Air Quality and Infant Health: La Oroya's Metallurgical Complex

Juan Campanario*
University of Pittsburgh

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Abstract

La Oroya, Peru has suffered from poor air quality since the early 1920s. In 2009, the company responsible unexpectedly closed. Using a difference in differences approach, I show infant health worsened during the closure likely due to the shutdown's impact on local government tax revenue and a subsequent reduction in government budgets. Birth weights fell by an average of 60 grams, a .14σ decline relative to infants born upwind the complex, and women reported 5% more miscarriages and stillbirths. I find evidence that those least likely to be financially impacted experience greater declines.

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*Department of Economics, 4700 Wesley W. Posvar Hall, 230 South Bouquet Street, Pittsburgh, PA 15260. Email: juc84@pitt.edu.

1 Introduction

Extractive industries, such as mining and oil extraction, have been shown to have mixed effects on a variety of outcomes such as schooling, income, and health (Agüero, Balcázar, Maldonado, & Ñopo, 2021; Maffioli, 2022; Von der Goltz & Barnwal, 2019). In emerging economies such as Ghana, Peru, and Brazil, a portion of income taxes or royalties generated by extractive industries is redistributed to local municipalities, and are earmarked for public expenditure. In Peru, these types of transfers have been found to increase test scores through educational investments (Agüero et al., 2021), but had no effect on access to public goods such as potable water or lighting (Maldonado, 2014). In the case of Brazil, health was worsened in localities with larger intital endowements of metallic minerals (Maffioli, 2022), and public service provision is smaller than expected given reported spending from oil windfalls (Caselli & Michaels, 2013). Previous studies of transfers from extractive industries studies rely on variation in either production or global prices to assess how fluctuations affect various outcomes, but few papers study closures (Von der Goltz & Barnwal, 2019).

In La Oroya, Peru, a refinery has been a crucial employer in the area, responsible directly and indirectly for approximately 19,000 jobs, and an egregious polluter (Cederstav & Barandiarán, 2002; Doe Run Peru, 2012). In May 2009, one month before a smelting and refining complex closed in La Oroya, Peru, the sulfur dioxide (SO_2) emissions exceeded 500 parts per billion over half the days, far exceeding the 1971 US EPA standard for 24-hour SO_2 of 140. When a coal plant in Pennsylvania was shutdown due to toxic emissions spewing into its neighboring state, New Jersey, the maximum 24-hour emissions of fewer than 300 parts per billion (New Jersey Department of Environmental Protection, 2010, pg.85).

The refinery temporarily closed in June 2009 due to an inability to access lines of credit and mounting fines related to previous environmental damage, partially reopening in August 2012.[1] The closure marked the first time in almost a century that residents of La Oroya could

[1]The company gained approval to restart its zinc-processiong circuit, but could not operationalize other circuits as they did not meet environmental standards.

breathe clean air (USA Committee of Foreign Affairs, 2012). Arrieta and Guillén (2018) argue that pollution reductions due to required investments before the same operation closed, designed to reduce pollution, resulted in a $.16\sigma$ increase in the birth weights of infants born in a private hospital in La Oroya to all other births in private hospitals across Peru.

I study the effect of the closure on infant health for those born within 50km of the operation. I focus on birth weights, gestational periods, and reportings of miscarriages and stillbirths. Using precise information on the date of birth and a comparison group that lives relatively close to the refinery, I estimate that infant health worsened during closure. Total birth weights fell by 62 grams, $.14\sigma$ effect size, erasing all the gains made by installing investments to limit air pollution at the site. Relative to the coal plant polluting New Jersey, where birth weights rose by $.05\sigma$, I estimate an effect size three times larger and in the opposite direction. In Peru, 50% of income tax paid by extractive industries is returned to the regional and local governments in which extraction occured and the funds must be used on public investment projects (Agüero et al., 2021; Canavire-Bacarreza, Martínez-Vázquez, & Sepulveda, 2012). I provide suggestive evidence that closure limited the amount of funds available to municipalities, decreasing investment in healthcare and education.

I use Peru's Live Birth Registry, which contains information on every registered birth in Peru, between 2005 and 2018. The data provides demographic information about the mothers, such as their age, birth place, current residence, and level of education. I then test for differential effects among migrants and mothers of lower socioeconomic status. Migrant status is a proxy for a mother's prolonged exposure, as nonmigrants face pollution from La Oroya for longer, and I use education level to provide additional evidence that infants born to mothers of lower socioeconomic status face a greater benefit to pollution abatement (Jayachandran, 2009; Tanaka, 2015). I find that infants born to migrants and nonmigrants experienced similar declines in birth weight, and the effects are concentrated among infants whose mothers completed primary or secondary education, which characterizes most of the population.

