)	0.536*** (0.150)
Mean of Dep. Var.	77.9	45.1	25.2	19.2
N	1231	1414	1416	1416
Month x Year FEs	Yes	Yes	Yes	Yes

	Impact of Air Pollution Instrumented by Fishmeal Production on Health		
	Hospitals	Adults	
	Respiratory Admissions	Any Health Issue	Log Medical Expenditure
		PM10	
Avg. PM^{10} Level in Last 30 Days x Near Plant	0.260 (0.526)	0.001*** (0.000)	−0.001 (0.001)
		PM2.5	
Avg. PM$^{2.5}$ Level in Last 30 Days x Near Plant	0.889** (0.434)	0.001*** (0.000)	−0.000 (0.001)
		NO$_2$	
Avg. NO$_2$ Level in Last 30 Days x Near Plant	3.699** (1.808)	0.002*** (0.000)	−0.000 (0.001)
		SO$_2$	
Avg. SO$_2$ Level in Last 30 Days x Near Plant	5.325** (2.602)	0.003*** (0.001)	−0.000 (0.002)
Mean of Dep. Var.	329.2	0.54	4.11
N	19976	33570	33583
Month x Near Plant FEs	Yes	Yes	Yes
Month x Year FEs	Yes	Yes	Yes
HH Controls	Yes	Yes	Yes

Hospital admissions measure total monthly admissions at the hospital level for hospitals whose closest port is Callao. Adult data includes those over 13 years of age whose closest port is Callao sampled in ENAHO (2007-2011). The top panel presents pollutant levels regressed on "Log Fishmeal Production" and month fixed effects. The bottom panel presents IV regressions of health outcomes on average pollutant levels in the last 30 days and average pollutant level in the last 30 days interacted with an indicator for "Near Plant" instrumented by "Log Fish Capture in Last 30 Days" and "Log Fish Capture in Last 30 Days × Near Plant." All pollutants are measured in $\mu g/m^3$. Daily pollutant levels are inverse distance weighted averages of readings at 5 pollution stations in Lima. Missing values at individual stations were imputed using the following technique: (i) construct the empirical distributions for each of the five stations. (ii) On days that data is missing, find the value of the empirical distribution on that day for each of the other stations. (iii) Take the inverse distance weighted average of those values. (iv) Replace the missing data for the station with the concentration corresponding to the point in the empirical distribution found in (iii). Outcomes for children are excluded due to a lack of observations near the port of Callao. Last 30 days refers to the calendar month for hospital data and to the 30 days preceding the survey date for survey data. "Near Plant" is defined as 5 kilometers for survey data and 20 kilometers for hospital data. All specifications include a dummy variable for living near a plant. Adult regressions include controls for age, gender, native language and level of education. Hospital and adult specifications include hospital and Centro Poblado fixed effects respectively, with standard errors clustered at the same level. A "Production Day" is defined by > 1000 MTs of input at the port level. Fishmeal production is based on daily inputs of fish, measured in 10,000s of MTs. Medical expenditure is measured in Peruvian Soles, all other dependent variables are binary. Mean of dep. var. gives unconditional mean for sample included in the corresponding regression. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table X
Cost Benefit Analysis of 2009 ITQ Reform

Panel A: Increase in Sector Profits		
Increase in net income for listed companies (USD)	$58,526,966	
Estimated sector wide increase in net income (USD)	$219,237,448	
Panel B: Health Costs		
Medical Expenditures:		
Estimated increase per person/year	$38	
Estimated total increase (USD)	$45,523,379	
Respiratory Hospital Admissions:		
Estimated increase in total hospital admissions	55,516	
Estimated increase in years lived with disability (YLDs)	5,681	
Estimated cost of years lived with disability (YLDs) A:	$297,455,874	(Leon and Miguel)
Estimated cost of years lived with disability (YLDs) B:	$128,097,109	(US EPA)
Panel C: Total Costs and Benefits		
Estimated benefit to sector (USD)		$219,237,448
Estimated total cost A: (medical exp. + cost of YLDs)		$342,979,253
Estimated total cost B: (medical exp. + cost of YLDs)		$173,620,488

Net income from public available firm financials, calendarized for April-April fiscal years. Sector wide estimates based on 2008 proportion of fishmeal production represented by publicly listed firms. Population estimates are based on total 2009 population living in locations with fishmeal plants from the Peru Institute of National Statistics and Information. Medical expenditure is annualized and extrapolated to the population based on estimates in Table IV. Disability weights translate health conditions over a given duration into an equivalent number of years lived with disability (YLDs). We estimate YLDs using the average disability weight for respiratory diseases (from the Global Burden of Disease Study 2010), and assume a total duration per disease episode of one year. VSL (value of statistical life) estimates for Peru are estimated as $5.42 million, based on an African VSL of $577,000 (from Leon and Miguel (2015)), scaled to Peru GNI using the elasticity in Hall and Jones (2007). We calculate the value of a statistical life year by dividing our VSL estimates by the average life expectancy in the relevant population (40.88, based on remaining life expectancy in Peru for the average individual experiencing a respiratory disease). We alternatively conduct our calculation using a United States VSL estimate of $7.87 million, per US EPA recommendations, again scaled by GNI. All numbers reported are in 2009 USD, calculated using the USA BLS inflation calculator. Scalings use World Bank estimates of GNI per capita (PPP).

Appendix

1.1 Background on fishmeal production, pollution and health in Peru

Case studies have found high levels of air pollution near fishmeal ports during the production seasons. Sueiro (2010) investigated the environmental situation in 2008 in the city surrounding the port of Chimbote, the largest in the country with 27 fishmeal plants operating at the time. The Swedish Meteorological and Hydrological Institute (SMHI) monitored the air quality in the same port area between April 2005 and April 2006. These studies found very high levels of air pollution. (SMHI found that the annual levels of SO_2 were around 110 $\mu g/m^3$ – exceeding the international standard of 80 $\mu g/m^3$. Monthly concentrations of hydrogen sulfide (H_2S) fluctuated between 20 and 40 $\mu g/m^3$ during the fishing seasons, and the hourly concentrations reached 80 to 90 $\mu g/m^3$, again exceeding the WHO standard of seven $\mu g/m^3$). In their reports, focusing especially on Ferrol Bay, the Ministry of the Environment (MINAM) cite investigations that found levels of sulfur dioxide near twice the level of international standards, hydrogen sulfide levels beyond international standards, and PM^{10} levels that vary dramatically over time and can at times reach more than twice the international standard. PM^{10} levels were higher near fishmeal plants (MINAM, 2010, 2011). A study by Consejo Nacional del Medio Ambiente (2010) of air pollution levels in Chimbote from April to August 2006 found a high correlation between PM^{10} and fishmeal production. The concentration of PM^{10} exceeded international standards throughout the study period.

Air pollution in the form of particulate matter has been shown to cause respiratory diseases, cardiovascular diseases and affect mortality in adults (see e.g. Brook RD et al., 2010; Moretti and Neidell, 2011; Schlenker and Walker, forthcoming; Chen et al., 2013; Currie et al., 2014). Some PM components are also associated with heartbeat irregularities, arterial narrowing, issues with lung function and increased emergency room visits (Stanek et al., 2011). PM has also been shown to cause respiratory diseases, skin diseases, eye diseases, and affect lung growth and mortality in children (see e.g. Currie et al., 2014; Currie and Walker, 2011; Gutierrez, 2013; Roy et al., 2012; Jayachandran, 2006; Chay and Greenstone, 2005; World Health Organization, 2006). Chemical pollutants and gases associated with fishmeal production have been linked to respiratory complications, heart disease, low blood cells counts and increased mortality (see e.g. Mustafa and Tierney, 1978; World Health Organization, 2006; Reiffenstein and Roth, 1992; Clarke et al., 2000). (Nitrogen oxide exposure is linked to respiratory effects, airway irritation and lung injury (Mustafa and Tierney, 1978). Short-term sulfur dioxide exposure is associated with higher hospital admissions due to heart disease and pulmonary complications and greater mortality (World Health Organization, 2006). Most organ systems are susceptible to hydrogen sulfide, including the nervous and respiratory systems (Reiffenstein and Roth, 1992). Clarke et al. (2000) found that dogs had reduced blood cell counts when exposed to sulfur).

