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 two-sector model with heterogeneous final good producers. 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 and the importance of the often ignored time profile of production.

JEL codes: D2, L5, O1, I1

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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 considers 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 focus on the 2009 introduction of individual property rights over fish, an "optimal" policy for preventing overextraction,[4] and make two contributions to the literature. 1. We provide a clean empirical demonstration of the costs of piecemeal regulatory design in an interlinked economy, and quantify the magnitude of those costs. Specifically, 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. 2. In documenting the mechanism through which downstream spillover effects arose, we provide a new finding that underscores the surprising importance 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 have far-reaching implications for the regulation of firms and sectors that operate as part of a larger network.

To investigate the costs of piecemeal regulatory design, we: (a) estimate the causal effect of downstream production on health that was ignored by the architects of the 2009 "individual, tradeable quota" (ITQ) reform upstream using a difference in differences approach comparing fishmeal and non-fishmeal locations during and outside of the production seasons. (b) Model and document the upstream and downstream industrial response to the ITQ reform. (c) Estimate the magnitude of adverse health impacts of the 2009 reform using a difference in difference approach comparing fishmeal and non-fishmeal locations pre- and post-reform. (d) Investigate the mechanism behind the exacerbation of downstream externalities. To do so we exploit the model's predictions on the local industry characteristics that should predict variation in how individuals' exposure to production changed post-reform and triple difference strategies. We ultimately

[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".

attribute the adverse average effect to the health consequences of most manufacturing plants spreading out production – and the associated pollution – across time post-reform.

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. 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.[8]

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.[9] 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

[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] In this approach we follow recent work on firms in developing countries – see e.g. Macchiavello and Morjaria (forthcoming); Antras and Foley (forthcoming); Casaburi et al. (2015); Ghani and Reed (2015). These studies do not focus on regulatory design.

[9] 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).

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. Among developing countries, Peru 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.

Fourth, the Peruvian setting allows us to exploit sharp variation in downstream production due to government-imposed, irregularly timed, semi-annual production ban periods,[10] and in the introduction of ITQs upstream.

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 fishmeal and non-fishmeal 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,[11] and are not driven by changes in incomes or labor markets during production periods. Instead we show that, at least in the Lima region (where ground-station measurements of air pollutants are available, and where 27 percent of our sample reside), the impact on health is due to air pollution emitted by the downstream fishmeal plants.

The two-sector model we develop 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.[12]

To identify how firms' response to the 2009 regulatory reform affected the downstream plants' impact on health, we compare fishmeal and non-fishmeal 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,[13] 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. Cost/benefit calculations that are suggestive but conservative indicate that the monetized cost of the reform's impact on health, USD 343 million per year, likely *surpassed* the increase in sector profits due to the decrease in overextraction.

We then investigate the mechanism underlying the downstream health impact of the 2009 reform. Geographical heterogeneity in the estimated reform effects supports the hypothesis that the introduction of ITQs upstream affected heath through changes in the time profile of production downstream. While there

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

[11]For example, we show that the estimates are robust to varying the radius around plants used to define fishmeal locations; to varying the exposure window; and to instrumenting for production/production days with non-ban days.

[12]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.

[13]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.

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. 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). Further, results from specifications that include measures of both the level and spread of plant production show that, for any given amount of production, a longer production period increases the impact on health.

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 – the form of the relationship between manufacturing production, pollution, and health – 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. 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. While the harmful effects of air pollution on adult and child (especially respiratory and pulmonary) health outcomes are convincingly documented in the existing literature,[14] 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).[15] 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, 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. Section 4

[14]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.

[15]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).

provides evidence on how and why fishmeal production affects health. Section 5 analyzes, theoretically and empirically, the industry's responses to the 2009 ITQ reform, and Section 6 how and why its impact on health changed as a consequence. Section 7 discusses the total costs and benefits of the reform and regulatory design, and Section 8 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[16] – 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. 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.[17] 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.

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

[16] 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.

[17] 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).

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.[18]

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.[19] 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.[20] 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$\times$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 is randomly determined. A subset of clusters are re-surveyed every year. Information on the "centro poblado" where each respondent is interviewed is recorded.[21] 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.

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

[19]For example, 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).

[20]The quota-share was based on historical catches and a boat's hull capacity.

[21]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.

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.[22] GPS coordinates for sample clusters are recorded. Women between 15 and 49 years old are interviewed, and information on 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.[23] 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",[24] and also separately report the outcome of the child experiencing a cough. Note that we get very similar results if we focus on children ≤ 1 rather than ≤ 5 (results available from the authors).

[22]From 2004 to 2007, a fixed set of 1131 clusters was 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 only 722 clusters were surveyed. From 2009 to 2011, 1132 clusters were used, including a panel of 566 clusters surveyed every year.

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

[24]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.

4 Fishmeal Manufacturing's Impact on Health

4.1 Empirical strategy

The primary goal of this paper is to identify how the introduction of a new regulatory system – individual property rights – among upstream suppliers affected the extent of externalities generated by downstream plants, and the mechanism through which any such spillover effects occurred. Since documenting the existence of the downstream externality is an intermediate step towards that goal, we first estimate the downstream plants' impact on health.

We now briefly lay out the identification strategy used to do so – details are in the appendix. We exploit time and spatial variation in exposure to production by comparing the health outcomes of individuals (y_{ijtmy}) in locations (j) within a given radius of fishmeal plants ($FishmealLocation_j = 1$) to individuals in locations further away from plants on dates (t) of varying production intensity ($Production_{jt}$) in the cluster of plants closest to the individual/hospital in question, as follows:

$$\begin{aligned} y_{ijtmy} = \alpha + \beta_1 Production_{jt} + \beta_2 FishmealLocation_j \times Production_{jt} + \beta_3 X_{ijt} \\ + \gamma_j + \delta_{my} + FishmealLocation_j \times \theta_m + \varepsilon_{ijtmy} \end{aligned} \tag{1}$$

where X_{ijt} are individual-level covariates,[25] γ_j is a centro poblado or district fixed effect, δ_{my} is a year×month fixed effect, and $FishmealLocation_j \times \theta_m$ is a $FishmealLocation$ specific month fixed effect that controls for possible differential seasonality in fishmeal locations. Standard errors are clustered at the centro poblado or district level. Regressions using hospital×month level outcomes are estimated through a similar specification (see the appendix). These include hospital fixed effects, but not individual-level covariates.

For outcomes drawn from the surveys, for which we have precise GPS data, we use five kilometers as the baseline "treatment 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 the hospital admissions outcomes, we use 20 kilometers as the baseline treatment radius so as to include the facilities used by those living near the fishmeal plants in the "treatment group".[26] 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. We also investigate how our estimates vary with the treatment radius used.

We consider two different continuous 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, during X days in the port (i.e., cluster of plants) nearest to the individual or hospital. 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 include results for a 90 day window, which roughly corresponds to the longest periods of continuous exposure observed in our data period. Finally, we investigate how our estimates depend on the exact lookback window used.

[25] The 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.

[26] 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 and ENAHO and ENDES sampling clusters.

4.2 Results and robustness

In Table I, we present summary statistics comparing fishmeal locations and non-fishmeal locations in and out of the production season. The numbers indicate that there is little seasonal work migration to the fishmeal locations,[27] probably because jobs in the industrial fishing sector are quite stable, as discussed above. We also see negligible changes in average incomes in fishmeal locations during the production season. While the industrial fishing sector does have linkages to the local economy, economic activity thus appears to vary less with the production cycle than one might expect. The summary statistics also show little change in mean household demographics, socioeconomic status and labor market outcomes during production seasons. Differences in household characteristics between fishmeal and non-fishmeal locations are modest.

Focusing on our outcome variables, the summary statistics in Table I hint at our results: individuals exposed to fishmeal production have worse health outcomes.[28] Table II shows the estimated effect of fishmeal production on adult and child health. 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 1.98 (1.2 percent) more hospital admissions for respiratory diseases; a 0.95 percentage point (1.6 percent) higher incidence of "Any Health Issue" among adults; and a 4.6 percent increase in medical expenditures. 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 2.1 percentage point (4.7 percent) increase in the incidence of "Any Health Issue" and a 1.95 percentage point (5.3 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 power to detect effects on child health is lower than for adult health due to much smaller sample sizes.[29] The last two panels of Table II 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 II 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; to specifying hospital admissions in logs; to varying the treatment radius and lookback window used;[30] and that a falsification exercise shows no significant effects on health outcomes that we would not expect to respond to plant production. The summary statistics in Table I show no sign of migratory

[27] The share of sampled adults that were born in a different district than where they were surveyed is lower in fishmeal locations in season (37 percent) than out of season (40 percent).

[28] Most health outcomes in fishmeal locations are considerably worse during plant production than outside of production periods. The average health outcomes in non-fishmeal locations most closely resemble the fishmeal location averages measured outside of production periods. Some health outcomes also appear to be worse in non-fishmeal locations during the times of the year when production takes places. This pattern is likely an artifact of the narrow "treatment radius" used, as can be seen e.g. in Figure A.I.

[29] 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.

[30] 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 II.

avoidance behavior, and some of the pollutants produced are so fine as to penetrate homes (e.g. $PM^{2.5}$). Any "residual" avoidance behavior would lead us to underestimate the direct health effects of production.

4.3 How fishmeal manufacturing affects health

In the appendix we show that fishmeal production affects the health of whole communities (not just those who work in the sector), and that the effect is not driven by labor market responses (average incomes and labor market outcomes are not significantly different during production periods). We also show that the adverse impact on health is not driven by ocean pollution. We now investigate if fishmeal production affects the health of the local population primarily through air pollution emitted by the manufacturing plants, as we hypothesize.

We first disaggregate respiratory hospital admissions into its ICD sub-categories. Doing so shows that the overall effect is driven primarily by a higher incidence of "Acute Upper Respiratory Infections" during production periods, consistent with air pollution as the underlying mechanism.[31]

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.

The top panel of Table III documents the effect of fishmeal production on air pollution. 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)[32]. (Using the max across stations, median across stations, or another of the pollutant measurement techniques used by Schlenker and Walker (forthcoming) gives similar results (see Appendix Table A.I)). 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.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 3.6 percent of a standard deviation, $PM^{2.5}$ by 4.7 percent of a standard deviation, NO_2 by 2.3 percent of a standard deviation, and SO_2 by 2.6 percent of a standard deviation.