2 Related Literature

Ambient pollution and the associated harms are widely described in epidemiology. The inhalation and digestion of SO_2 and heavy metals such as copper, lead, and arsenic are associated with long-term health issues. Respiratory disease and low birth weights are discovered early in life, and consistent exposure can lead to early death. [2] Chay and Greenstone (2003) use variation in total suspended particulates, caused by the 1981-82 recession, to show infant mortality improves as air pollution falls. Exploiting within state variation, counties with a one percentage point reduction in the particulates experience a 0.35 percent decline in infant mortality. Relying on the infant health indicator, authors mitigate concerns regarding exposure history, but assigning pollution exposure is still a challenge. Individual exposure to pollutants can be the result of sorting, in which richer individuals with preferences for clean air may move away from exposure points (Banzhaf & Walsh, 2008) and those individuals may have underlying health endowments or tools to reduce the negative consequences of exposure that differ systematically from those that cannot move. Currie and Schmieder (2009) use the exact addresses of mothers and the distance of homes to air quality monitors, to identify exposure to air pollutants for pregnant women in the United States. They find that reductions in emissions in heavy metals accounts for 3.9 percent of the decrease in infant mortality throughout the 90s. More recent literature identifies infant outcomes through the opening or closure of industrial plants (Currie, Davis, Greenstone, & Walker, 2015), coal plants (Yang & Chou, 2018), and shale gas wells (Hill, 2018).

Moreover, the relationship between intial levels of pollution, regulation efforts, and their effect on health outcomes likely varies with context (Fukushima et al., 2021; Greenstone & Hanna, 2014; Tanaka, 2015; Von der Goltz & Barnwal, 2019). In emerging markets, pollution concerns are arguably more salient as individuals are often exposed to greater levels of pollution in combination with sparse monitoring stations (Almond, Chen, Greenstone, &

[2] See Stieb, Chen, Eshoul, and Judek (2012) for a comprehensive summary of the literature on SO_2 particulate matter, and nitrogen dioxide and Zheng et al. (2016) for heavy metal exposure.

Li, 2009; Arceo, Hanna, & Oliva, 2016). Jayachandran (2009) documents a reduction in the size of birth cohorts, with larger magnitudes corresponding to relatively poorer areas, caused by wildfires in Indonesia. Closely related, Tanaka (2015) shows a reduction in infant mortality due to stringent air quality regulation in China, with a larger improvement among infants born to mothers with lower levels of education.

La Oroya, Peru is consistently recognized as one of the most polluted cities in the world, and egregious pollution is well-documented (Blacksmith Institute, 2008). Medical research primarily focuses on documenting the blood level exposure of children and pregnant women (Álvarez Tolentino, 2009; Cederstav & Barandiarán, 2002; Serrano, 1999; Villena Chávz, 2008a). The samples extracted in 1999, 2005, and 2009 show that while the plant was operating, the extremely poor air quality was detrimental to health. Serrano (1999) find 97% of children between six months and six years old had blood lead levels above the World Health Organization's (WHO) persmissable level.[3]

Arrieta and Guillén (2018) provide evidence on how how investments in sulfuric acid treatment plants reduced contamination and improved infant health. Using yearly data on births within a subset of hospitals, they show a significant increase in birth weights in the province containing La Oroya compared to the infants born in similar hospitals across all of Peru. Alternatively, I focus on the effect of closure, which marks the first time since 2007 that monthly emissions readings were consistently below the legally permissable level as shown in Figure 5b, on all the births within 50 km up and downwind of the complex. Arrieta and Guillén (2018) relies on data for *EsSalud* hospitals, which services about 25% of the population (Vermeersch, Medici, & Narvaez, 2014).[4] The live birth registry I utilize contains both the births in *EsSalud* and those in all other hospitals as well as at-home

[3]The WHO's permissible level is 10 μg/dl. The US CDC recommends monitoring children with levels above 5 μg /dl, citing that even low blood levels result in irreversible, adverse outcomes such as lower cognitive function and kidney damage.

[4]*EsSALUD* is the national insurance provider for formal sector workers and pensioners while the public hospitals serve both the uninsured and those covered by the public national insurance, *Seguro Integral de Salud*. Public hospitals, mandated by the Ministry of Health, provide healthcare services for about 70% of the Peruvians (Vermeersch et al., 2014).

births. In addition, I use the date of birth to form month-year pairs to identify a more precise treatment window, as opposed to the yearly variation.

I find that closure results in worsening infant health, with a reduction in birth weights and reports of miscarriages and stillbirths. I find this effect holds for those living within 50km and that there is no effect on birth weights or gestational lengths for infants born within 50 and 100km. I show the effects are not driven by income changes as districts that are further away and within 50km experienced the largest decreases in birth weights. I provide suggestive evidence that the effect is driven by a reduction in canon transfer. Theses transfers are funds provided to municipalities through the redistribution of the income tax revenue generated by firms in extractive industires. The greatest proportion of the funds falls to the producting district and districts within the same province. I find that the districts with the greater reductions in the transfer closure experience larger effects.