We are aware of one study of the health effects of air pollution generated by fishmeal plants in Peru. The Regional Health Offices found that, among children 3 to 14 years of age, those in schools located near fishmeal plants had a 10 percent incidence of respiratory diseases in 2003; much higher than in comparable populations (see Sueiro, 2010).

Peru's fishmeal plants are also alleged to pollute the ocean by releasing "stickwater" onto the beaches or into the ocean (see e.g. Rivas, Enriquez and Nolazco, 2008; Elliott et al., 2012). Stickwater can cause skin- and gastrointestinal diseases and conjunctivitis in humans (a) through direct exposure and (b) indirectly, by stimulating the growth of pathogens in the ocean, which can enter seafood and thus, ultimately, humans (Pruss, 1998; Fleming and Walsh, 2006; Garcia-Sifuentesa et al., 2009).

1.2 Robustness

We include a number of alternative specifications as robustness checks of the impact of fishmeal production on health. Here, we discuss those that receive limited attention in the main text.

Instrumental Variables: As the timing of fishmeal production is determined by government-mandated, semi-annual fishing ban periods (which "bind"), we consider the variation in production to be exogenous. However, we can alternatively explicitly instrument for production and production days during the last 30 or 90 days using the number of non-ban days during the same period. The resulting estimates are very similar to those in Table III when using survey-measured health outcomes, as seen in Appendix Table A.I.[62]

Log of Hospital Admissions: While our primary specifications include the count of hospital admissions as a dependent variable, we alternatively present our specifications with ln(hospital admissions) as a dependent variable in Appendix Table A.II. The results are qualitatively similar in terms of sign and significance to our primary specifications.

Varying Treatment Radius and Lookback Window: The treatment radius and lookback windows used in Table III were informed by the existing literature and the window used in the ENAHO survey questions[63], but nevertheless involved a degree of choice. In Figure A.II, we plot treatment effects estimated for all radii between 0 and 30 kilometers from fishmeal ports, for all outcomes.[64] For survey outcomes, the impact on health decays with distance from the nearest plant, although effects on "Any Health Issue" persist even at larger radii. For hospitals the effects become large and precisely estimated with radii that allow the inclusion of hospitals at most ports, as expected. In Figure A.III, we plot treatment effects for production days estimated with a lookback window varying from 0 to 120 days. For production days within the lookback window, the point estimates are generally biggest in short windows for adults. For children, the effects are imprecisely estimated at short windows, but become precisely estimated and significant with larger windows. The estimates in Figures A.II and A.III support the choice of 5/20 kilometer treatment radii and 30/90 lookback windows, and a causal interpretation of the estimates in Table III.

Falsification Exercise: In Appendix Table A.IV we show estimates from a falsification exercise using hospital admissions due to health issues that should not be affected by plant production as dependent variables: "Congenital Disorders", "External Factors such as injury and poisoning", and "Mental, Behavioral, and Neurodevelopmental disorders." We find no significant effects.

Alternative Channels for the Health Impact of Fishmeal Production: Whether the estimated adverse health effects in the full sample are due to worse health during the production periods for those who work in the sector, or if instead whole communities are affected, is informative about the underlying mechanism. Recall that fishmeal production is a capital intensive industry. Only five percent of the adult sample in fishmeal locations report to work in "fishing", a broader category that includes the fishmeal sector. In Table A.V, we show results from estimating equation (1) separately for those who work in fishing. We

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[62] The lack of cross-sectional variation in the instrument leads to imprecise estimates for the hospital admissions outcome variable. While survey-measured outcomes vary by day (and production and the instrument can therefore also be measured at the daily level), hospital admissions is measured only at the monthly level.

[63] A typical ENAHO question reads "Did you experience X in the past 30 days?".

[64] Production here is defined as the number of production days in the last 90 days, as this is the time window in which we find significant effects of fishmeal production on the health also of chidren.

see that fishing workers display health effects that are similar to those of other individuals.[65] One notable exception is a bigger increase in medical expenditures for fishing workers during production seasons, which may partly reflect an income effect. Overall, these results suggest that the estimated adverse health effect in the full sample are not driven by effects on the health of workers in the industry.

Another possible mechanism is that industrial fishing/fishmeal production affects health through labor market responses. In Table A.VI we investigate the impact of fishmeal production on labor market outcomes. As expected, we do see increases in the likelihood of having a job and in total income for workers in the industry during production seasons. However, fishmeal production does not affect average incomes and labor market outcomes in the full sample of adults. This suggests that the observed health effects are not due to changes in local labor markets during the production seasons.

A third possibility is that a part of the observed effect of fishmeal production on "Any Health Issue" operates through pollution of the ocean.[66] However, as seen in Table A.V, we do not observe bigger health effects for those who work in fishing, who presumably have greater direct exposure to the ocean. Moreover, in Appendix Table A.VII, we show that (a) the estimated health effects are not of greater magnitude for individuals who consume more fish, and (b) fishmeal production does not increase pollution at beaches near ports relative to those further away. We conclude that ocean pollution is unlikely to contribute noticeably to the estimated health effects of fishmeal production.

Alternative Hospital Outcomes: In Appendix Table A.X, we expand the set of health outcomes to consider hospital admissions not only for respiratory issues (the type of disease episodes that we hypothesize to be most likely to respond to short-term variation in air pollution), but also for other health issues that the previous literature has found to correlate with air pollution. We find that fishmeal production increases total hospital admissions, admissions for digestive diseases (see also Kaplan et al., 2010), and for pregnancy complications. These results underline the seriousness of the fishmeal industry's impact on the health of Peru's coastal population.

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[65] The small number of fishing workers in our sample gives us limited power to detect differential effects but also suggests that fishing workers do not drive the aggregate effects we find.

[66] If greasy "stickwater" is released onto the beaches or directly into the ocean, a process of eutrophication can lead organisms (e.g. algae) and bacteria to grow excessively. Toxins can in turn affect human health either through direct exposure or through the consumption of seafood (World Health Organization, 2002; Committee on Nutrient Relationships in Seafood, 2007). (Effects on respiratory hospital admissions and coughs are unlikely to be due to ocean pollution).

1.3 Theoretical framework

In this section, we present a simple two-sector model with homogeneous suppliers (boats) upstream and heterogeneous final good producers (plants) downstream. The model predicts how the introduction of individual property rights over intermediate goods will tend to affect the spatial and temporal distribution of final good production. With an added hypothesis on how the distribution of final good production matters for the impact of downstream externalities, the model thus delivers a prediction for upstream Coasian solutions' downstream consequences. As explained in the body of the paper, the model's predictions will help us test hypotheses on why the fishmeal industry's impact on health may have changed as a result of Peru's ITQ reform.

The intuition of the model is as follows. An industry wide quota regime encourages boats to "race" for fish early in the season. A high per-period fish capture early in the season in turn decreases the price of fish and thereby allows less efficient fishmeal plants to survive. When boats' incentive to race for fish is removed with the introduction of individual quotas, fishing is spread out in time, the price of fish increases and less efficient plants are forced to reduce their production or exit the industry.

The model consists of two sectors: homogeneous fishing boats, who capture and sell fish, and heterogeneous fishmeal plants, who buy fish to use as an intermediate good and sell fishmeal on the international market. We assume that the price of fishmeal is fixed, and that the price of fish is determined in equilibrium based on the contemporaneous demand for and supply of fish.

Fishing boats. Our specification of the boat sector follows Clark (1980) and subsequent research. There are N identical boats, who capture fish (q_i) as a function of (costly) effort e_i and the stock of fish x, according to $q_i = \gamma x e_i$, where γ is a constant. Boats face an increasing and convex cost of effort $c(e_i)$, and a decreasing inverse market demand $p(q)$. Within each season, the fish stock declines according to the amount captured, that is $x(t) = x_0 - \int_0^t \gamma x(t') \sum_i^N e_i(t') dt'$.

Let the maximum length of the season under any regulatory regime be T. We first consider the case of an industry wide total allowable catch (TAC) quota, with magnitude H.[67] We take boats to be small relative to the industry, and assume they take the path of prices $p(t)$ and the fish stock $x(t)$ as given. Each boat chooses $e_i(t)$ for all t to maximize:

$$\pi_i = \int_0^{t^*} [p(t)\gamma x(t) e_i(t) - c(e_i(t))] dt \tag{5}$$

which gives optimal effort $e_i^*(t)$ defined by the first order condition $c_i'(e_i^*(t)) = p(t)\gamma x(t)$. Under the TAC regime, boats simply choose effort to equate marginal revenue and marginal costs, without internalizing their impact on the fish stock.