Figure II instead plots the data on air pollution concentration levels on a given day against the level of fishmeal production on the day in question, 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 III, 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.[33] We present these IV regressions to illustrate the magnitude of the component of

[31] Using specifications identical to those in Table II with admissions for different subcategories of respiratory admissions as dependent 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.

[32] 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).

[33] 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.

fishmeal production's impact on health that may arise through air pollution, acknowledging that the exclusion restriction is likely violated.[34] While distinguishing the relative contributions of different air pollutants is not the exercise in this paper, 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 III.[35]

The results in Table III show that a one standard deviation (10 μg/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 μg/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 μg/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 μg/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, 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.[36]

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.[37] In the next section we explore how the upstream suppliers, and in turn the downstream plants, responded to the 2009 introduction of individual, transferable quotas upstream, and how downstream plants' impact on health changed as a consequence.

5 Upstream and Downstream Response to the Introduction of Individual Property Rights Upstream

5.1 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 solu-

[34] 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).

[35] 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.

[36] 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.

[37] 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.

tions' downstream consequences. 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.[38] 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:

$$\pi_i = \int_0^{t^*} [p(t)\gamma x(t) e_i(t) - c(e_i(t))] dt \tag{2}$$

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:

$$\max \int_0^{\tilde{t}} [p(t)\gamma x(t) e_i(t) - c(e_i(t))] dt \tag{3}$$

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.[39] 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 $t \leq \tilde{t}$.

[38]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.

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

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:

$$c'(e_i^*) = p(\gamma x e_i^*)\gamma x \tag{4}$$

$$c'(\tilde{e}_i) = [p(\gamma x \tilde{e}_i) - \lambda_i]\gamma x \tag{5}$$

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.[40] 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.[41]

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:

$$MC_j(q^f, p(t)) = MC(q^f) + \alpha_j + p(t) \tag{6}$$

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

$$p_j^* = 1 - r - \alpha_j \tag{7}$$

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:

$$q(p(t)) = M \int_{p(t)}^{1} \tilde{q}(p(t), p_j^*) dF(p_j^*) \tag{8}$$

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.

[40] 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.

[41] 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.

5.2 Empirical evidence

The 2009 ITQ reform is widely seen as a success. The downstream plants reported an increase in profits and boats an improvements in the fish stock (International Sustainability Unit, 2011). Any positive effects on the sustainability of the fish stock likely came primarily through changes in the *intensity* of fishing – capture of juvenile fish fell (Paredes and Gutierrez, 2008) – as the reform did not target total capture. 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. On average production fell. These changes reflect a combination of factors.[42]

Natividad (2014) documents that the price of anchovy rose after the reform, consistent with our theoretical framework. To test how suppliers and plants responded to the new regulations, we now 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 was 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.[43]

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.

Figure VI shows that the plants that produced for comparatively longer periods after the reform tended to be the efficient plants. In the top panels we plot production and production days after the reform against plants' pre-reform output (of fishmeal) / input (of fish) ratio (a proxy for cost discussed in Sub-section 6.3). While the pattern is noisy, a clear upward slope emerges. Similarly, the bottom panels show 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. 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.

[42] 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.

[43] 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.

5.3 How should we expect the industrial response to the upstream reform to affect downstream plants' impact on health?

On the basis of the evidence in Sub-section 5.2, we conclude that, from the perspective of local communities, the two sectors' response to the 2009 ITQ 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? 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, consistent with Figure II.

When it comes to the health production function, the existing literature generally analyzes the underlying duration response and dose response relationships separately. We focus for now on research in economics, and return to the epidemiological literature in Sub-section 6.4. Few existing studies overcome the formidable challenges of estimating the causal effect on health of *sustained* exposure to air pollution; examples include Chen et al. (2013), Anderson (2015) and Barron and Torero (2015) (see also Isen, Rossin-Slater and Walker, forthcoming). While the level of exposure differs considerably across these studies, they all find much bigger effects on health (mortality and respiratory infections) than (the effects found elsewhere of) short-term exposure. 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. 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).

While 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)) 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. We thus hypothesize that the move from "short, sharp" to "long, low" production downstream post-reform worsened the impact of the fishmeal plants on health.

6 The Introduction of Individual Property Rights Upstream, Production Downstream, and Health

6.1 Empirical strategy

We now estimate the causal effect of the 2009 ITQ reform on health outcomes in fishmeal locations. We compare fishmeal and non-fishmeal locations before and after the reform, using the following difference in differences specifications:

$$\begin{aligned} y_{ijtmy} = \alpha + \beta_1 FishmealLocation_j * Reform_{jt} + \beta_2 X_{ijt} \\ + \gamma_j + \delta_{my} + FishmealLocation_j \times \theta_m + \varepsilon_{ijtmy} \end{aligned} \tag{9}$$

$$
\begin{aligned}
y_{imy} = \alpha &+ \beta_1 FishmealLocation_i * Reform_{it} \\
&+ \gamma_i + \delta_{my} + FishmealLocation_i \times \theta_m + \varepsilon_{imy}
\end{aligned} \tag{10}
$$

for survey and hospital admissions outcomes respectively. y_{ijtmy} is an outcome variable for individual i, who lives in location j, and was interviewed on date t, in calendar month m and year y, and y_{imy} is an outcome variable for hospital i, in calendar month m and year y. $Reform_{jt}$ ($Reform_{it}$) is a dummy variable equal to one after the reform took effect in the fishmeal port (cluster of plants) nearest to location j (hospital i). Other variables are as defined in Section 4. In some regressions we additionally include $FishmealLocation_j \times \tau_{my}$ (or $FishmealLocation_i \times \tau_{my}$), a time trend that is specific either to a given centro poblado/district or to $FishmealLocation$ vs not status.

The identifying assumption is that, after controlling for time, location and seasonality fixed effects, and linear time trends, trends in health across the date when the reform took effect would have been similar in fishmeal and non-fishmeal locations in the absence of the ITQ reform. The summary statistics in Table I show that fishmeal and non-fishmeal locations had similar mean household demographic characteristics, labor market outcomes, and health outcomes before the reform.[44] We show extensive evidence supporting the identifying assumption in the next sub-section.

6.2 Results and robustness

The summary statistics in Table I hint at our results. Most health outcomes worsen in fishmeal locations after the reform. While there is also a deterioration in health in non-fishmeal locations (a pattern that is likely an artifact of the narrow "treatment radius" used, as discussed in the appendix) the decline is considerably greater in fishmeal locations.

Table IV presents the results. In the top panel, in which we limit the sample to the last year before and first year after the reform, we see respiratory hospital admissions increase by 7.3 percent in fishmeal locations, relative to non-fishmeal 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.[45] We discuss the magnitude of the results below.

The second panel of Table IV presents results from a regression that is identical to the one in the top panel, except that we additionally control for $FishmealLocation$ specific time trends to account for the possibility that individuals in fishmeal locations may have been on a different health trajectory prior to the reform. Their inclusion has little effect on the reform effect estimated using survey outcomes, but the estimated reform effect on respiratory hospital admissions increases somewhat.

The third panel instead includes centro poblado specific time trends. The estimated impact on hospital admissions loses significance, although the coefficient decreases only slightly. The estimated impact on adult health is unchanged, while the estimated impact on child health outcomes increases in magnitude and significance.

In the bottom panel of Table IV, we re-estimate the reform effects including data from the last two years

[44] An exception is respiratory hospital admissions, which are considerably higher in fishmeal locations pre-reform.

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

before and first two years after the reform. Again the significance and magnitude of the coefficients is similar to the estimates in the top panel, with some changes for specific outcomes.

In Appendix Table A.II we specify hospital admissions in logs. With the appropriate transformation the estimated coefficients are comparable to those in Table IV throughout, and significant in three out of four cases. The estimated reform effects are also robust to varying the "treatment radius" around ports used to define fishmeal locations.

Finally, Figure VII shows trends in health outcomes in fishmeal and non-fishmeal locations before and after the reform took effect. We see similar trends in the two groups before the reform, 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,[46] is also apparent in Figure VII, 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 (also post-reform), and, perhaps more importantly, (b) the medical expenditures estimates suggests that the total cost to individuals of their health problems increased significantly post-reform.

6.3 Understanding the effect of the introduction of individual property rights upstream on health

Total production *decreased* after the reform.[47] Why did the introduction of individual property rights upstream then worsen plants' impact on health? While Appendix Table A.III shows that average incomes and labor market outcomes are not significantly different during fishmeal production periods, a first possibility is nevertheless that the impact of the reform on health was due to changes in labor markets post-reform. As seen in Table V, 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. In Appendix Table A.IV, we also show that the adverse health impact of the reform estimated in the full sample is not driven by impacts on fishing workers' health. Note that it is also clear that the impact of the reform on health is not explained by pollution from the fishing boats,[48] nor by production expanding into periods of the year in which the impact of air pollution differs.[49]

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

[47] The estimated reform effects are robust to excluding the two ports that saw an increase in total, yearly production after the reform. Because post-reform movements in the level of production across ports were limited, it is clear that market share moving towards areas in which the impact on health of a given level of production (with a given time profile) is worse (see e.g. Fowlie, 2010) does not explain the adverse average effect of the reform on health. For example, the overall reform effect is not explained by more efficient plants (that gain market-share post-reform) being more polluting / having a greater impact on health in general – we see adverse reform effects also in inefficient ports in the North.

[48] 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.

[49] 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 (11) and (12), 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 most noteworthy change in the industry after the reform was in the downstream manufacturing plants' time profile of production. As seen in Sub-section 5.2, the reform led to significant changes in suppliers' (boats') "organization of production" and industry dynamics, which in turn led downstream production, on average across locations, to be spread out in time. We hypothesize that this explains the plants' exacerbated impact on health, and now investigate this possibility. First note that the average change in the time profile of production seen in Figure IV masks considerable heterogeneity across locations. 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 VIII.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 VI shows results from a difference in differences in differences specification in which we interact the double difference term in specification (9) 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).[50] Overall, the results in Table VI, with a deterioration in health in the North/Central region after the reform and signs of improvement in the South, supports the hypothesis that the downstream industry's exacerbated impact on health after the introduction of ITQs upstream operates through changes in the time profile of production.

In a second 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.[51] 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 VI shows results from a difference in differences in differences specification in which we interact the double difference term in specification (9) with port level efficiency. The adverse health effects of the reform for adults are concentrated in locations with efficient plants; beneficial, though 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,

the reform.