3 Context

Cerro de Pasco Copper Company began smelting and refining operations in 1922. Mineral concentrates were purchased from other mines north of La Oroya, which used the railway system cutting through the city to a seaside port in Lima (Barrios 2008, p.89). The operation opened with a copper smelter and refining circuit and later expanded to include lead and zinc circuits. The economic development in the city induced migration as "jobs were plentiful and pay was good" (Neumann, 2016), and the company has since been the primary employer in the city.[5] The refinery has changed hands a few times since opening, having been nationalized in 1974, sold to Doe Run Peru in 1997, and purchased by a collective of miners in 2019. Regardless of the propreitor, air pollution has been the principle issue.[6]

[5]Prior to closure, Doe Run Peru had approximately 2,400 employees and an additional 1,000 contractors. Many local businesses relied on the workers, and thus, DRP is said to be indirectly responsible for an additional 16,000 jobs (Doe Run Peru, 2012).

[6]Effluent discharge does occur, with significant improvements made to reduce industrial emissions points between 1997 and 2003, resulting in a 70% decrease in acid effluents and a 95% reduction in slag granulation in the copper and lead refineries (Doe Run Peru, 2012).

In 1924, Cerro was responsible for an estimated 32,500 tons of toxic gas emissions and the death of thousands of livestock (Barrios, 2008). In 1983, shows workers had abnormally high levels of cadmium in their urine samples, and airborne cadmium exposure was 45 times greater than the eight hour industrial maximum set by WHO (Ramírez, 1986). Villena Chávz (2008a) finds an average blood lead level of 33.6 μg/dl among 346 sampled children between ages 3 and 9 in 1999. Data reported in May of 2000 shows SO_2 concentrations reached levels 10 times greater than WHO's hourly recommendations, and data from monitoring stations around the main chimney stack reported heavy metal emissions of cadmium, lead, and arsenic well above WHO's standards (Cederstav & Barandiarán, 2002). Heavy metal exposure related to inhalation and SO_2 are emphasized as the primary cause of the negative health outcomes experienced, as dust particles easily pass through the mucous membranes, the bloodstream, and biological membranes, with digestion and inhalation as the main exposure pathways (Doe Run Peru, 2008). Prolonged exposure can worsen lung function, cause respiratory ailments, heart disease, kidney disease, and affect infant health (Stieb et al., 2012; Zheng et al., 2016).

Following the 2008 recession, the syndicate of banks that had previously lent funds withdrew. Doe Run Peru was unable to secure mineral concentrates to process in its smelters and forwent investments required in an environmental protection plan attached to the 1997 purchase of the refinery. The delivery of new concentrates was suspended and mounting fines for failing to meet the requirements forced closure on June 3, 2009. The company entered agreements with three workers unions to maintain employment relationships, paying approximately 70% of salaries and benefits to encourage workers to stay in La Oroya (Bnamericas, 2010). In Figure 5d, I show there is small decline in income over the closure period for downwind districts relative to those upwind.

SO_2 emissions dropped significantly; in late 2009 SO_2 levels fell 99.54% relative to 2007, and there was a 98.82% reduction in airborne lead and lead content in children had decreased to levels that had never been recorded in La Oroya (Álvarez Tolentino, 2009). As part of

the environmental plan, reports were sent to the Ministry of Health including daily monitor readings for monitors placed around La Oroya. Figure 5b shows the SO_2 readings aggregated to the monthly level for the three nearest monitors to the city of La Oroya. Monitor readings during operation were often above the legally permissable limit, 365 $\mu g/m^3$, but fall close to zero once the refinery shutdown.

4 Data

To study the effect of improved air quality on infant health, I use infant data from Peru's Live Birth Registry between January 2006 and August 2012, when the plant re-opens.[7] Infants are the closest to an ideal subject as they do not have a history of exposure. I focus on low birth weights and premature births, defined as births under 2500 grams and gestational lengths shorter than 37 weeks, respectively. Birth weight is one of the most widely used indicators of infant health and has been shown to predict adult well-being (Almond & Currie, 2011; Black, Devereux, & Salvanes, 2007). Premature births are associated with respiratory distress and in severe cases, bronchopulmonary dysplasia, often due to a lack of development (Greenough, 2012; Smith, McKay, van Asperen, Selvadurai, & Fitzgerald, 2010).[8] The registry also includes information about miscarriages and stillbirths, which I code as binary variables as an additional birth outcome. I restrict the sample to singleton births, as deliveries with multiple births typically are of lower birth weights, to mothers older than 13 and excluded infants born weighing less than 100 or greater than 6,000 grams.

I define treatment using a district-level geographic identifier for each mother's residence. Infants born downwind of La Oroya are treated, as they faced exposure to the pollutants, while those upwind were unaffected by the emissions. Downwind and upwind status are de-

[7]Law N^{o} 26497 requires the registration of all live births, and in 2015, Peruvian National Institute of Statistics and Information estimated that 72% of live births were covered that year. Some areas, such as the Amazon, has limited coverage due to a lack of public services, but La Oroya and its surrounding districts are unaffected.