We next turn to the individual quota regime (ITQ). We assume that each boat is assigned a quota of H/N. There is no fixed t^*; instead each boat implicitly chooses a path of effort that determines when their quota is exhausted (time $\tilde{t}$) – an optimal control problem for each boat's cumulative catch, $y_i(t)$. Each boat solves:

$$\max \int_0^{\tilde{t}} [p(t)\gamma x(t) e_i(t) - c(e_i(t))] dt \tag{6}$$

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[67] We focus on situations where the quota binds. The season ends when the total quantity of fish captured is equal to the industry quota H.

subject to $\frac{dy_i}{dt} = \gamma x(t)e_i(t)$ for $0 \leq t \leq \tilde{t}$, $y_i(0) = 0$, $y_i(\tilde{t}) = H/N$, and $\tilde{t} \leq T$. This gives $c'(e_i(t)) = (p(t) - \lambda_i)\gamma x(t)$ and $\frac{d\gamma_i}{dt} = -\frac{\partial \mathcal{H}}{\partial y_i} = 0 \Rightarrow \lambda_i$ constant.[68] If the quota binds, $\lambda_i > 0$.

λ_i represents each boat's internalization of the reduction in season length generated by an additional unit of effort. We can write the inverse demand in equilibrium in terms of the individual effort decision and stock of fish. We can then rewrite the first order conditions (with e^* representing the optimal effort level of a boat under the TAC regime, and $\tilde{e}$ representing the optimal effort level under the ITQ regime) as $c'(e_i^*(t)) = p(\gamma x(t)e_i^*(t))\gamma x(t)$ for $t \leq t^*$ and $c'(\tilde{e}_i(t)) = [p(\gamma x(t)\tilde{e}_i(t)) - \lambda_i]\gamma x(t)$ for $t \leq \tilde{t}$.

With λ_i in hand the effort decision at any t is determined by $x(t)$ at all points. It is thus helpful to consider each boat as simply solving a static problem (at any t) that differs under the two regimes as follows:

$$c'(e_i^*) = p(\gamma x e_i^*)\gamma x \tag{7}$$

$$c'(\tilde{e}_i) = [p(\gamma x \tilde{e}_i) - \lambda_i]\gamma x \tag{8}$$

These two equations imply that (a) facing an equal stock of fish x, effort at any t must be weakly higher in the TAC regime, and (b) fish capture is decreasing in the stock of fish under both regimes.[69] Together (a) and (b) imply that the highest fish capture, and lowest price, occur under the TAC regime (when the stock of fish is at its initial x_0). Finally, (c) the fish stock must always be weakly higher under the ITQ regime than under the TAC regime. Hence, the season must be longer under the ITQ regime.[70]

Fishmeal plants. We now turn to the plant sector. There is a mass M of fishmeal plants with heterogenous marginal costs that require one unit of intermediate good q to produce each unit of the homogeneous final good q^f. The price of the final good is normalized to one. The price of the intermediate good at time t is $p(t)$. Let plant j's marginal cost be given by:

$$MC_j(q^f, p(t)) = MC(q^f) + \alpha_j + p(t) \tag{9}$$

where α_j is a plant-specific constant. If firms share common technology outside of the α_j, the minimum average cost for each firm can be described as $r + \alpha_j + p(t)$, where r is the minimum average cost for a firm with $\alpha_j = 0$ and facing 0 cost of the intermediate good. Firm j produces some positive amount so long as $r + \alpha_j + p(t) < 1$. This means that as firms face higher input prices $p(t)$, the less efficient firms – those with high α_j – decrease production and eventually drop out of the market. Each firm has a threshold price

$$p_j^* = 1 - r - \alpha_j \tag{10}$$

above which it will not produce. Let p_j^* be distributed among firms in the industry on [0,1] according to $F(\cdot)$. For firm j, denote demand by $\tilde{q}(p(t), p_j^*)$ (where demand is 0 for $p(t) < p_j^*$). We can then describe the market demand $q(p(t))$ by:

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[68] The Hamiltonian is: $\mathcal{H} = p(t)\gamma x(t)e_i(t) - c(e_i(t)) + \lambda_i \gamma x(t)e_i(t)$.

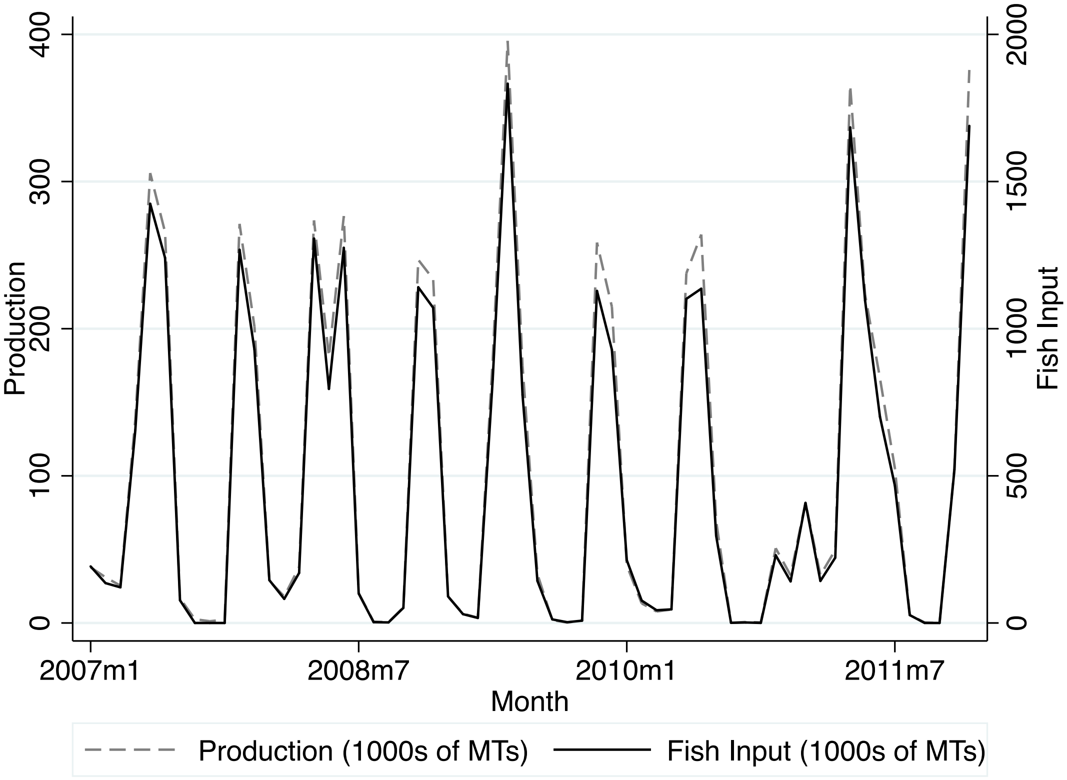
[69] Suppose, for the TAC regime, that $x > x'$, but $\gamma x' e_i' \geq \gamma x e_i$. Then $e_i' > e_i$, so $c'(e_i) < c'(e_i') = p(\gamma x' e_i')\gamma x' < p(\gamma x e_i)\gamma x = c'(e_i)$. An identical argument holds for the ITQ regime.

[70] Note that a necessary condition for $x^*(t) > \tilde{x}(t)$, for some t, is that there be some x such that the equilibrium effort at fish stock x is higher under the ITQ regime than under the TAC regime.

$$q(p(t)) = M \int_{p(t)}^{1} \tilde{q}(p(t), p_j^*) dF(p_j^*) \tag{11}$$

Under standard assumptions, this gives decreasing market demand. As discussed above, the highest per-period production, and lowest price, occur under the TAC regime. For fishmeal plants, this implies that (d) a greater mass of plants have non-zero production (at some point in the season) in the TAC regime than in the ITQ regime, and (e) the plants that produce in the TAC regime but not in the ITQ regime are those with the lowest p_j^*, that is, those with the highest marginal cost. We test the model's predictions in the next section.