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

[51]With the objective of testing the hypothesis that days of production is the primary driver of the fishmeal industry's impact on health in a given location in mind, efficiency thus defined is the proxy most closely tied to our model. The maximum output/input ratio observed among plants in a port is 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. We have also tried alternative efficiency proxies; these give qualitatively similar results.

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.V. 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.[52] 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.

An alternative way to test the proposed explanation of the adverse reform effects downstream is to exploit time and geographical variation in the profile of production to estimate how the spread across time matters for health, controlling for the level of production. We thus run the specifications used in Sub-section 4.2 with the difference that we include *both* production days and total production interacted with the "Near Plant" indicator. While the results shown in Table VII are noisier due to the high correlation between the two variables, they indicate that, for any given amount of production, a longer production period increases the impact on health, especially in the 90 day window and for adults. The findings in Table VII thus corroborate those based on geographical heterogeneity in the estimated reform effects, providing further evidence that the introduction of ITQs upstream affected health through changes in the time profile of production downstream.

We have now shown that spatial variation in the estimated post-reform change in downstream plants' impact on health is qualitatively consistent with the impact on health of the level and spread of production estimated in Sub-section 4.2. Are the two sets of estimates also quantitatively consistent with each other? Suppose that what matters most for the plants' impact on health is the number of days of production in the recent past, as e.g. the findings in Table VII suggest. Table IV suggests that each hospital admits an additional 12.24 patients for respiratory diseases per month after the reform. The findings in Section 4.2 imply that an additional day of production during the last 90 days generates 0.22 additional admissions for respiratory diseases per hospital, which in turn suggests that approximately 56 additional days of production would be necessary to generate the reform effect estimated here.[53] While this number is somewhat larger than the average increase in days of production exposure post-reform, several large ports saw much longer increases in the production season. (Chimbote, the largest fishmeal port in terms of production, saw an additional 71 days of production in 2009 relative to 2008, for example). Figure A.I, discussed in the appendix, also suggests that some of the deterioration in health post-reform may have occured outside of the lookback windows we use in Section 4.2. While the comparison of the two sets of estimates is by necessity back-of-the-envelope in nature, we thus conclude that the mid-2009 deterioration in health estimated here was plausibly a direct result of changes in the time profile of plant 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

[52] Appendix Table A.IV 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.

[53] Similarly, our estimates imply that an additional day of production gives a 0.1 percentage point increase in the probability of "Any Health Issue" for adults. The restimated reform effect is 5.9 percentage points, which then translates into 59 additional days of production.

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.[54]

6.4 Why the time profile of downstream production matters for 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.

There is in fact a considerable body of evidence in the epidemiological literature indicating that air pollution in high-concentration contexts is likely to 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 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".

[54] 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.

[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.

In this paper we have directly demonstrated that (1) the reason why health deteriorated in fishmeal locations in the wake of the upstream regulatory reform was the fact that (a given amount of) polluting downstream production was spread out over time. The evidence we present on (2) *why* dispersing polluting manufacturing across time exacerbates health impacts by necessity draws more on the existing epidemiological and medical literature, given the pollution data available for developing countries like Peru and the variation we exploit in this paper. Nonetheless, the changes seen the concentration of air pollutants after the upstream reform took effect, and the existing evidence on dose and duration response, clearly indicate that the answer to (2) lies in the shape of the health production function. It appears that the decrease in daily intensity of exposure early in the season was far outweighed by the increase in the duration of exposure because of the concave nature of the concentration response function at the pollution levels seen in Peru. The on-and-off nature of downstream production in our context (with two production seasons per year) makes it difficult to determine if there are also compounding effects of cumulative (days of) exposure (see Isen, Rossin-Slater and Walker, forthcoming), but, if so, such compounding effects would add to the importance of concurrent exposure we identify to further reinforce the adverse consequences of increased production duration.

7 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 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. To scale these up to a yearly, sector-wide estimate, we "extrapolate" based on the share of production the publicly listed firms account for in each year. 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 Table VIII).

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. We convert the respiratory disease episodes caused to an 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

[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).

[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.

(VSL)" method to monetize the DALYs lost.[59] As there are no existing convincing estimates of the value of a statistical life year in Peru, we use 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. We scale the estimate up based on GNI per capita in Sub-Saharan Africa and Peru with the commonly used elasticity recommended by Hall and Jones (2007).[60] The per-year costs of the 2009 ITQ reform due to its impact on respiratory disease episodes estimated using this methodology is USD 297 million. To this we add the additional medical expenditures caused to arrive at a total, yearly health cost of the reform of USD 343 million.[61]

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. Figure IX provides suggestive evidence that the reform succeeded at slowing the decline in the fish stock. While 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,[62] we prefer to count only the per-year gap.[63]

It thus appears that the costs of the 2009 introduction of individual property rights among industrial fishing boats in Peru, due to its add-on effect on downstream plants' impact on health, surpassed its benefits. While our calculation probably underestimates the total health costs, the methodology used to monetize the health costs rests on strong assumptions and the resulting numbers should be interpreted with caution. It is clear, though, that the costs of the exacerbation of downstream externalities are very large relative to the upstream benefits of the piecemeal reform we analyze.

8 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 the downstream plants that convert fish from Peru's industrial fishing boats into fishmeal harm adult and child health through air pollution emitted in the process. We then analyze how and why the impact on health changed with a 2009 reform that introduced individual, transferable quotas (ITQs)

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

[60]Using the elasticity calculated by Leon and Miguel (2015) gives even larger total costs.

[61]Our preferred method gives a value of USD 52,358 per statistical life year in Peru. If we alternatively use the VSL estimated for the U.S. by the EPA (Murray, 2012; U.S. Environmental Protection Agency, 2010) and equivalent scaling, we get a value of USD 22,548 per statistical life year in Peru, and a total, yearly health cost of the reform of USD 174 million. We prefer the estimate based on scaling up Leon and Miguel (2015)'s VSL for Africans to Peru's GNI per capita over the one based on scaling down the EPA's VSL for the U.S. because Peru's GNI per capita (in 2009 USD PPP) – USD 8,760 – is much closer to Sub-Saharan Africa's – USD 2,108 – than that of the U.S. – USD 47,420. Similarly, Kremer et al. (2011) estimate an unusually low VSL, but for a sample that is much further from ours in income levels than the one in Leon and Miguel (2015) – Kenyan villagers with per capita incomes below USD 100.

[62]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.

[63](i) We only have access to fish stock numbers at the regional (North/Central versus South) level, and, as seen in Figure IX, the numbers can vary considerably from year to year (and also depend on e.g. the size of the total quota allowed). (ii) To what extent the increase in profits due to the reform will persist is unclear. (iii) Reasonable discount factors will in any case mean that later years will receive little weight in the cumulate cost calculation.

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 of USD 343 million that likely *surpassed* the benefits of the reform.

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 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 large enough to outweigh the decrease in the targeted externality, 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.[64] 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.