[8]Gestation period is measured at the physician's discretion, meaning that either the last reported menstrual cycle, ultrasound, or Capurro method is used to calculate.

termined by the prevailing winds northeasterly winds (Reuer et al., 2012), and distance to the refinery is in relation to the principal chimney on the site (Tapia Barriga & Ceroni Galloso, 2007; Villena Chávz, 2008b), which is shown in Figure 1. Figure 2 shows the distribution of birth weights for downwind and upwind births. Infants born to mothers residing downwind are more likely to be a lower birth weight. Table 1 confirms that birth weights on average are lower and the incidence of low birth weights is much greater in downwind districts. As shown in Figure 5a, birth weights display parallel trends through much of the pre-preiod, with increases in downwind birth weights pre-closure related to the sulfuric acid treatment plants made on site as studied by Arrieta and Guillén (2018).

The birth registry also includes maternal demographic information such as age, marital status, and level of education as well as the geographic identifier for the mother's birth district. Along all demographics, there are statistically significant differences. Mothers in downwind districts are half a year younger, more educated, more likely to be partnered, either married or cohabitating, and live closer to the chimney, as shown in Table 1. In Figure 4, I plot the quarterly averages for each demographic variable, which shows variation in maternal demographics over the period. Overwhelmingly, the demographics fluctuate similarly up and downwind, providing confidence that there is not differential sorting that would bias any treatment effects.[9] Table 2 shows that demographic information is not changing with respect to closure for either the upwind and downwind mothers, aside from an increase in the proportion of mothers with a post-secondary degrees. Focusing on infants born to nonmigrants, there are no differences. Thus, while there are baseline differences, in demographics, there are no differential trends between upwind and downwind mothers.

5 Methodology

I compare the birth outcomes of infants whose mothers reside downwind to those upwind, 3 months after the refinery closed. The refinery closes in June 2009, infants born through

[9]For example, if healthier women move downwind, then results would be biased upwards.

February 2010 are treated to some extent as they were in utero for some time while the complex is open. To avoid concerns related to continous treatments and the dosage relationship between the level of pollution experience, for which the data is not appropriate, I define treatment as being born before or after October 1st, which is 3 full months after the plant closes. Figure 3 illustrates the treatment and control window as well as the dates the plant closes and re-opens.[10] I determine treatment using both the month-year of birth and the district in which the mother resides. The prevailing wind patterns are used to determine downwind status. Reuer et al. (2012) document a predominant northeasterly wind around La Oroya.

Infants whose mothers reside downwind face greater exposure than those upwind, experiencing worse quality air throughout pregnancy. I use the latitude and longitude of the main stack, located on-site in La Oroya Antigua, as the reference point. Downwind status is determined using the longitude and latitude of each district capital in relation to the main chimney. My estimating equation is

$$HealthOutcome_{idt} = \beta_0 DW_d + \beta_1 Post_t * DW_d + \beta_2 \mathbf{X}_{idt} + \gamma_t + f(x,y)_d + \epsilon_{ijt}, \qquad (1)$$

in which i denotes an infant whose mother resides in district d in month-year t. Downwind status, DW_{ij}, and whether a child was born before or after October 1st 2010, $Post_t$, are coded as indicator variables. The month by year fixed effects, γ_t, control for common shocks to in utero health such as weather, acting effectively as a cohort fixed effect. Since treatment is determined by a month-year pair, $Post_t$ is collinear with γ_t and is excluded from the regression. $\mathbf{X}_{ijt}$ is a vector that includes maternal controls for the age, education level of the mother, marital status, and an indicator for whether the birth occurred in a medical establishment or at home. Distance to the chimney affects exposure, which I control for

[10]Results are robust to other specifications such as 6-month cutoff and dropping the first 9 months of treatment.

using a quadratic polynomial to distance to the chimney based on latitude and longitude. I restrict the sample to districts within 50km of the chimney, as pollutants fall off at further distances (Luechinger, 2014; Yang & Chou, 2018). Standard errors are clustered at the district level.[11] The sample is restricted to singleton births, weighing between 100 and 6,000 grams and born to mothers over the age of 13.[12]

Identification requires that (i) mothers residing downwind will experience the greatest benefit from the closure, while those upwind are minimally affected as the pollutants do not reach those mothers and (ii) the population of mothers does not change in response to closure. If women with unobservably better health stock move to downwind districts after closure then there would be upward bias as there would be an improvement in infant health, unrelated to the improved air quality, captured in the estimate. As economic opportunities, especially in La Oroya, are intimately tied to the refinery, working-age women or households may migrate to other districts. Table, 2 provides empirical evidence that there is no systematic migration, based on demographic features observed in the data, out of downwind districts following closure. There is an increase in the proportion of highly educated women in the full sample, which would bias estimates upward, and there are no differences after closure for the sample of nonmigrant mothers. In column (8), I use the number of singleton births born each month, showing no differences in the number of infants born.