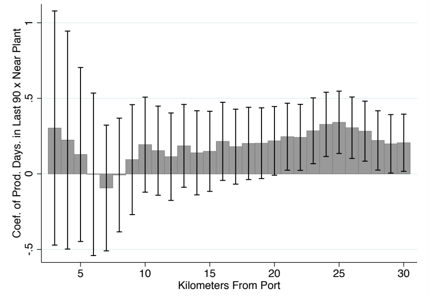
Figure A.I
Relationship Between Fishmeal Production and Input of Fish



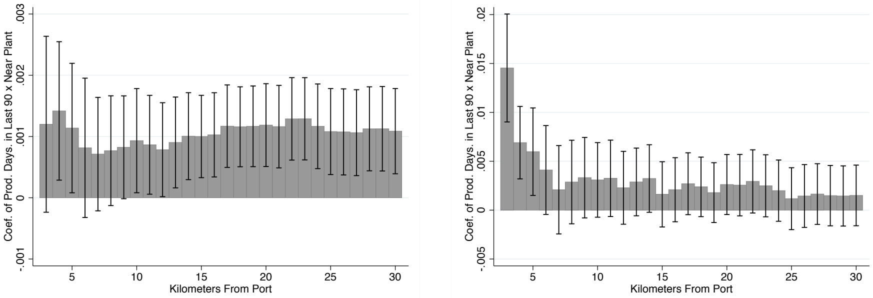
Monthly port level fishmeal production (dashed line) and fish input (solid line), measured in 1000s of metric tons. Input based on daily boat level fish capture as weighed at fishmeal plants. Production based on monthly plant level reports.

Figure A.II
Impact of Fishmeal Production on Health: Varying Treatment Radius

(a) Respiratory Admissions



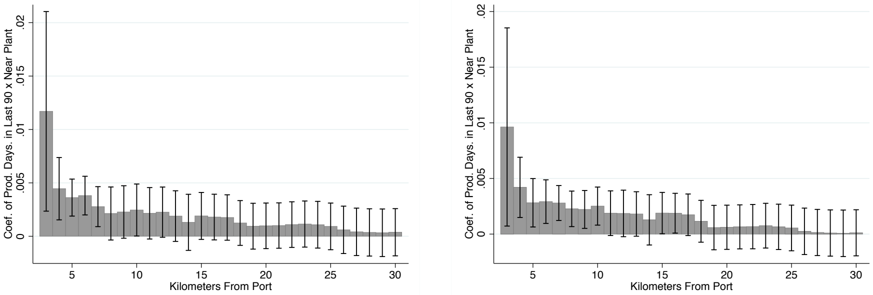
Adults



(a) Any Health Issue

(b) Log Medical Expenditure

Children (≤ 5)



(c) Any Health Issue

(d) Cough

Children (≤ 1)

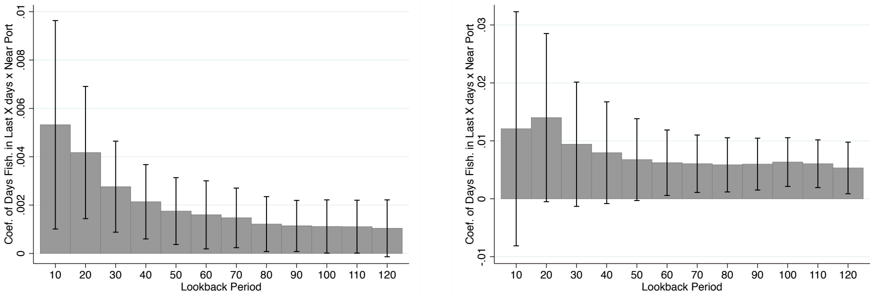
We plot the coefficient of "Production Days in the Last 90 Days × Near Plant", based on regressions similar to those in Table III. We allow the treatment radius that defines "Near Plant" to vary up to 30 kilometers and correspondingly vary the control group, defined as those living outside the treatment radius. 95% confidence intervals based on standard errors clustered as in Table III are shown.

Figure A.III
Impact of Fishmeal Production on Health: Varying Lookback Window

Adults

(a) Any Health Issue

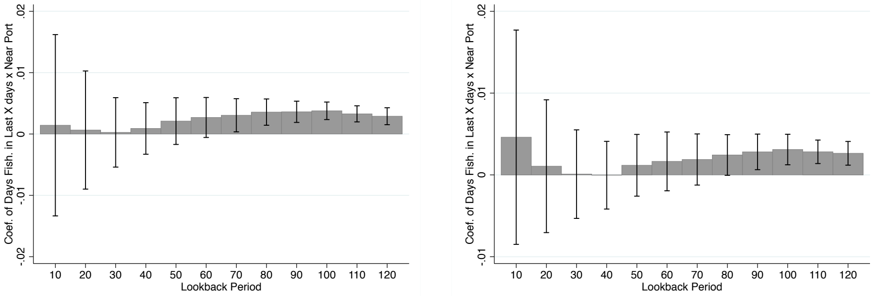
(b) Medical Expenditure



Children (≤ 5)

(c) Any Health Issue

(d) Cough



We plot the coefficient of "Production Days in the Last x Days × Near Plant", based on regressions similar to those in Table III. We allow the length of the lookback window "x" to vary up to 120 days. 95% confidence intervals based on standard errors clustered as in Table III are shown. Figures for hospital admissions are not shown as the data only allows for monthly variation in the lookback window.

Table A.I
Impact of Fishmeal Production Instrumented by Fishing Seasons on Health

	Hospitals	Adults		Children: ≤ 5	
	Respiratory Admissions	Any Health Issue	Log Medical Expenditure	Any Health Issue	Cough
	Log Fishmeal Production in Last 30 Days				
Log Fishmeal Prod. in Last 30 Days		0.002	−0.015	0.034	0.013
		(0.009)	(0.042)	(0.032)	(0.033)
Log Fishmeal Prod. in Last 30 Days x Near Plant	−6.316	0.068***	0.243**	0.010	0.033
	(6.870)	(0.021)	(0.095)	(0.048)	(0.055)
	Log Fishmeal Production in Last 90 Days				
Log Fishmeal Prod. in Last 90 Days		−0.002	−0.031	−0.002	−0.032
		(0.012)	(0.053)	(0.024)	(0.026)
Log Fishmeal Prod. in Last 90 Days x Near Plant	−3.531	0.147*	0.516*	0.045	0.103**
	(14.704)	(0.089)	(0.304)	(0.056)	(0.049)
	Production Days in Last 30 Days				
Production Days in Last 30 Days		0.001	−0.003	0.004	0.002
		(0.001)	(0.007)	(0.004)	(0.004)
Production Days in Last 30 Days x Near Plant	−0.566	0.008**	0.024*	0.001	0.004
	(0.615)	(0.003)	(0.013)	(0.006)	(0.007)
	Production Days in Last 90 Days				
Production Days in Last 90 Days		−0.001	−0.001	−0.000	−0.003
		(0.001)	(0.004)	(0.002)	(0.002)
Production Days in Last 90 Days x Near Plant	−0.087	0.005***	0.018**	0.004	0.009**
	(0.362)	(0.002)	(0.007)	(0.005)	(0.004)
Hospital/Centro Poblado/District FEs	Yes	Yes	Yes	Yes	Yes
Month x Year FEs	Yes	Yes	Yes	Yes	Yes
Month x Near Plant FEs	Yes	Yes	Yes	Yes	Yes
HH Controls	No	Yes	Yes	Yes	Yes