[64] 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

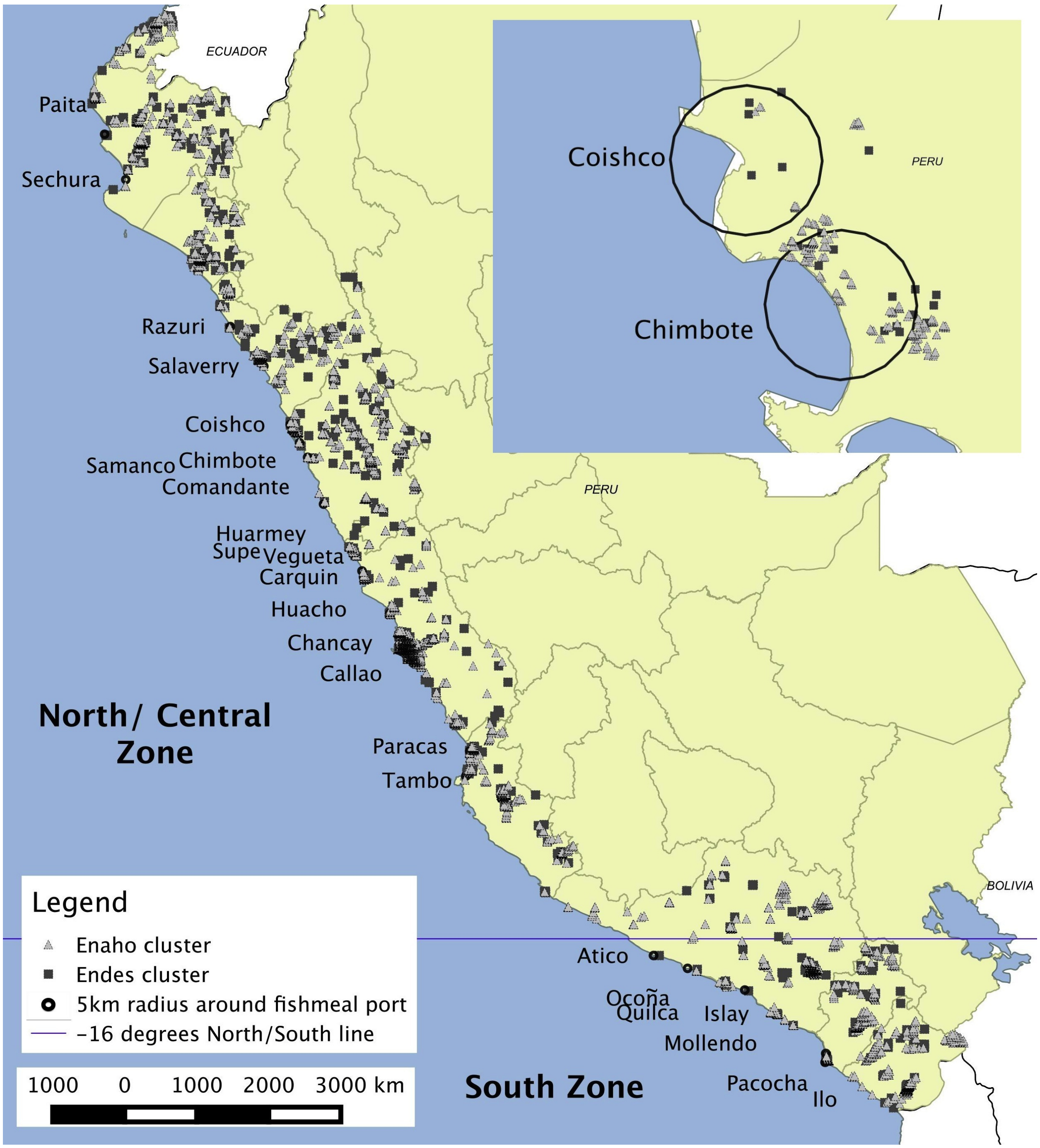
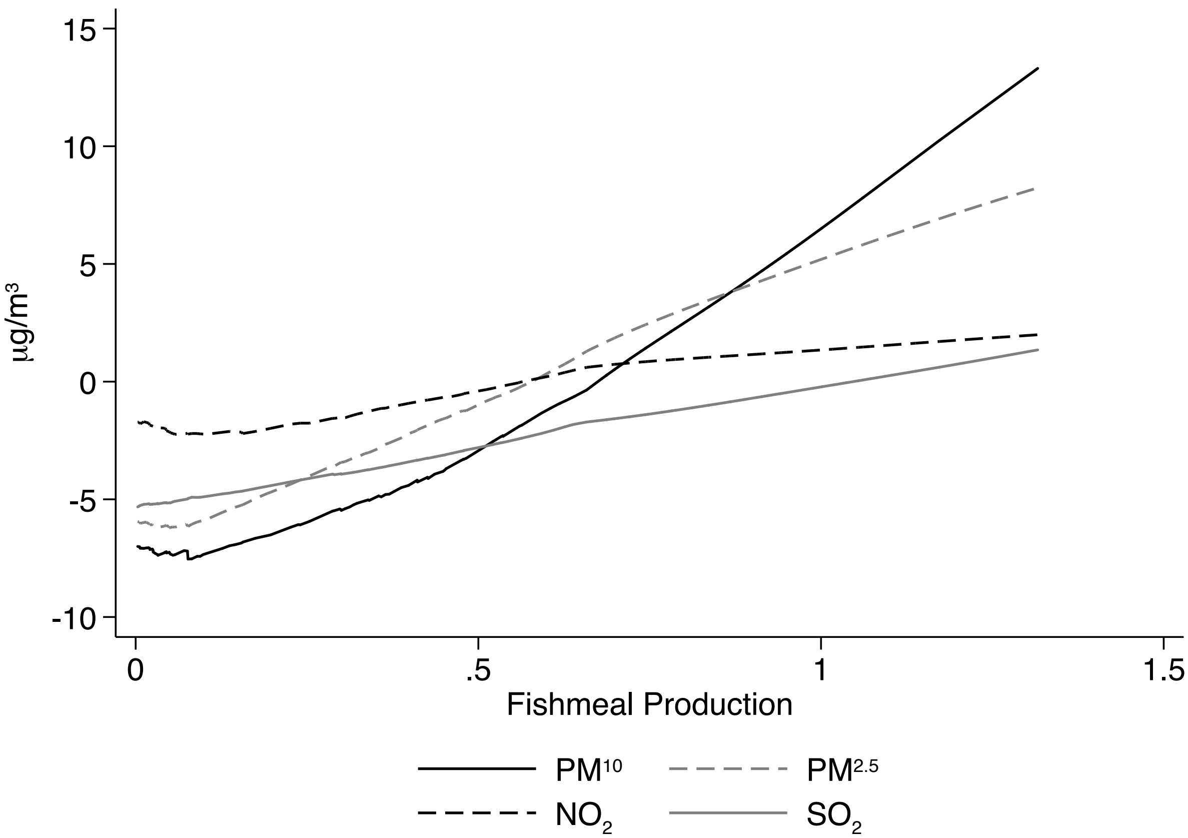
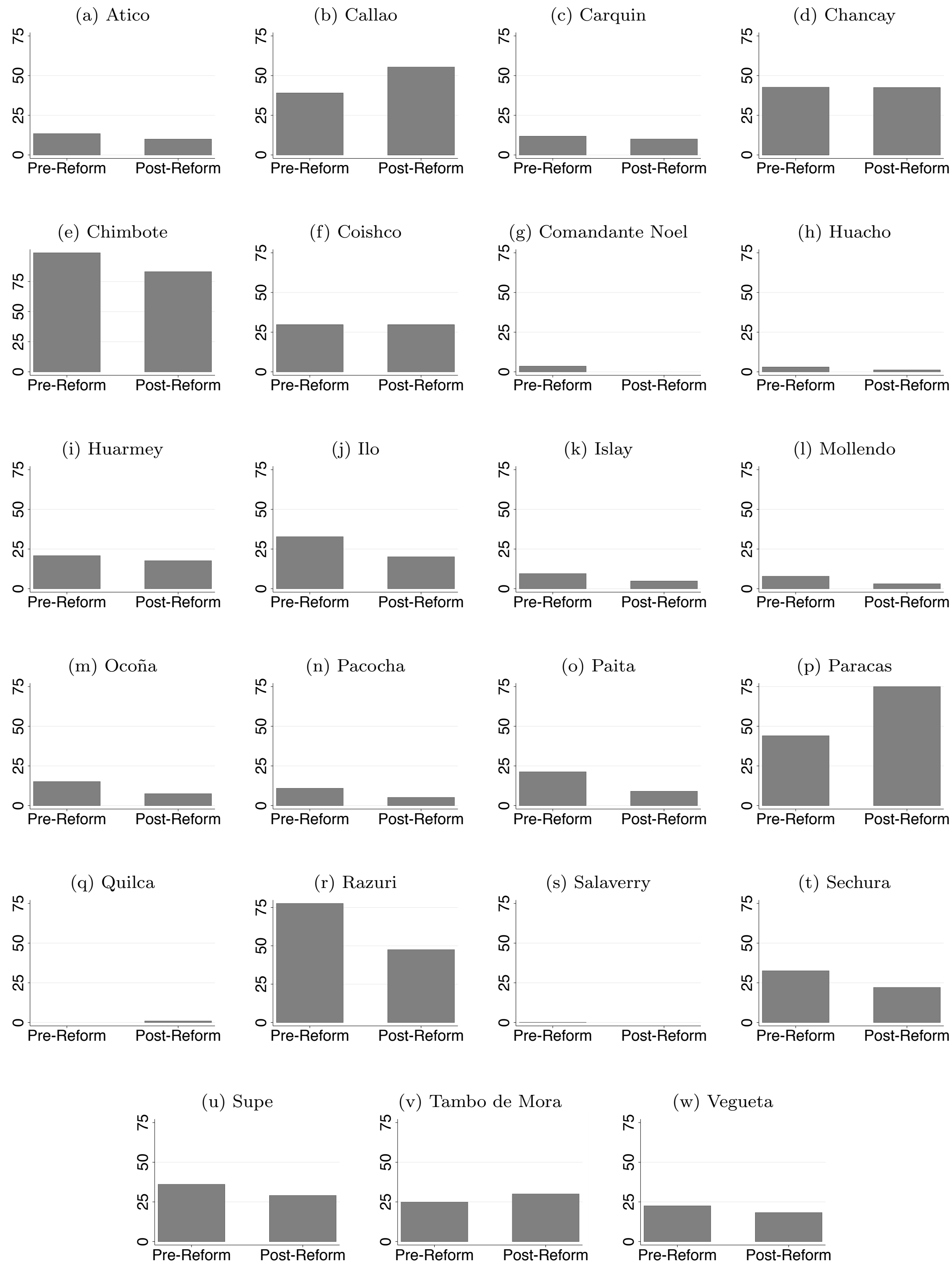


Figure II
Daily Fishmeal Production and Air Pollution in Lima



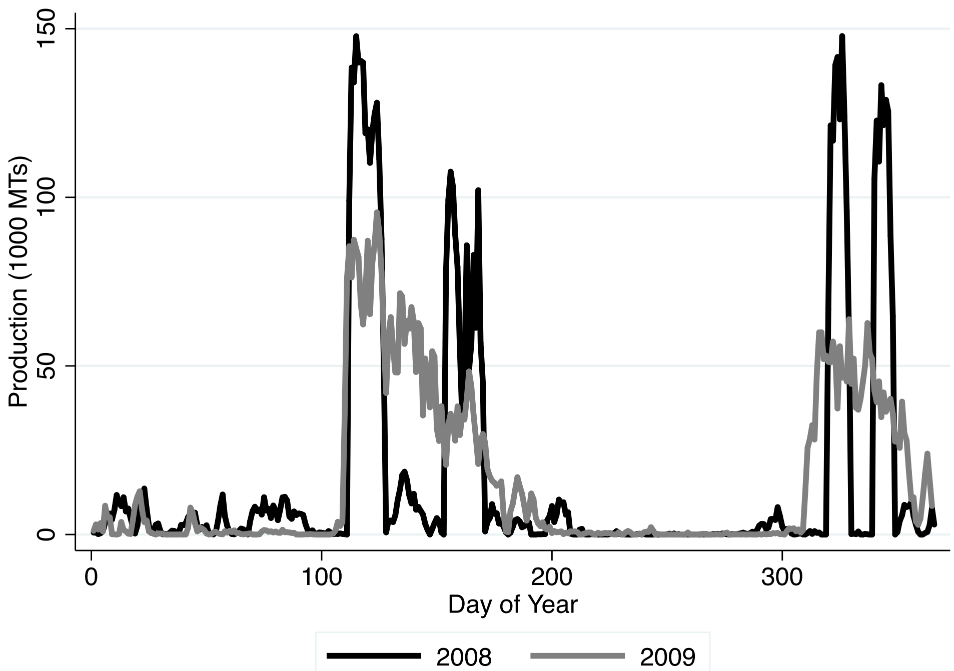
Lowess smoothing of month demeaned pollutant levels (in $\mu g/m^3$) against daily fishmeal production in Callao (measured as inputs in 10,000s of MTs) for days with positive production. Pollutant levels at the port of Callao are calculated as the inverse distance weighted mean of 5 air quality measurement 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 III
Port-Level Fishmeal Production Pre- and Post-Reform



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

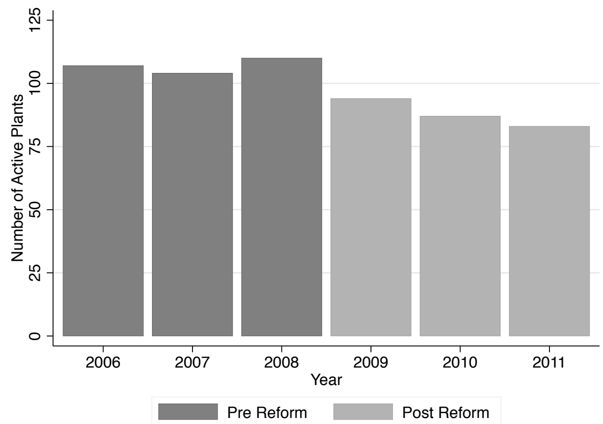
Figure IV
Time Profile of Fishmeal Production