6 Results

Table 3 contains the main results on the incidence of low birth weights and total birth weight, prematurity, gestational length, and miscarriages and stillbirths. Controlling for maternal demographics, including birth district, there is no statistical difference in baseline infant health outcomes measured in the registry. In column (1), I find infants born downwind weigh 62 grams less than those upwind post-closure, signficant at the 1% level. The estimated effect

[11] Bootstrap standard errors are used within 50km as there are too few clusters.
[12] Results are robust to the including the groups.

is equivalent to a .14σ decline in birth weights. For infants of nonmigrant mothers, column (2), I find a 76 gram decline, significant at the 10%. While not significant at conventional levels, the incidence of low birth weights rose 1.5 percentage points when controlling for all demographics. Similarly, I find that premature births rose by 0.9 percentage points, a .05σ increase. The failure to reject the null on the extensive margin is due to low statistical power; however, the point estimates provide additional evidence that infant health is worsening. In columns (9) and (10), there are no significant differences in reportings of misscariages and stillbirths prior to closure; however, after closure I find a signficant increase in the proportion of mothers reporting miscarriages and stillbirths. For the full sample, column (9), there is a 3.3% increase, which is equivalent to a .1σ increase.

Consequences of pollution have been shown to vary with socioeconomic status (Jayachandran, 2009; Tanaka, 2015). Tables 6 and 7presents seperate regressions by educational attainment, as proxy. The estimates on total birth weight range between a 32 and 106 gram decline. There is a statistically significant reduction in total birth weight for mothers with a primary education residing in their own birth district as well as for the set all mothers that have completed secondary schooling. Importantly, mothers with primary and secondary schooling consitute over 70% of the sample. Along all other outcomes, I find that evidence of worsening health as all outcomes are directionally negative, aside from miscarriages and stillbirths which are increasing. In Table 5, I regress the outcomes separately for migrant and nonmigrants. I find signficant declines in total birth weight for both groups. Birth weights of infants born to non-migrants and migrants fell by 77 grams, or .17σ , and 52 grams, or .12σ, respectively. Non-migrant mothers also experience a 4.6%, .14σ, increase in misscarriages and stillbirths. Thus, both groups faced a similar decline.

7 Discussion

In studies of infant health and pollution reductions, there are often health improvements. Tanaka (2015) finds that after regulations efforts in China, incidence of low birthweights fell by $.22\sigma$. Yang and Chou (2018) find that shutting down a coal-fired power plant in Pennsylvania increased birth weights in New Jersey by 26 grams, a $.05\sigma$ effect size. Fukushima et al. (2021) shows that the 1956 UK Clean Air Act eliminated differences in seasonal infant mortality, accouting for 70% of the observed decline. Arrieta and Guillén (2018) find a 72 gram, or $.16\sigma$, increase in birth weights following investments made at the same complex I study. In fact, closure counteracts the improvement to infant health that occurred due to the installation of sulfuric acid treatment plants. I find a similar effect size to Hill (2018), which the introduction of shale gas wells led to a $.11\sigma$ decline in birth weights. Two likely explanations are income changes resulting from closure and changes to local budgets via reductions in canon transfers. The complex is a main source of economic opportunity in the region, as opposed to the plant in Pennsylvania, and municipal budgets are deeply affected.

The refinery at La Oroya was largely responsible for economic opportunity within the area (Doe Run Peru, 2012). Therefore, individuals living near the refinery are more likely to experience an income shock. While the workers are compensated during shutdown, those indirectly benefiting from workers' salaries are not being compensated and experience depressed earnings. In Figure 5d, I use Peru's National Survey of Households to show that reported earnings are experiencing a small decrease over the time the complex is shutdown. Two drawbacks to using the survey is that it is not representative at the district level and few districts on both sides of the geographic cutoff are surveyed each year. An alternative approach is using travel time to the complex as a proxy for the income shock. Those living in districts that are closer, based on the time it would take to drive to the complex, are more likey to experience the income shock. To calculate the travel time, I use Google Maps to determine the time it would take to drive from each district capital to the chimney. In Figure

6a, I plot the coefficient estimates for each district within 50km post-closure.[13] In Panel (b), the districts that are furthest away based on travel time experienced the greatest decline in birth weights. In the figure, I do not report standard errors due to power concerns.[14] Lastly, in Table 4, I exclude La Oroya, and there is a significant decline in birth weights.