IV regressions of health outcomes regressed on measures of production ("Log Fishmeal Production" and "Production Days") and those measures of production interacted with a dummy for living near a plant. We instrument for production and the interaction with the number of days the fishing season was open in last 30 or 90 days and number of days the fishing season was open × "Near Plant." Hospital admissions measure total monthly admissions at the hospital level. Adult data includes those over 13 years of age living in costal regions sampled in ENAHO (2007-2011), child data includes those under 6 years old living in coastal regions sampled in ENDES (2007-2011). Last 30 or 90 days is calculated as last 1 or 3 months for hospital data. "Near Plant" is defined as 5 kilometers for survey data and 20 kilometers for hospital data. All specifications include a dummy variable for living near a plant. Production not interacted with near plant excluded from hospital regressions due to collinearity with Month × Year fixed effects. Adult regressions include controls for age, gender, native language and level of education. Child regressions include controls for age gender, household assets and mother's level of education. Hospital, adult and child specifications include hospital, Centro Poblado and district fixed effects, respectively, with standard errors clustered at the same level. A "Production Day" is defined by $>$ 1000 MTs of input at the port level. Fishmeal production is based on daily inputs of fish, measured in 10,000s of MTs. "Respiratory Admissions" is a count, medical expenditure is measured in Peruvian Soles and all other dependent variables are binary. Mean of dep. var. gives unconditional mean for sample included in the corresponding regression. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table A.II
Impact of Fishmeal Production on Log Hospital Admissions

	ln(Hospital Admissions)			
Log Fishmeal Prod. in Last 30 Days	0.021*** (0.005)			
Log Fishmeal Prod. in Last 30 Days x Near Plant	0.016 (0.011)			
Log Fishmeal Prod. in Last 90 Days		0.037*** (0.005)		
Log Fishmeal Prod. in Last 90 Days x Near Plant		0.021* (0.012)		
Production Days in Last 30 Days			0.002** (0.001)	
Production Days in Last 30 Days x Near Plant			0.004*** (0.001)	
Production Days in Last 90 Days				0.001*** (0.000)
Production Days in Last 90 Days x Near Plant				0.003*** (0.001)
Mean of Dep. Var.	4.26	4.26	4.26	4.26
N	141981	141981	141981	141981
Hospital FEs	Yes	Yes	Yes	Yes
Month x Year FEs	Yes	Yes	Yes	Yes
Month x Near Plant FEs	Yes	Yes	Yes	Yes

OLS regressions. Hospital admissions measure total monthly admissions at the hospital level. Last 30 or 90 days is calculated as last 1 or 3 months for hospital data. Near plant is defined as 20 kilometers for hospital data. Hospital fixed effects are included and standard errors are clustered at the hospital level. A "Production Day" is defined by > 1000 MTs of input at the port level. Fishmeal production is based on daily inputs of fish, measured in 10,000s of MTs. Mean of dep. var. gives unconditional mean for sample included in the corresponding regression. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table A.III
Impact of Fishmeal Production on Health - Before 2009 Reform

	Hospitals	Adults		Children: ≤ 5	
	Respiratory Admissions	Any Health Issue	Log Medical Expenditure	Any Health Issue	Cough
			Log Fishmeal Production in Last 30 Days		
Log Fishmeal Prod. in Last 30 Days	−7.196***	0.009*	0.001	0.012	−0.001
	(0.864)	(0.005)	(0.027)	(0.032)	(0.032)
Log Fishmeal Prod. in Last 30 Days x Near Plant	8.741***	0.012	0.087	0.220***	0.087**
	(2.985)	(0.011)	(0.076)	(0.038)	(0.034)
			Log Fishmeal Production in Last 90 Days		
Log Fishmeal Prod. in Last 90 Days	−6.905***	−0.002	0.003	0.035*	0.020
	(0.616)	(0.004)	(0.022)	(0.021)	(0.025)
Log Fishmeal Prod. in Last 90 Days x Near Plant	1.701	0.026***	0.012	0.468***	0.192
	(3.159)	(0.009)	(0.097)	(0.119)	(0.152)
			Production Days in Last 30 Days		
Production Days in Last 30 Days	−1.244***	0.001	0.003	0.001	−0.002
	(0.155)	(0.001)	(0.005)	(0.005)	(0.005)
Production Days in Last 30 Days x Near Plant	1.203**	0.003**	0.009	0.014**	−0.004
	(0.581)	(0.002)	(0.009)	(0.006)	(0.005)
			Production Days in Last 90 Days		
Production Days in Last 90 Days	−0.634***	−0.000	0.003	0.002	0.000
	(0.070)	(0.001)	(0.003)	(0.002)	(0.002)
Production Days in Last 90 Days x Near Plant	−0.233	0.002	−0.003	0.022***	0.006
	(0.344)	(0.001)	(0.003)	(0.007)	(0.009)
Mean of Dep. Var.	170.1	0.57	3.60	0.48	0.41
N	56675	63128	63138	3677	3675
Hospital/Centro Poblado/District FEs	Yes	Yes	Yes	Yes	Yes
Month x Year FEs	Yes	Yes	Yes	Yes	Yes
Month x Near Plant FEs	Yes	Yes	Yes	Yes	Yes
HH Controls	No	Yes	Yes	Yes	Yes

OLS regressions. Hospital admissions measure total monthly admissions at the hospital level. Adult data includes those over 13 years of age living in costal regions sampled in ENAHO (2007-2009), child data includes those under 6 years old living in coastal regions sampled in ENDES (2007-2009). Last 30 or 90 days is calculated as last 1 or 3 months for hospital data. "Near Plant" is defined as 5 kilometers for survey data and 20 kilometers for hospital data. All specifications include a dummy variable for living near a plant. Adult regressions include controls for age, gender, native language and level of education. Child regressions include controls for age, gender, household assets and mother's level of education. Hospital, adult and child specifications include hospital, Centro Poblado and district fixed effects respectively, with standard errors clustered at the same level. A "Production Day" is defined by > 1000 MTs of input at the port level. Fishmeal production is based on daily inputs of fish, measured in 10,000s of MTs. "Respiratory Admissions" is a count, medical expenditure is measured in Peruvian Soles and all other dependent variables are binary. The reform began on April 20th, 2009 in the North/Central region and July 7th, 2009 in the South. Mean of dep. var. gives unconditional mean for sample included in the corresponding regression. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table A.IV
Impact of Fishmeal Prod. on Hosp. Admis. – Placebo Outcomes

	Congenital Disorders	Ext. Factors: Injury/Poisoning	Mental Health
	Log Fishmeal Production in Last 30 Days		
Log Fishmeal Prod. in Last 30 Days	0.016 (0.018)	−0.032 (0.052)	0.063 (0.070)
Log Fishmeal Prod. in Last 30 Days x Near Plant	0.051 (0.100)	0.060 (0.145)	0.254 (0.358)
Mean of Dep. Var.	1.30	3.37	9.45
N	141981	141981	141981
	Log Fishmeal Production in Last 90 Days		
Log Fishmeal Prod. in Last 90 Days	0.035* (0.020)	−0.039 (0.059)	0.071 (0.073)
Log Fishmeal Prod. in Last 90 Days x Near Plant	0.095 (0.085)	−0.102 (0.167)	0.409 (0.385)
Mean of Dep. Var.	1.30	3.37	9.45
N	141981	141981	141981
	Production Days in Last 30 Days		
Production Days in Last 30 Days	0.003 (0.002)	−0.003 (0.007)	0.006 (0.009)
Production Days in Last 30 Days x Near Plant	0.016 (0.011)	0.017 (0.024)	0.097 (0.063)
Mean of Dep. Var.	1.30	3.37	9.45
N	141981	141981	141981
	Production Days in Last 90 Days		
Production Days in Last 90 Days	0.002 (0.002)	−0.006 (0.006)	−0.001 (0.006)
Production Days in Last 90 Days x Near Plant	0.009 (0.006)	0.006 (0.017)	0.070 (0.043)
Mean of Dep. Var.	1.30	3.37	9.45
N	141981	141981	141981
Hospital FEs	Yes	Yes	Yes
Month x Year FEs	Yes	Yes	Yes
Month x Near Plant FEs	Yes	Yes	Yes

OLS regressions. Hospital admissions measure total monthly admissions at the hospital level. Last 30 or 90 days is calculated as last 1 or 3 months for hospital data. “Near Plant” is defined as 20 kilometers for hospital data. Hospital fixed effects are included and standard errors are clustered at the hospital level. A “Production Day” is defined by > 1000 MTs of input at the port level. Fishmeal production is based on daily inputs of fish, measured in 10,000s of MTs. Mean of dep. var. gives unconditional mean for sample included in the corresponding regression. Categorizations based upon International Classification of Disease Codes (ICD). * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table A.V
Impact of Fishmeal Production on Adult Health – By Job Category