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

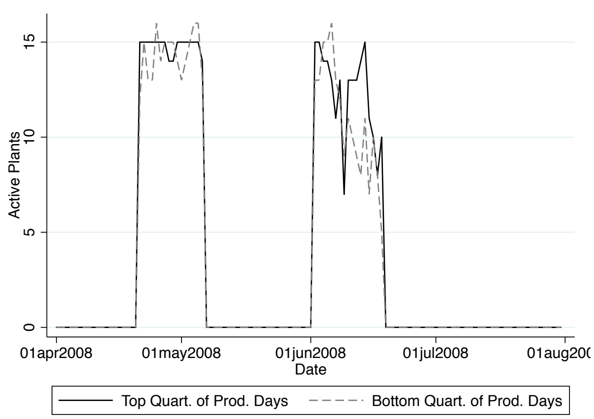
Number of Active Plants Across Years



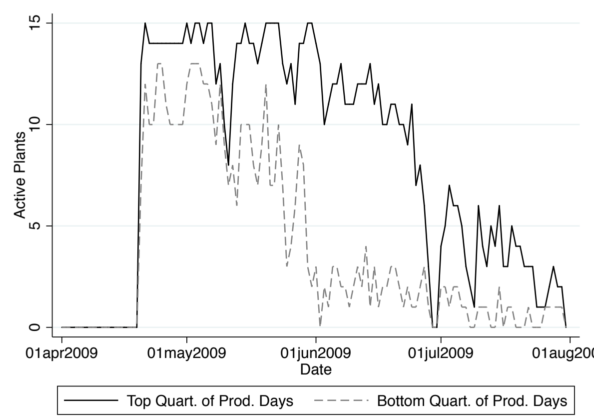
Number of Active Plants During the Season: Top vs. Bottom Quartiles of 2009 Production Days

Active Plants

(a) 2008



(b) 2009

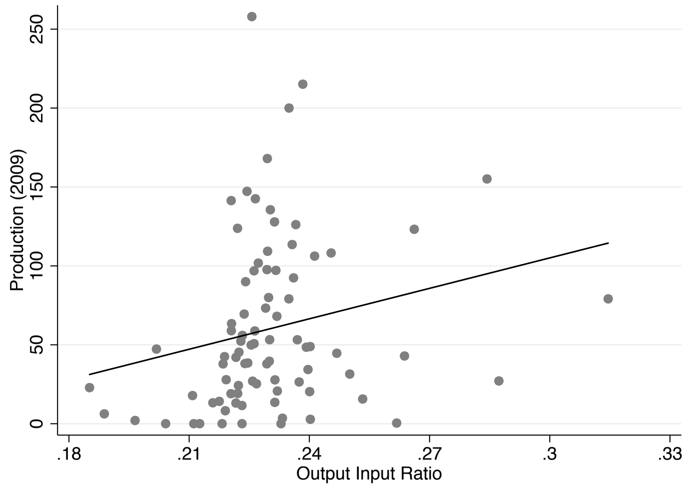


Top figure plots total number of active plants by year, where a plant is considered active if it purchases fish input any day of the year. The lower figures plot the number of active plants during the first production seasons in 2008 and 2009. The solid line in each shows plants in the top quartile of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

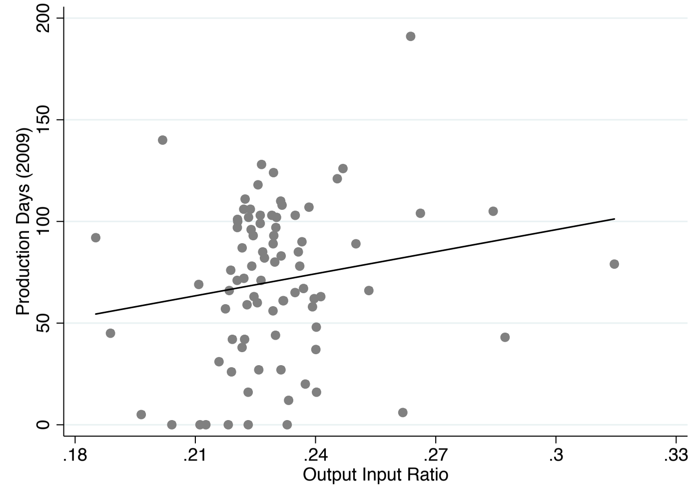
Figure VI
Production by Port and Plant Level Efficiency

Fishmeal Production and Plant Level Efficiency

(a) Production

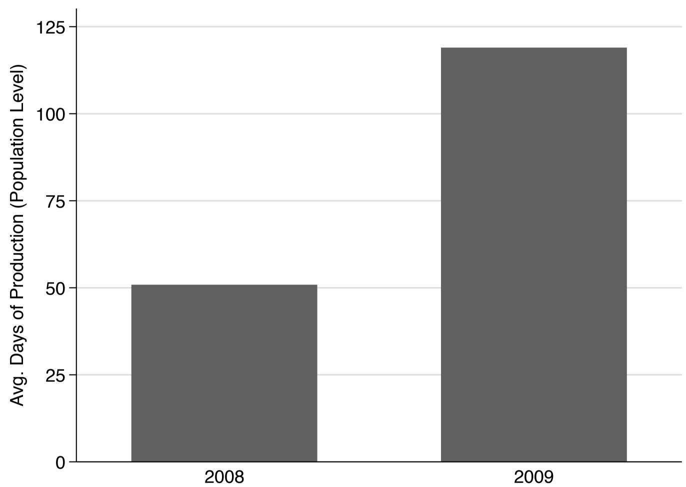


(b) Production Days

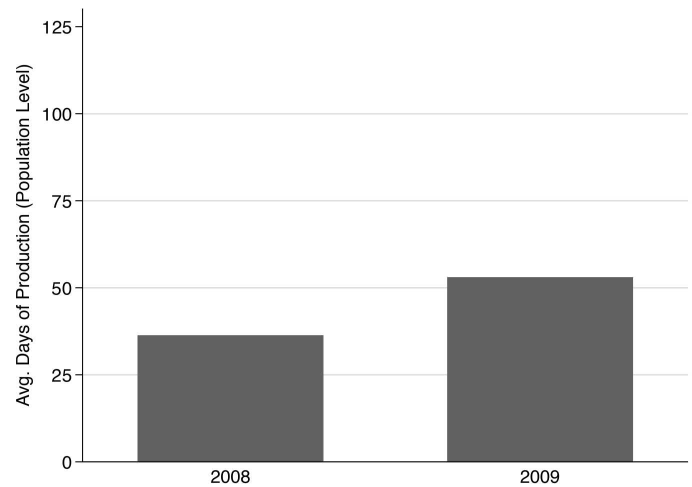


Average Port Level Days of Production by Efficiency: Pre-Reform vs. Post-Reform

(a) Ports in Top Quartile of Efficiency



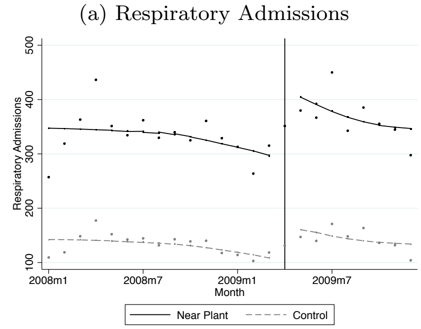
(b) Ports in Bottom Quartile of Efficiency



Top figures show the relationships between efficiency and 2009 production or production days. Bottom 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. A production day is defined by $>$ 1000 MTs of input at the port level. Efficiency is measured as output/input ratio (Fishmeal/Fish Input) for plants and the maximum port level output/input ratio for ports. In the top figures, we omit plants in the top and bottom 5% of efficiency

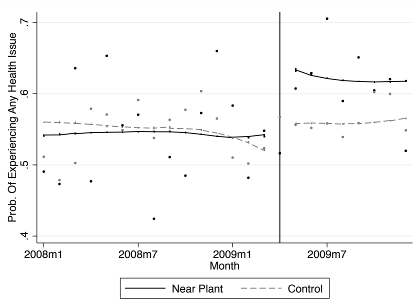
Figure VII
Plotting Health Outcomes Across Time Pre- and Post-Reform

(a) Respiratory Admissions

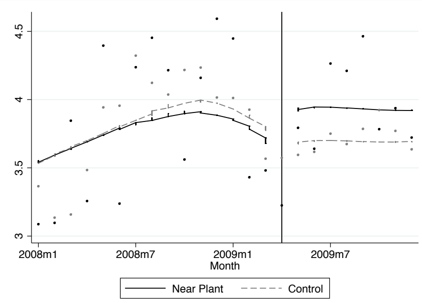


Adults

(b) Any Health Issue

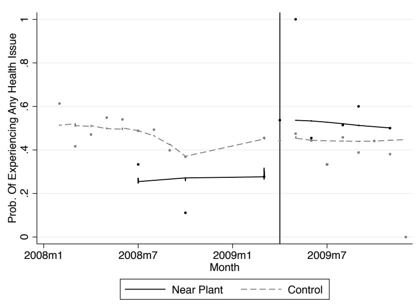


(c) Log Medical Exp.