Another likely explanation is that the reduction in mineral production influenced the local provision of public goods. In accordance with national law, a portion of income tax paid by firms within extractive industries are redistributed to the districts in which the product was generated as well as surrounding districts based on poverty metrics (Agüero et al., 2021; Canavire-Bacarreza et al., 2012). Referred to as the canon transfer, it represented 26.5% of total sub-national expenditure in 2008, and importantly the use of funds is bound to the Public Investment National System (Canavire-Bacarreza et al., 2012). The system stipulates that transfer must be used to close gaps in infrastructure or access to public services and other public investments. The shutdown reduced the amount districts would recieve via the income tax, which may have limited the provision of medical supplies, equipment, and hospital function. Figure 5c documents that there is a substantial reduction in per capita canon transfers downwind, using the 2007 Census as a reference population. Downwind districts receive a much larger transfer throughout the period, and see a significant decline begining with 2009. In the following years, the transfer does does not return return to its initial pre-treatment level. Upwind districts recieve a smaller amount throughout the period, see an increase in the transfer relative to the pre-treatment periods. Additionally, upwind districts are in a different province than all of the downwind districts; therefore, any differences are unlikely to be related to the complex closing diue to the framework regarding the transfer.

Ideally, one would split the sample between infants born in private and public hospitals, running a separate regression for each; however, the provided registry does not contain the

[13]The omitted district is Tarma, which borders La Oroya.

[14]To detect a 50 gram difference in birth weights given the sample average and standard deviation, a district would require approximately 1000 observations over the period, which only half within 50km satisfy.

unique identifier or the name of the hospital in 2008 and 2010 as well as missing the information for approximately 30% of births in other years.[15] Instead, in Figure 7, I plot the relationship between canon transfers in 2008 and 2010 and the district-level cofficient estimates; I do not use 2009 to calculate differences as the complex operated for half the year. In Panel (a), I use the total difference in canon transfers to highlight the large drop experienced by downwind districts relative to upwind. Importantly, all of the upwind districts belong to a different province, which severly limits the amount they could recieve from the portion of canon coming from the complex itself. For the upwind districts, differences are minimal and the coeficient estimates vary widely, signalling that the canon transfer differences do not impact the upwind districts birth weights. For downwind distrist, there is greater variation in the amount recieved and birth weights. Aside from the outlier district, those with greater reductions in the transfer experienced larger declines in birth weights. In Panel (b), similarly, the downwind districts with the largest percentage changes in canon transfers experience larger declines in birth weights. For upwind districts, due to the relatively small amounts received, the direction is much less clear.

8 Robustness and Additional Results

In Tables 8 and 9, I redefine the treatment window to account for differences in dosage. Those born closer to the date the complex closes experience more pollution while in utero. In Table 8, I show that defining treatment as whether or not an infant was born at least 6 months after treatment, meaning they were exposed to toxic emissions for at most a trimester, does not change the results qualitatively. There is a 57 gram, $.13\sigma$ decline, signifcant at the 1% for the full sample, and a 71 gram decline for the nonmigrant mothers. In addition, there is a statistically significant increases in reportings of miscarriages and stillbirths. In Table 9, compare births that occur before shutdown to births at least 9 monthes later, finding similar worsening health outcomes: total birth weights fall by 62 grams and stillborns and

[15] In addition, data on resources within hospitals is not publicly available prior to 2009.

miscarriages rise by 4.8%.

In Table 10, I apply the same empirical design to the districts within 50 and 100km of the boundary to provide evidence of the geographic limits of SO_2 emissions. I find no significant effect on birth weights; the estimated coefficients are near zero for the full sample. There is no effect on low birth weight and prematurity, and there is a significant decrease in gestational length which is equivalent to a single day difference in length. Lastly, I find no significant difference in reportings of miscarriages and stillbirths for the full sample, but a signficant improvement, 6.7% or $.19\sigma$, for the mothers residing in their birth district. In Figure 8, I show that there no changes in income and while canon transfers fall during closure, they rebound in 2010. In addiition, all of the districts outside 50km are in not in the same region as the complex; therefore, they do not receive canon funds related to complex's production.

9 Conclusion

I estimate the effect of closing La Oroya's Metallurgical Complex on infant health. Since 1922, there have been negative health consequences for living in La Oroya due to the refining and smelting operation that has consistently exceeded environmental standards for air pollution. Many have quantified the effect of living near the operation on outcomes such as infant health, women's health, and workers (Álvarez Tolentino, 2009; Arrieta & Guillén, 2018; Ramírez, 1986; Serrano, 1999; Villena Chávz, 2008a). I build on their work by studying the effect of closure, and causally identifiying the effect using data on all infants born in the area. My identification strategy relies on comparing infants born upwind to those downwind, before and after the complex closes.

I find that total birth weight declined by $.14\sigma$, and 5% increase in reported miscarriages and stillbirths. I find an effect size on total birth weight similar to other research on pollution, ranging between $.05\sigma$ to $.17\sigma$ but in the opposing direction. These effects counteract the improvements experienced through the implementation of sulfuric acid treatment plants prior

to closure. Infants experienced a decline in birth weight regardless of their mothers' migrant status, and the effects are concentrated among mothers lacking post-secondary education, which characterizes most of the population. While the operation is responsible for much of the economic opportunitiy, I show that districts with shorter travel time to the complex suffered less than those further away. I provide suggestive evidence that the loss in canon transfers, which are used for public investment, contribute to worsening health. Without the transfers given to local municipalities, the public provision of healthcare may have detiorated and led to worse outcomes. Future work focused on the use of canon transfers and municipal-level health care expenditure, as well as investigating how reopening the refinery in late 2012, would provide additional insight on on the consequences of extractive industries.