	Non-Fishing Workers		Fishing Workers		Non-Fishing Workers		Fishing Workers	
	Any Health Issue	Log. Medical Expenditure	Any Health Issue	Log. Medical Expenditure	Any Health Issue	Log. Medical Expenditure	Any Health Issue	Log. Medical Expenditure
	Production Days in Last 30 Days				Production Days in Last 90 Days			
Production Days in Last 30 Days	0.001***	0.001	−0.002	0.000	0.000**	0.000	−0.001	−0.004
	(0.000)	(0.002)	(0.002)	(0.012)	(0.000)	(0.001)	(0.001)	(0.006)
Production Days in Last 30 Days x Near Plant	0.003***	0.009	0.003	0.040**	0.001**	0.006***	−0.000	0.010
	(0.001)	(0.006)	(0.003)	(0.017)	(0.001)	(0.002)	(0.002)	(0.009)
	Log Fishmeal Production in Last 30 Days				Log Fishmeal Production in Last 90 Days			
Log Fishmeal Prod. in Last 30 Days	0.011***	0.005	−0.019	−0.005	0.006**	0.016	−0.011	−0.014
	(0.003)	(0.014)	(0.018)	(0.102)	(0.003)	(0.014)	(0.017)	(0.097)
Log Fishmeal Prod. in Last 30 Days x Near Plant	0.020***	0.083*	0.017	0.341***	0.013**	0.074**	−0.037	0.052
	(0.006)	(0.047)	(0.031)	(0.128)	(0.005)	(0.033)	(0.038)	(0.156)
Mean of Dep. Var.	0.59	3.72	0.54	3.13	0.59	3.72	0.54	3.13
N	158456	158489	3317	3317	158456	158489	3317	3317
Centro Poblado FEs	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Month x Year FEs	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Month x Near Plant FEs	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
HH Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

OLS regressions. Data from ENAHO (2007-2011). Adults older than 13 living in coastal regions are included. “Near Plant” is defined as within 5 kilometers, and all specifications include a “Near Plant” dummy. Also included are controls for age, gender, native language and level of education. Standard errors, clustered at the Centro Poblado level, are included in parentheses. A “Production Day” is defined by > 1000 MTs of input at the port level. Fishmeal production is based on daily inputs of fish, measured in 10,000s of MTs. Medical expenditure is measured in Peruvian Soles, all other dependent variables are binary. Mean of dep. var. gives unconditional mean for sample included in the corresponding regression. Labor categories are based on 3 digit job codes. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table A.VI
Impact of Fishmeal Production on Labor Market Outcomes

	Panel A: All Adults							
	Has Any Job	Has 2nd Job	Total Labor Hours	Log. Total Income	Has Any Job	Has 2nd Job	Total Labor Hours	Log. Total Income
	Log Fishmeal Production in Last 30 Days				Log Fishmeal Production in Last 90 Days			
Production Days in Last 30(90) Days	0.001*	−0.000	0.000	0.027	−0.000	−0.000**	−0.001	0.004
	(0.000)	(0.000)	(0.002)	(0.018)	(0.000)	(0.000)	(0.001)	(0.008)
Production Days in Last 30(90) Days x Near Plant	−0.000	0.000	−0.002	−0.018	0.000	0.000	−0.000	−0.021
	(0.001)	(0.001)	(0.006)	(0.037)	(0.000)	(0.000)	(0.002)	(0.015)
	Log Fishmeal Production in Last 30 Days				Log Fishmeal Production in Last 90 Days			
Log Fishmeal Prod. in Last 30(90) Days	0.006**	0.001	0.011	0.260	0.002	−0.001	0.003	0.163
	(0.002)	(0.002)	(0.016)	(0.160)	(0.002)	(0.001)	(0.013)	(0.124)
Log Fishmeal Prod. in Last 30(90) Days x Near Plant	−0.007	0.002	−0.028	−0.243	−0.002	0.005	−0.019	0.140
	(0.009)	(0.005)	(0.053)	(0.405)	(0.006)	(0.003)	(0.031)	(0.346)
Mean of Dep. Var.	0.64	0.11	3.46	30.3	0.64	0.11	3.46	30.3
N	161612	161612	161612	161612	161612	161612	161612	161612
	Panel B: Non-Fishing Workers							
	Production Days in Last 30 Days				Production Days in Last 90 Days			
Production Days in Last 30(90) Days	0.001*	−0.000	0.000	0.028	0.000	−0.000**	−0.001	0.005
	(0.000)	(0.000)	(0.002)	(0.018)	(0.000)	(0.000)	(0.001)	(0.008)
Production Days in Last 30(90) Days x Near Plant	−0.000	0.000	−0.004	−0.027	−0.000	0.000	−0.002	−0.029*
	(0.001)	(0.001)	(0.005)	(0.041)	(0.000)	(0.000)	(0.002)	(0.017)
	Log Fishmeal Production in Last 30 Days				Log Fishmeal Production in Last 90 Days			
Log Fishmeal Prod. in Last 30(90) Days	0.006**	0.001	0.011	0.261	0.003	−0.001	0.003	0.158
	(0.003)	(0.002)	(0.016)	(0.163)	(0.002)	(0.001)	(0.013)	(0.127)
Log Fishmeal Prod. in Last 30(90) Days x Near Plant	−0.008	0.002	−0.046	−0.327	−0.001	0.005	−0.024	0.099
	(0.009)	(0.005)	(0.052)	(0.465)	(0.006)	(0.003)	(0.035)	(0.393)
Mean of Dep. Var.	0.63	0.11	3.41	30.1	0.63	0.11	3.41	30.1
N	158295	158295	158295	158295	158295	158295	158295	158295
	Panel C: Fishing Workers							
	Log Fishmeal Production in Last 30 Days				Log Fishmeal Production in Last 90 Days			
Production Days in Last 30(90) Days	−0.002*	−0.001	0.000	−0.066	0.000	0.000	0.004	0.020
	(0.001)	(0.001)	(0.008)	(0.089)	(0.001)	(0.001)	(0.004)	(0.057)
Production Days in Last 30(90) Days x Near Plant	0.003**	0.004**	0.031***	0.142	−0.000	0.002	0.010*	−0.011
	(0.001)	(0.002)	(0.010)	(0.176)	(0.001)	(0.001)	(0.006)	(0.086)
	Log Fishmeal Production in Last 30 Days				Log Fishmeal Production in Last 90 Days			
Log Fishmeal Prod. in Last 30(90) Days	−0.011	−0.001	−0.003	−0.153	0.005	−0.001	0.085*	1.288*
	(0.007)	(0.011)	(0.063)	(0.784)	(0.007)	(0.011)	(0.051)	(0.757)
Log Fishmeal Prod. in Last 30(90) Days x Near Plant	0.012	0.016	0.290***	1.065	−0.011	0.012	0.077	−0.136
	(0.009)	(0.020)	(0.090)	(1.334)	(0.010)	(0.017)	(0.113)	(1.276)
Mean of Dep. Var.	0.93	0.13	5.64	43.0	0.93	0.13	5.64	43.0
N	3317	3317	3317	3317	3317	3317	3317	3317
Centro Poblado FEs	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Month x Year FEs	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Month x Near Plant FEs	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
HH Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

OLS regressions. Data from ENAHO (2007-2011). Adults older than 13 living in coastal regions are included. “Near Plant” is defined as within 5 kilometers, and all specifications include a “Near Plant” dummy. Also included are controls for age, gender, native language and level of education. Standard errors, clustered at the Centro Poblado level, are included in parentheses. A “Production Day” is defined by > 1000 MTs of input at the port level. Fishmeal production is based on daily inputs of fish, measured in 10,000s of MTs. Total income is measured in Peruvian Soles. Mean of dep. var. gives unconditional mean for sample included in the corresponding regression. Labor categories are based on 3 digit job codes. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table A.VII
Impact of Fishmeal Production on Seawater Quality and on Adult Health by Fish Consumption