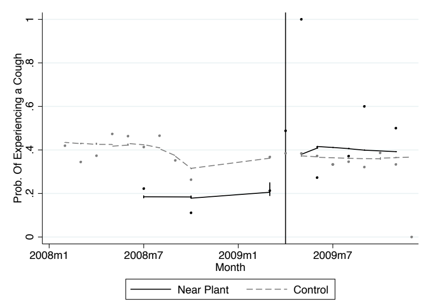


Children ≤ 5

(d) Any Health Issue



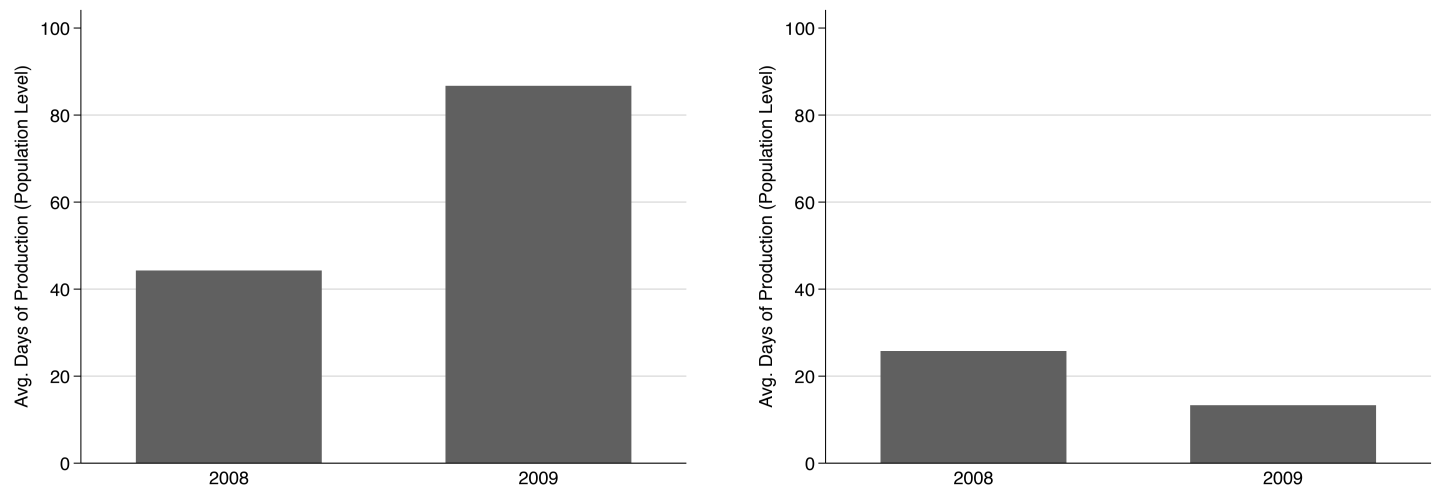
(e) Cough



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.

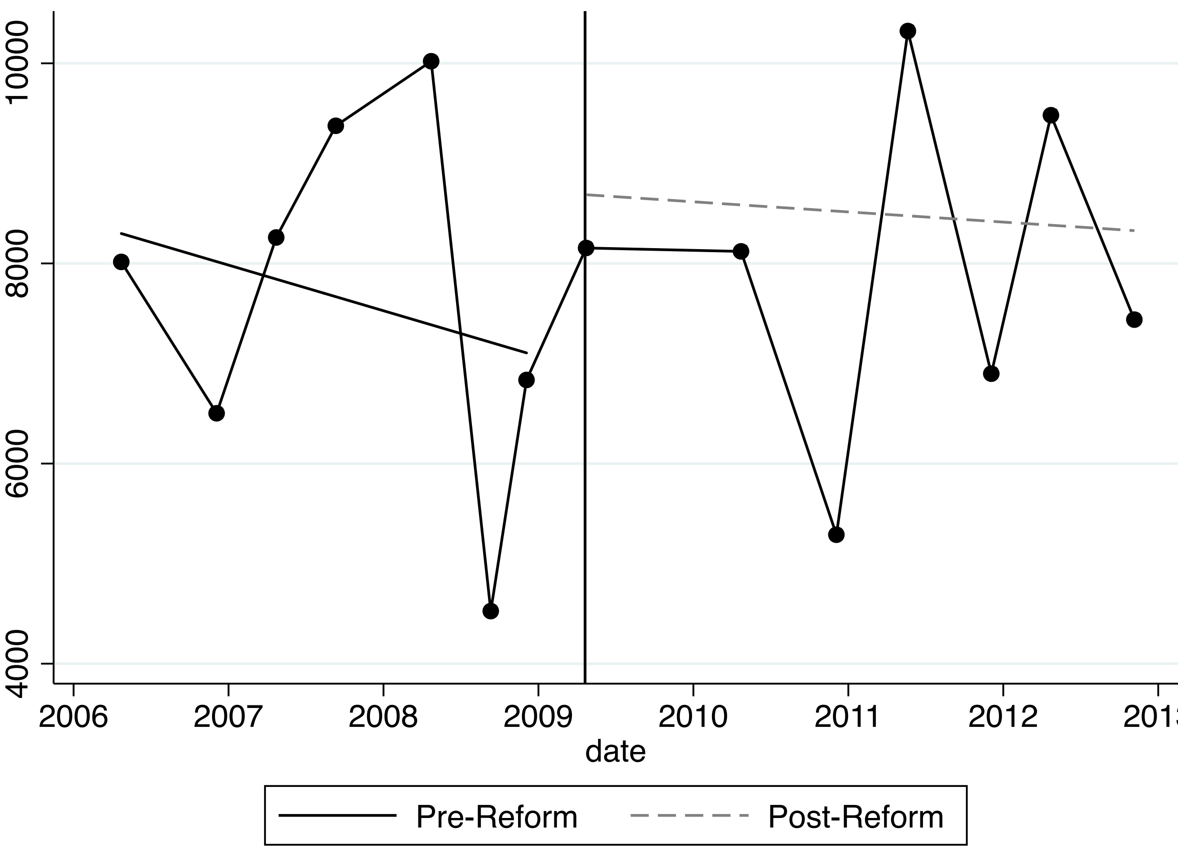
Figure VIII
Average Port Level Days of Production by Region: Pre-Reform vs. Post-Reform

(a) North/Central Region (b) South Region



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.

Figure IX
Anchoveta Stock Pre- and Post-Reform



Total biomass of anchoveta between 2006-2012 from IMARPE, with linear trends pre- and post-reform. We omit 2010 from the trend line estimation due to the occurrence of El Niño. Vertical line represents beginning of reform in North/Central region (April 20th, 2009).

Table I

Summary Statistics: Health Outcomes

	Health Outcomes															
	Near Plant				Control				Near Plant				Control			
	No Prod.		Prod. Season		No Prod.		Prod. Season		Pre-Ref.		Post-Ref.		Pre-Ref.		Post-Ref.	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Respiratory Admissions	317.8	331.9	334.9	348.9	129.7	173.4	132.7	183.0	327.5	352.5	322.3	327.2	136.5	183.6	124.7	169.4
Any Health Issue (Adults)	0.58	0.49	0.62	0.49	0.59	0.49	0.59	0.49	0.55	0.50	0.64	0.48	0.57	0.50	0.60	0.49
Log Medical Expend.	3.88	2.88	3.88	2.86	3.71	2.86	3.68	2.88	3.66	2.89	4.06	2.84	3.59	2.86	3.79	2.88
Any Health Issue (Children)	0.40	0.49	0.46	0.50	0.44	0.50	0.48	0.50	0.39	0.49	0.43	0.50	0.47	0.50	0.45	0.50
Cough	0.32	0.47	0.38	0.49	0.36	0.48	0.40	0.49	0.32	0.47	0.35	0.48	0.39	0.49	0.37	0.48
	Adult Labor Outcomes and Covariates															
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Has Any Job	0.58	0.49	0.57	0.49	0.64	0.48	0.64	0.48	0.56	0.50	0.59	0.49	0.63	0.48	0.65	0.48
Has 2nd Job	0.090	0.29	0.088	0.28	0.12	0.32	0.11	0.31	0.070	0.25	0.10	0.31	0.10	0.30	0.12	0.33
Total Labor Hours	28.5	28.5	28.5	28.7	30.4	27.4	30.6	27.6	29.2	29.3	27.9	28.0	30.6	27.8	30.3	27.2
Total Labor Income	3.52	3.17	3.41	3.19	3.42	3.14	3.51	3.15	3.36	3.13	3.56	3.21	3.40	3.09	3.50	3.18
Fishing Worker	0.084	0.28	0.068	0.25	0.025	0.16	0.027	0.16	0.082	0.27	0.072	0.26	0.027	0.16	0.025	0.16
Manual Laborer	0.26	0.44	0.26	0.44	0.37	0.48	0.34	0.47	0.27	0.44	0.25	0.44	0.35	0.48	0.36	0.48
Current. Lives in Birth Prov.	0.43	0.49	0.47	0.50	0.39	0.49	0.40	0.49	0.45	0.50	0.45	0.50	0.40	0.49	0.38	0.49
Current. Lives in Birth Dist.	0.60	0.49	0.63	0.48	0.59	0.49	0.63	0.48	0.62	0.49	0.61	0.49	0.62	0.49	0.59	0.49
Age	35.8	21.3	37.2	20.0	35.7	20.6	36.3	20.2	37.7	20.0	35.4	21.3	36.2	19.7	35.7	21.0
Male	0.49	0.50	0.48	0.50	0.49	0.50	0.48	0.50	0.49	0.50	0.48	0.50	0.49	0.50	0.49	0.50
Years of Education	9.87	4.21	9.69	4.29	9.21	4.60	9.47	4.48	9.64	4.27	9.90	4.22	9.32	4.54	9.30	4.57
Indigenous Language	0.078	0.27	0.11	0.31	0.13	0.34	0.13	0.34	0.099	0.30	0.088	0.28	0.13	0.34	0.13	0.34
	Child Covariates															
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Age	2.44	1.42	2.54	1.42	2.50	1.43	2.50	1.43	2.39	1.40	2.50	1.43	2.51	1.44	2.49	1.43
Male	0.52	0.50	0.52	0.50	0.51	0.50	0.50	0.50	0.50	0.50	0.53	0.50	0.50	0.50	0.50	0.50
Mothers Years of Educ.	10.8	3.51	11.6	3.04	9.54	4.14	9.81	3.99	10.9	3.36	11.1	3.38	9.69	4.19	9.60	4.05
HH Asset Index	0.83	0.67	0.90	0.65	0.29	0.93	0.44	0.91	1.00	0.68	0.80	0.64	0.60	0.90	0.21	0.91
Observations (Adults)	5172		4563		93852		58225		4388		5347		7013		9176	
Observations (Children)	631		319		9203		4531		255		695		4558		9176	
Observations (Hospitals)	13563		8979		77463		41976		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. Income and medical expenditure are measured in Peruvian Soles. The share of sampled adults that report to work in "fishing" is actually slightly higher outside of the production season. The reason may be that many (boat and plant) industrial fishing workers work as artisan fishermen outside of the industrial season.