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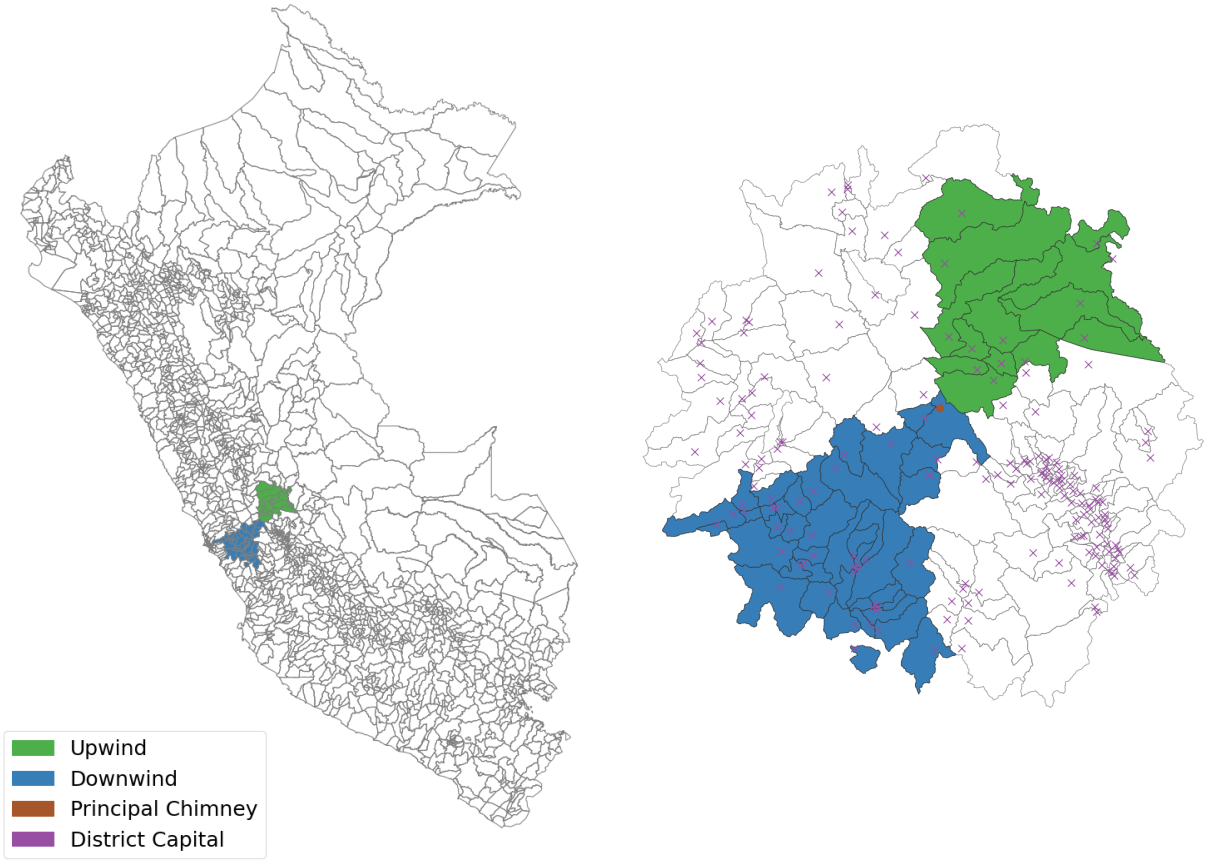
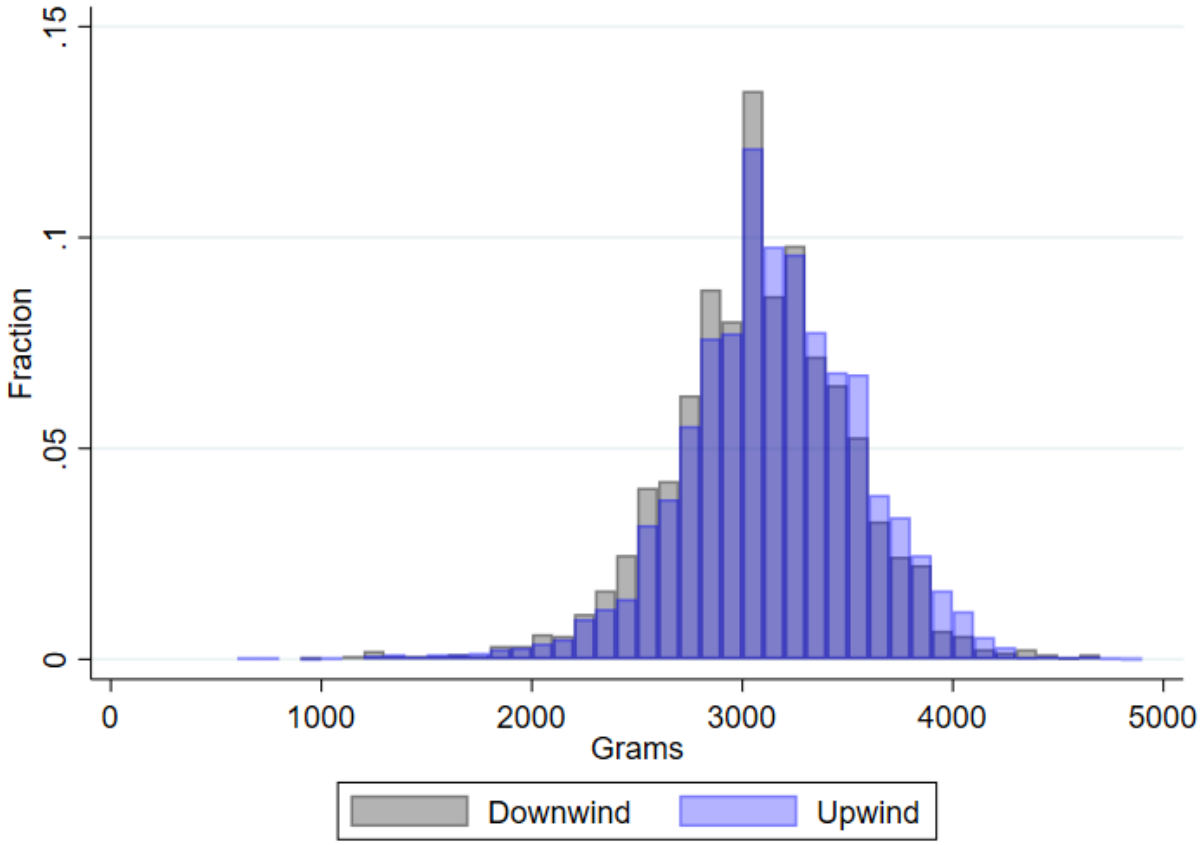
Figure 1: Study Region