Panel A: Impact of Fishmeal Production on Adult Health by Fish Consumption

	Production Days				Log Fishmeal Production			
	30 Days		90 Days		30 Days		90 Days	
	Any Health Issue	Log. Medical Expenditure	Any Health Issue	Log. Medical Expenditure	Any Health Issue	Log. Medical Expenditure	Any Health Issue	Log. Medical Expenditure
Consumed Fresh Fish	0.002 (0.004)	0.118*** (0.023)	0.002 (0.004)	0.122*** (0.030)	0.000 (0.004)	0.108*** (0.021)	0.000 (0.004)	0.110*** (0.024)
Consumed Fresh Fish x Near Plant	0.004 (0.019)	0.008 (0.127)	0.016 (0.024)	0.105 (0.141)	0.003 (0.019)	0.022 (0.114)	0.005 (0.020)	0.080 (0.119)
Log Fishmeal Prod. in Last 30 (90) Days	0.013*** (0.004)	0.035** (0.017)	0.007** (0.003)	0.029* (0.018)				
Log Fishmeal Prod. in Last 30 (90) Days x Near Plant	0.019* (0.010)	0.120* (0.066)	0.016 (0.010)	0.139*** (0.051)				
Log Fishmeal Prod. in Last 30 (90) Days x Consumed Fresh Fish	−0.002 (0.003)	−0.035** (0.017)	−0.001 (0.003)	−0.019 (0.016)				
Log Fishmeal Prod. in Last 30 (90) Days x Consumed Fresh Fish x Near Plant	−0.002 (0.010)	−0.042 (0.077)	−0.009 (0.011)	−0.089* (0.053)				
Production Days in Last 30 (90) Days					0.001*** (0.000)	0.004* (0.002)	0.000* (0.000)	0.001 (0.001)
Production Days in Last 30 (90) Days x Near Plant					0.003* (0.001)	0.015* (0.008)	0.001 (0.001)	0.011*** (0.003)
Production Days in Last 30 (90) Days x Consumed Fresh Fish					−0.000 (0.000)	−0.003 (0.002)	0.000 (0.000)	−0.001 (0.001)
Production Days in Last 30 (90) Days x Consumed Fresh Fish x Near Plant					−0.000 (0.001)	−0.008 (0.008)	−0.000 (0.001)	−0.007* (0.004)
Mean of Dep. Var.	0.59	3.74	0.59	3.74	0.59	3.74	0.59	3.74
N	161773	161806	161773	161806	161773	161806	161773	161806
Centro Poblado FEs	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Month x Year FEs	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Month x Near Plant FEs	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
HH Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Panel B: Impact of Fishmeal Production on Seawater Quality

	Log Fishmeal Production				Production Days			
	Near Port = Within 5 kilometers		Near Port = Within 20 kilometers		Near Port = Within 5 kilometers		Near Port = Within 20 kilometers	
	30 Days	90 Days	30 Days	90 Days	30 Days	90 Days	30 Days	90 Days
Log Fishmeal Prod. in Last 30 (90) Days	−0.045*** (0.006)	−0.016*** (0.006)	−0.041*** (0.006)	−0.009 (0.005)				
Log Fishmeal Prod. in Last 30 (90) Days x Near Plant	0.028 (0.033)	0.024 (0.023)	−0.002 (0.015)	−0.013 (0.013)				
Production Days in Last 30 (90) Days					−0.006*** (0.001)	−0.002*** (0.001)	−0.005*** (0.001)	−0.001** (0.001)
Production Days in Last 30 (90) Days x Near Plant					0.003 (0.004)	0.003 (0.002)	−0.001 (0.002)	−0.001 (0.001)
Mean of Dep. Var.	0.82	0.82	0.82	0.82	0.82	0.82	0.82	0.82
N	14547	14547	14547	14547	14547	14547	14547	14547
Beach FEs	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Month x Year FEs	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Panel A: OLS regressions. Adult data includes those over 13 years of age living in costal regions sampled in ENAHO (2007-2011). "Near Plant" is defined as 5 kilometers for survey data. All specifications include a "Near Plant" dummy. Adult regressions include controls for age, gender, native language and level of education. Standard errors are clustered at the Centro Poblado level. A "Production Day" is defined by $>$ 1000 MTs of input at the port level. Fishmeal production is based on daily inputs of fish, measured in 10,000s of MTs. Medical expenditure is measured in Peruvian Soles. We define consumption of fresh fish as the purchase of fresh fish at the household level. Mean of dep. var. gives unconditional mean for sample included in the corresponding regression. Panel B: OLS regressions. Data collected approximately weekly at the beach level from January 2007-April 2009. Quality is a binary variable equal to 1 for low levels of coliforms ($\leq$1000 NMP/100ml) and 0 for high levels. Note that fishmeal production is correlated with the prevalence of coliforms at public beaches, but the correlation is not greater inside versus outside a five, 20 or 50 kilometer treatment radius around fishmeal ports. Standard errors, clustered at the beach level, are included in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table A.VIII

Impact of Fishmeal Industry on Health Before and After 2009 ITQ Reform – By Job Category

	Reform Effect				Efficient vs. Inefficient Ports				North/Central vs. South			
	Non-Fishing Workers		Fishing Workers		Non-Fishing Workers		Fishing Workers		Non-Fishing Workers		Fishing Workers	
	Any Health Issue	Log Medical Expenditure	Any Health Issue	Log Medical Expenditure	Any Health Issue	Log Medical Expenditure	Any Health Issue	Log Medical Expenditure	Any Health Issue	Log Medical Expenditure	Any Health Issue	Log Medical Expenditure
						North Vs. South						
Post-Reform x Near Plant	0.053^{**}	0.225	0.143	0.679	−0.091	-0.325^{*}	−0.154	0.636	−0.086	−0.359	−0.127	0.118
	(0.027)	(0.145)	(0.124)	(0.531)	(0.057)	(0.180)	(0.315)	(0.971)	(0.053)	(0.342)	(0.282)	(1.376)
North/Central Region x Post-Reform					0.041^{**}	-0.272^{*}	−0.018	−0.177				
					(0.019)	(0.149)	(0.198)	(0.784)				
North/Central Region x Post-Reform x Near Plant					0.142^{**}	0.545^{**}	0.276	0.346				
					(0.056)	(0.220)	(0.281)	(1.058)				
Pre-Reform Max. Efficiency x Post-Reform									−0.021	-1.415^{***}	0.388	4.944
									(0.068)	(0.481)	(0.490)	(3.236)
Pre-Reform Max. Efficiency x Post-Reform x Near Plant									0.388^{***}	1.872^{**}	0.585	1.871
									(0.119)	(0.806)	(0.846)	(3.726)
Mean of Dep. Var.	0.57	3.71	0.52	3.16	0.59	3.75	0.54	3.16	0.59	3.75	0.54	3.16
N	60886	60895	1272	1272	56979	56988	1164	1164	56097	56106	1153	1153
Centro Poblado	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Month x Year FEs	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Month x Near Plant FEs	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
HH Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

OLS regressions. Data from ENAHO (2007-2011). Adults older than 13 living in coastal regions are included. “Near Plant” is defined as within 5 kilometers, and all specifications include a “Near Plant” dummy. Also included are controls for age, gender, native language and level of education. Standard errors, clustered at the Centro Poblado level, are included in parentheses. The reform began on April 20th, 2009 in the North/Central region and July 7th, 2009 in the South. The port of Ilo is excluded from North vs. South specification due to production outside of designated seasons. Efficiency determined by the maximum 2008 output/input ratio for any plant within the port. Efficiency is included as a continuous variable interacted with both living near a plant and post-reform. Mean of dep. var. gives unconditional mean for sample included in the corresponding regression. Labor categories are based on 3 digit job codes. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table A.IX
Impact of Fishmeal Industry on Health Before and After 2009 ITQ Reform – Efficient vs. Inefficient Ports – North Only

	Hospitals	Adults		Children: ≤ 5	
	Respiratory Admissions	Any Health Issue	Log Medical Expenditure	Any Health Issue	Cough
		High Vs. Low Cost Ports			
Post-Reform x Near Plant	2.021	−0.059	0.167	−1.490***	−0.831***
	(26.470)	(0.065)	(0.407)	(0.176)	(0.250)
Pre-Reform Max. Efficiency x Post-Reform	−36.093**	−0.054	0.427	0.115	0.467
	(17.590)	(0.115)	(0.614)	(0.500)	(0.455)
Pre-Reform Max. Efficiency x Post-Reform x Near Plant	38.986	0.328**	0.058	4.170***	2.956***
	(98.722)	(0.162)	(0.887)	(0.504)	(0.592)
Mean of Dep. Var.	174.3	0.56	3.80	0.46	0.38
N	47815	49902	49910	4445	4443
Hospital/Centro Poblado/District FEs	Yes	Yes	Yes	Yes	Yes
Month x Year FEs	Yes	Yes	Yes	Yes	Yes
Month x Near Plant FEs	Yes	Yes	Yes	Yes	Yes
HH Controls	No	Yes	Yes	Yes	Yes