Table II
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 III
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 Port	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 Port	0.889** (0.434)	0.001*** (0.000)	−0.000 (0.001)
		NO_2	
Avg. NO_2 level in last 30 Days x Near Port	3.699** (1.808)	0.002*** (0.000)	−0.000 (0.001)
		SO_2	
Avg. SO_2 level in last 30 Days x Near Port	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
Hospital/Centro Poblado FEs	Yes	Yes	Yes
Month x Year FEs	Yes	Yes	Yes
HH Controls	No	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 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
	Sample Limited to 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
	Sample Limited to 2008-2009 – 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
	Sample Limited to 2008-2009 – 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 Limited 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
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 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 VI
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)
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)
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 VII
Impact of Level and Dispersion of Fishmeal Production on Health

	Hospitals	Adults		Children: ≤ 5	
	Respiratory Admissions	Any Health Issue	Log Medical Expenditure	Any Health Issue	Cough
			Last 30 Days		
Log Fishmeal Prod. in Last 30 Days	−1.579	0.010	−0.016	−0.004	−0.001
	(1.089)	(0.006)	(0.033)	(0.020)	(0.023)
Production Days in Last 30 Days	−0.101	0.000	0.003	0.001	0.000
	(0.127)	(0.001)	(0.004)	(0.002)	(0.003)
Log Fishmeal Prod. in Last 30 Days x Near Plant	7.785*	−0.013	0.054	0.100*	0.119**
	(4.123)	(0.015)	(0.094)	(0.056)	(0.053)
Production Days in Last 30 Days x Near Plant	−0.470	0.004**	0.005	−0.010	−0.013**
	(0.443)	(0.002)	(0.011)	(0.006)	(0.005)
			Last 90 Days		
Log Fishmeal Prod. in Last 90 Days	0.690	0.002	0.031	0.011	0.016
	(0.745)	(0.004)	(0.022)	(0.013)	(0.013)
Production Days in Last 90 Days	−0.211***	0.000	−0.001	−0.001	−0.002**
	(0.059)	(0.000)	(0.001)	(0.001)	(0.001)
Log Fishmeal Prod. in Last 90 Days x Near Plant	3.644	−0.008	−0.001	−0.030	0.008
	(3.171)	(0.008)	(0.043)	(0.022)	(0.025)
Production Days in Last 90 Days x Near Plant	0.076	0.001**	0.007**	0.005***	0.002**
	(0.182)	(0.001)	(0.003)	(0.001)	(0.001)
Mean of Dep. Var.	160.7	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 VIII
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)	$297,455,874	
Panel C: Total Costs and Benefits		
Estimated benefit to sector (USD)		$219,237,448
Estimated total cost (medical exp. + cost of YLDs)		$342,929,254

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. US estimates give an estimated total cost of $173,620,448. 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

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).

Background on estimation of fishmeal production's impact on health

The specification we use when estimating the impact of fishmeal production on survey outcomes is as follows:

$$
\begin{aligned}
y_{ijtmy} = \alpha + \beta_1 Production_{jt} + \beta_2 FishmealLocation_j \times Production_{jt} + \beta_3 X_{ijt} \\
+ \gamma_j + \delta_{my} + FishmealLocation_j \times \theta_m + \varepsilon_{ijtmy}
\end{aligned}
\tag{11}
$$

where y_{ijtmy} is an outcome variable for individual i, who lives in location j, and was interviewed on date t, in calendar month m and year y. X_{ijt} are individual-level covariates – 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 – that control for possible changes in the sample surveyed across time/space. γ_j is a centro poblado or district fixed effect,[65] δ_{my} is a year×month fixed effect, and $FishmealLocation_j \times \theta_m$ is a $FishmealLocation$ specific month fixed effect. The centro poblado/district and year×month fixed effects control for any time- or location-invariant shocks to the study population's health that may be correlated with fishmeal production, while $FishmealLocation_j \times \theta_m$ controls for possible differential seasonality in fishmeal locations. ε_{ijtmy} is an iid error clustered at the centro poblado or district level. 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.[66]

The estimation equation for hospital admissions outcomes is as follows:

$$
\begin{aligned}
y_{imy} = \alpha + \beta_1 Production_{imy} + \beta_2 FishmealLocation_i \times Production_{imy} \\
+ \gamma_i + \delta_{my} + FishmealLocation_i \times \theta_m + \varepsilon_{imy}
\end{aligned}
\tag{12}
$$

The primary difference between (12) and (11) is that monthly hospital level outcomes do not require use of a j or t subscript, nor individual level controls. In (12) γ_i is a hospital fixed effect.

For outcomes drawn from the ENAHO and ENDES surveys, for which an observation is associated with a specific date, we use the past X days to construct $Production$. For hospital admissions outcomes, which are recorded at the monthly level, we use current month for 30 day regressions and current and past two months for 90 day regressions. 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.II, the output of fishmeal very closely tracks the input of fish.

[65] 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.

[66] In a slight abuse of notation, for ENDES outcomes we use j to denote both the location that determines a child's treatment status – (the centroid of) its sampling cluster – and also the geographical level for which we can include fixed effects in ENDES regressions – districts. For ENAHO survey outcomes, the centro poblado is used both to determine treatment status and in the geographical fixed effects.

Robustness

We include a number of alternative specifications as robustness checks of the impact of fishmeal production on health:

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 II when using survey-measured health outcomes, as seen in Appendix Table A.VI.[67]

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.VII. The results are qualitatively similar in terms of sign and significance to our primary specifications.

Alternative Hospital Outcomes: In Appendix Table A.VIII, 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.

Varying Treatment Radius and Lookback Window: The treatment radius and lookback windows used in Table II were informed by the existing literature and the window used in the ENAHO survey questions[68], but nevertheless involved a degree of choice. In Figure A.I, we plot treatment effects estimated for all radii between 0 and 30 kilometers from fishmeal ports, for all outcomes.[69] 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.I 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 II.

Falsification Exercise In Appendix Table A.IX 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.

[67]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.

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

[69]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.

How fishmeal production affects health

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.X, we show results from estimating equation (11) separately for those who work in fishing. We see that fishing workers display health effects that are similar to those of other individuals.[70] 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.III 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.

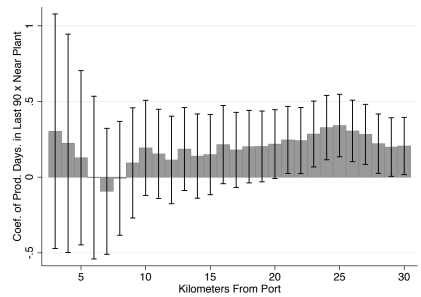
A third possibility is that a part of the observed effect of fishmeal production on "Any Health Issue" operates through pollution of the ocean.[71] However, as seen in Table A.X, we do not observe bigger health effects for those who work in fishing, who presumably have greater direct exposure to the ocean. Moreover, in Appendix Table A.XI, 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.

[70] 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.

[71] 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).

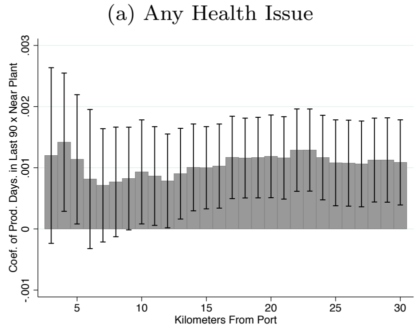
Figure A.I
Impact of Fishmeal Production on Health: Varying Treatment Radius

(a) Respiratory Admissions

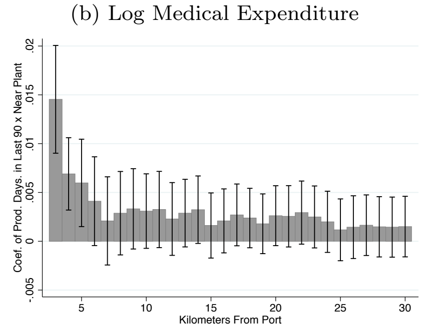


Adults

(a) Any Health Issue

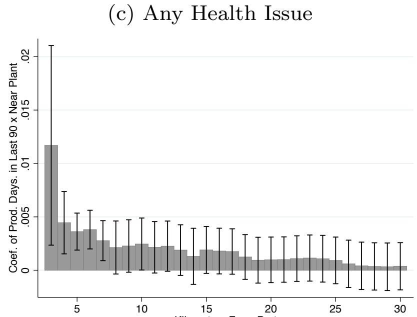


(b) Log Medical Expenditure

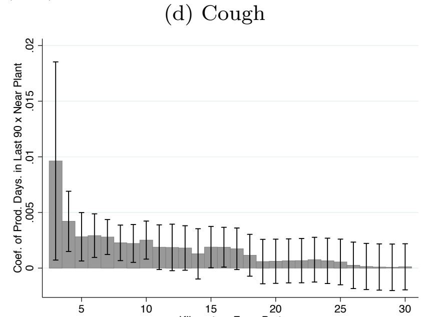


Children (≤ 5)

(c) Any Health Issue



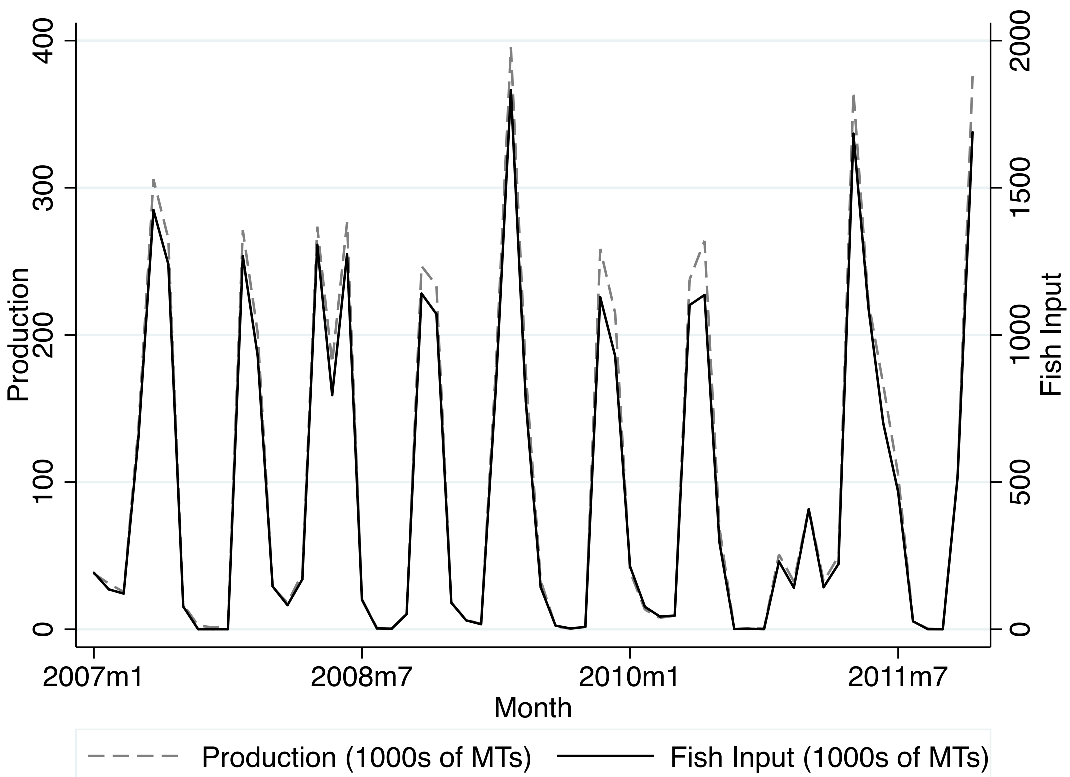
(d) Cough



Children (≤ 1)