OLS regressions. Hospital admissions measure total monthly admissions at the hospital level, limited to 2008/2009. Adult data includes those over 13 years of age living in costal regions sampled in ENAHO (2008-2009). The reform began on April 20th, 2009 in the North/Central region and July 7th, 2009 in the South. All specifications include a dummy variable for living near a plant. Adult regressions include controls for age, gender, native language and level of education. Hospital, adult and child specifications include hospital, Centro Poblado and district fixed effects respectively, with standard errors clustered at the same level. "Respiratory Admissions" is a count, medical expenditure is measured in Peruvian Soles, all other dependent variables are binary. Efficiency is determined by the maximum 2008 output/input ratio for any plant within the port. Efficiency is included as a continuous variable interacted with both living near a plant and post-reform. Mean of dep. var. gives unconditional mean for sample included in the corresponding regression. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table A.X
Impact of Fishmeal Production on Hospital Admissions – Non-Respiratory Issues

	Total Admissions	Blood Disorders	Nervous System	Circulatory System	Digestive System	Pregnancy Complications	Perinatal Issues
			Log Fishmeal Production in Last 30 Days				
Log Fishmeal Prod. in Last 30 Days	0.570	−0.004	0.075**	−0.049	1.161***	0.262***	0.017
	(1.180)	(0.013)	(0.036)	(0.046)	(0.375)	(0.085)	(0.017)
Log Fishmeal Prod. in Last 30 Days x Near Plant	2.277	−0.052	−0.133	−0.142	−1.069	0.934***	0.152
	(5.000)	(0.076)	(0.237)	(0.214)	(1.278)	(0.330)	(0.139)
			Log Fishmeal Production in Last 90 Days				
Log Fishmeal Prod. in Last 90 Days	4.268***	0.000	0.124***	−0.047	1.480***	0.486***	0.030
	(1.362)	(0.018)	(0.047)	(0.058)	(0.358)	(0.100)	(0.021)
Log Fishmeal Prod. in Last 90 Days x Near Plant	11.509*	−0.005	−0.071	0.322	2.379*	0.888**	0.071
	(6.075)	(0.084)	(0.211)	(0.230)	(1.295)	(0.391)	(0.100)
			Production Days in Last 30 Days				
Production Days in Last 30 Days	0.238	−0.000	0.005	−0.002	0.159***	0.021*	0.000
	(0.150)	(0.002)	(0.004)	(0.005)	(0.049)	(0.011)	(0.003)
Production Days in Last 30 Days x Near Plant	1.438**	0.002	−0.010	0.014	0.334**	0.186***	0.017
	(0.569)	(0.013)	(0.044)	(0.025)	(0.166)	(0.050)	(0.017)
			Production Days in Last 90 Days				
Production Days in Last 90 Days	0.182*	−0.001	0.006*	−0.004	0.084***	0.015*	0.000
	(0.108)	(0.001)	(0.003)	(0.004)	(0.027)	(0.008)	(0.002)
Production Days in Last 90 Days x Near Plant	1.157***	−0.001	−0.014	0.011	0.339***	0.128***	0.001
	(0.407)	(0.009)	(0.028)	(0.020)	(0.107)	(0.036)	(0.010)
Mean of Dep. Var.	516.0	1.47	6.00	8.60	71.3	16.5	1.73
N	141981	141981	141981	141981	141981	141981	141981
Hospital FEs	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Month x Year FEs	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Month x Near Plant FEs	Yes	Yes	Yes	Yes	Yes	Yes	Yes

OLS regressions. Hospital admissions measure total monthly admissions at the hospital level. Last 30 or 90 days is calculated as last 1 or 3 months for hospital data. "Near Plant" is defined as 20 kilometers for hospital data. Hospital fixed effects are included and standard errors are clustered at the hospital level. A "Production Day" is defined by $>$ 1000 MTs of input at the port level. Fishmeal production is based on daily inputs of fish, measured in 10,000s of MTs. Mean of dep. var. gives unconditional mean for sample included in the corresponding regression. Categorizations based upon International Classification of Disease Codes (ICD). We found at least one paper associating each of the categories used: (see Medeiros et al., 1983; Dusseldorp et al., 1995; Xu, Ding and Wang, 1995; Gordian et al., 1996; Landgren, 1996; Ponka and Virtanen, 1996; Wang et al., 1997; Dejmek et al., 1999; Pope III et al., 1999; Seaton et al., 1999; Van der Zee et al., 1999; Brook et al., 2002; Bruce, Perez-Padilla and Albalak, 2002; Hoek et al., 2002; Pope III et al., 2004; Riediker et al., 2004; Baccarelli et al., 2007; Kaplan et al., 2010; Moulton and Yang, 2012). * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table A.XI
Impact of Fishmeal Production on Health Through Air Pollution in Lima
Alternative Construction of Pollution Measurements

	Port Level Correlation Between Fishmeal Production and Air Pollution			
	PM^{10}	$PM^{2.5}$	NO_2	SO_2
Log Fishmeal Prod. in Last 30 Days	1.210** (0.552)	1.574*** (0.192)	0.742*** (0.159)	1.638*** (0.392)
Mean of Dep. Var.	101.9	46.7	28.7	19.5
N	1231	1414	1416	1416
Month x Year FEs	Yes	Yes	Yes	Yes

	Impact of Air Pollution Instrumented by Fishmeal Production on Health		
	Hospitals	Adults	
	Respiratory Admissions	Any Health Issue	Log Medical Expenditure
		PM10	
Avg. PM^{10} level in last 30 Days x Near Plant	0.205 (0.416)	0.001*** (0.000)	−0.001 (0.000)
		PM2.5	
Avg. $PM^{2.5}$ level in last 30 Days x Near Plant	0.802** (0.392)	0.001*** (0.000)	−0.000 (0.001)
		NO_2	
Avg. NO_2 level in last 30 Days x Near Plant	1.737** (0.849)	0.002*** (0.000)	−0.000 (0.001)
		SO_2	
Avg. SO_2 level in last 30 Days x Near Plant	1.870** (0.914)	0.002*** (0.001)	−0.000 (0.001)
Mean of Dep. Var.	329.2	0.54	4.11
N	19976	33570	33583
Month x Near Plant FEs	Yes	Yes	Yes
Month x Year FEs	Yes	Yes	Yes
HH Controls	Yes	Yes	Yes

Hospital admissions measure total monthly admissions at the hospital level for hospitals whose closest port is Callao. Adult data includes those over 13 years of age whose closest port is Callao sampled in ENAHO (2007-2011). The top panel presents pollutant levels regressed on "Log Fishmeal Production" and month fixed effects. The bottom panel presents IV regressions of health outcomes on average pollutant levels in the last 30 days and average pollutant level in the last 30 days interacted with an indicator for "Near Plant" instrumented by "Log Fish Capture in Last 30 Days" and "Log Fish Capture in Last 30 Days × Near Plant." All pollutants are measured in $\mu g/m^3$. Daily pollutant levels are taken from nearest station to callao with consistent data quality (one station is slightly closer to the port, but has 50% fewer observations for some pollutants). Missing values were imputed using the following technique: (i) construct the empirical distributions for each of the five stations. (ii) On days that data is missing, find the value of the empirical distribution on that day for each of the other stations. (iii) Take the inverse distance weighted average of those values. (iv) Replace the missing data for the station with the concentration corresponding to the point in the empirical distribution found in (iii). Outcomes for children are excluded due to a lack of observations near the port of Callao. Last 30 days refers to the calendar month for hospital data and to the 30 days preceding the survey date for survey data. "Near Plant" is defined as 5 kilometers for survey data and 20 kilometers for hospital data. All specifications include a dummy variable for living near a plant. Adult regressions include controls for age, gender, native language and level of education. Hospital and adult specifications include hospital and Centro Poblado fixed effects respectively, with standard errors clustered at the same level. A "Production Day" is defined by > 1000 MTs of input at the port level. Fishmeal production is based on daily inputs of fish, measured in 10,000s of MTs. Medical expenditure is measured in Peruvian Soles, all other dependent variables are binary. Mean of dep. var. gives unconditional mean for sample included in the corresponding regression. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.