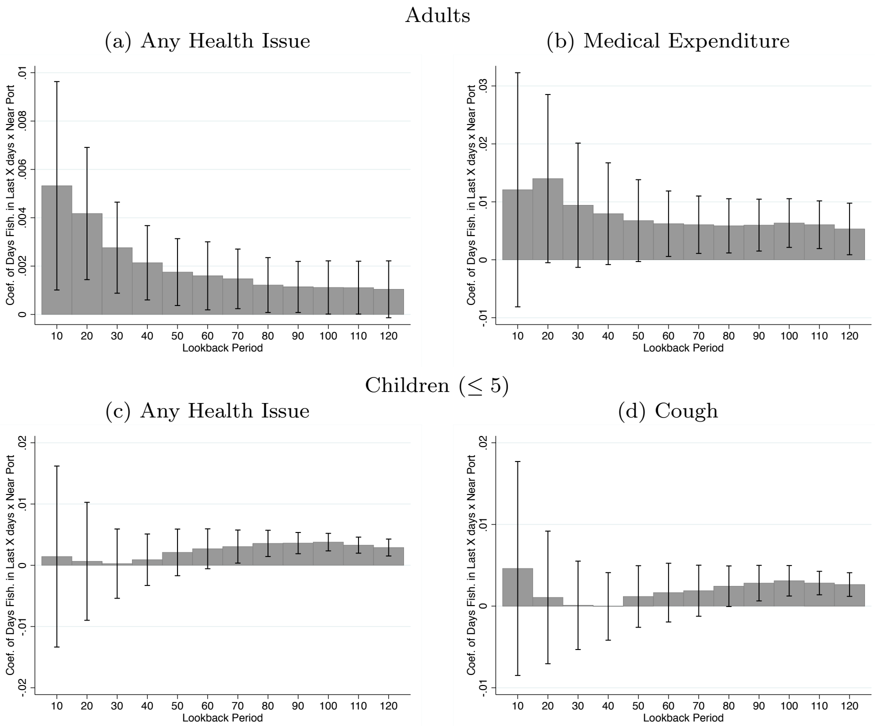
We plot the coefficient of "Production Days in the Last 90 Days $\times$ Near Plant", based on regressions similar to those in Table II. We allow the treatment radius that defines "Near Plant" to vary up to 30 kilometers and correspondingly vary the control group, defined as those living outside the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

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



We plot the coefficient of "Production Days in the Last x Days × Near Plant", based on regressions similar to those in Table II. 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 II 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 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**	1.574***	0.742***	1.638***
	(0.552)	(0.192)	(0.159)	(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 Port	0.205	0.001***	−0.001
	(0.416)	(0.000)	(0.000)
		PM2.5	
Avg. $PM^{2.5}$ level in last 30 Days x Near Port	0.802**	0.001***	−0.000
	(0.392)	(0.000)	(0.001)
		NO_2	
Avg. NO_2 level in last 30 Days x Near Port	1.737**	0.002***	−0.000
	(0.849)	(0.000)	(0.001)
		SO_2	
Avg. SO_2 level in last 30 Days x Near Port	1.870**	0.002***	−0.000
	(0.914)	(0.001)	(0.001)
Mean of Dep. Var.	329.2	0.54	4.11
N	19976	33570	33583
Hospital/Centro Poblado FEs	Yes	Yes	Yes
Month x Year FEs	Yes	Yes	Yes
HH Controls	No	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. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table A.II
Impact of Fishmeal Production on Hospital Admissions

	ln(Hospital Admissions)		
Post-Reform x Near Port	0.083**	0.180***	−0.035
	(0.035)	(0.032)	(0.048)
Mean of Dep. Var.	4.31	4.30	4.31
N	57554	114755	57554
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. Near plant is defined as 20 kilometers for hospital data. Hospital fixed effects are included and standard errors are clustered at the hospital level. 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.III
Impact of Fishmeal Production on Labor Market Outcomes

	Has Any Job	Has 2nd Job	Total Labor Hours	Log. Total Income	Has Any Job	Has 2nd Job	Total Labor Hours	Log. Total Income
	Panel A: All Adults							
	Log Fishmeal Production in Last 30 Days				Log Fishmeal Production in Last 90 Days			
Production Days in Last 30(90)	0.001*	−0.000	0.000	0.027	−0.000	−0.000**	−0.001	0.004
Days	(0.000)	(0.000)	(0.002)	(0.018)	(0.000)	(0.000)	(0.001)	(0.008)
Production Days in Last 30(90)	−0.000	0.000	−0.002	−0.018	0.000	0.000	−0.000	−0.021
Days x Near Plant	(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	0.006**	0.001	0.011	0.260	0.002	−0.001	0.003	0.163
30(90) Days	(0.002)	(0.002)	(0.016)	(0.160)	(0.002)	(0.001)	(0.013)	(0.124)
Log Fishmeal Prod. in Last	−0.007	0.002	−0.028	−0.243	−0.002	0.005	−0.019	0.140
30(90) Days x Near Plant	(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)	0.001*	−0.000	0.000	0.028	0.000	−0.000**	−0.001	0.005
Days	(0.000)	(0.000)	(0.002)	(0.018)	(0.000)	(0.000)	(0.001)	(0.008)
Production Days in Last 30(90)	−0.000	0.000	−0.004	−0.027	−0.000	0.000	−0.002	−0.029*
Days x Near Plant	(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	0.006**	0.001	0.011	0.261	0.003	−0.001	0.003	0.158
30(90) Days	(0.003)	(0.002)	(0.016)	(0.163)	(0.002)	(0.001)	(0.013)	(0.127)
Log Fishmeal Prod. in Last	−0.008	0.002	−0.046	−0.327	−0.001	0.005	−0.024	0.099
30(90) Days x Near Plant	(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)	−0.002*	−0.001	0.000	−0.066	0.000	0.000	0.004	0.020
Days	(0.001)	(0.001)	(0.008)	(0.089)	(0.001)	(0.001)	(0.004)	(0.057)
Production Days in Last 30(90)	0.003**	0.004**	0.031***	0.142	−0.000	0.002	0.010*	−0.011
Days x Near Plant	(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	−0.011	−0.001	−0.003	−0.153	0.005	−0.001	0.085*	1.288*
30(90) Days	(0.007)	(0.011)	(0.063)	(0.784)	(0.007)	(0.011)	(0.051)	(0.757)
Log Fishmeal Prod. in Last	0.012	0.016	0.290***	1.065	−0.011	0.012	0.077	−0.136
30(90) Days x Near Plant	(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. 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 A.IV

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. 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. 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.V
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.VI
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 (0.009)	−0.015 (0.042)	0.034 (0.032)	0.013 (0.033)
Log Fishmeal Prod. in Last 30 Days x Near Plant	−6.316 (6.870)	0.068*** (0.021)	0.243** (0.095)	0.010 (0.048)	0.033 (0.055)
		Log Fishmeal Production in Last 90 Days			
Log Fishmeal Prod. in Last 90 Days		−0.002 (0.012)	−0.031 (0.053)	−0.002 (0.024)	−0.032 (0.026)
Log Fishmeal Prod. in Last 90 Days x Near Plant	−3.531 (14.704)	0.147* (0.089)	0.516* (0.304)	0.045 (0.056)	0.103** (0.049)
		Production Days in Last 30 Days			
Production Days in Last 30 Days		0.001 (0.001)	−0.003 (0.007)	0.004 (0.004)	0.002 (0.004)
Production Days in Last 30 Days x Near Plant	−0.566 (0.615)	0.008** (0.003)	0.024* (0.013)	0.001 (0.006)	0.004 (0.007)
		Production Days in Last 90 Days			
Production Days in Last 90 Days		−0.001 (0.001)	−0.001 (0.004)	−0.000 (0.002)	−0.003 (0.002)
Production Days in Last 90 Days x Near Plant	−0.087 (0.362)	0.005*** (0.002)	0.018** (0.007)	0.004 (0.005)	0.009** (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.VII
Impact of Fishmeal Production on Hospital Admissions

	ln(Hospital Admissions)			
Log Capture in Last 30 Days	0.021***			
	(0.005)			
Log Capture in Last 30 Days x Near Port	0.016			
	(0.011)			
Log Capture in Last 90 Days		0.037***		
		(0.005)		
Log Capture in Last 90 Days x Near Port		0.021*		
		(0.012)		
Fishing Days in Last 30 Days			0.002**	
			(0.001)	
Fishing Days in Last 30 Days x Near Port			0.004***	
			(0.001)	
Fishing Days in Last 90 Days				0.001***
				(0.000)
Fishing Days in Last 90 Days x Near Port				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.VIII
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.IX
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	−0.032	0.063
	(0.018)	(0.052)	(0.070)
Log Fishmeal Prod. in Last 30 Days x Near Plant	0.051	0.060	0.254
	(0.100)	(0.145)	(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*	−0.039	0.071
	(0.020)	(0.059)	(0.073)
Log Fishmeal Prod. in Last 90 Days x Near Plant	0.095	−0.102	0.409
	(0.085)	(0.167)	(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	−0.003	0.006
	(0.002)	(0.007)	(0.009)
Production Days in Last 30 Days x Near Plant	0.016	0.017	0.097
	(0.011)	(0.024)	(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	−0.006	−0.001
	(0.002)	(0.006)	(0.006)
Production Days in Last 90 Days x Near Plant	0.009	0.006	0.070
	(0.006)	(0.017)	(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.X
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. 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. 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.XI
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 20kilometers		Near Port = Within 5 kilometers		Near Port = Within 20kilometers	
	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 dummy variable for living near a plant. 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. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.