Note: Districts within 100km.

Figure 2: Birth Weights, within 50km



Notes: The sample includes singleton births, weighing between 100 and 6,000 grams, to mothers over the age of 13.

Figure 3: Treatment Timeline

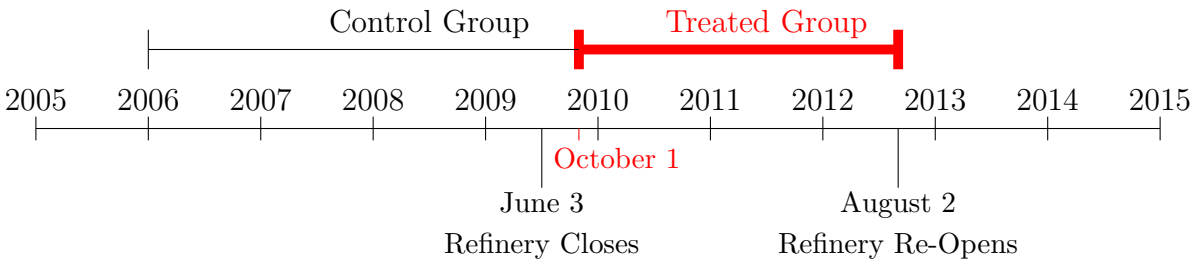


Table 1: Summary Statistics: Infant and Mother Demographics, 50km

	(1) Downwind	(2) Upwind	(3) Difference
Panel A: Infant Characteristics			
Birth Weight	3038.672	3143.737	-105.065***
	(439.682)	(438.735)	
Fewer than 2500g	0.081	0.054	0.026***
	(0.272)	(0.227)	
Gestational Period	38.886	38.929	-0.043
	(1.590)	(1.499)	
Fewer than 37 weeks	0.054	0.050	0.005
	(0.227)	(0.217)	
Panel B: Mother's Demographics			
Age	26.926	26.335	0.592***
	(6.802)	(6.843)	
Did Not Complete Primary	0.068	0.145	-0.077***
	(0.252)	(0.352)	
Completed Primary	0.281	0.360	-0.078***
	(0.450)	(0.480)	
Completed Secondary	0.485	0.350	0.135***
	(0.500)	(0.477)	
Completed Post-Secondary	0.166	0.145	0.020***
	(0.372)	(0.353)	
Partnered	0.917	0.907	0.010*
	(0.275)	(0.290)	
Distance from Mother's Birth District to Chimney	8.244	26.777	-18.533***
	(11.701)	(5.306)	
Observations	4099	10035	14134

* $p < .1$, ** $p < .05$, *** $p < .01$

Notes: Low birth weight is an indicator equaling 1 if an infant weighs under 2500 grams. Prematurity is an indicator equaling 1 if an infant is born under 37 weeks. The sample includes singleton births, weighing between 100 and 6,000 grams, to mothers over the age of 13.

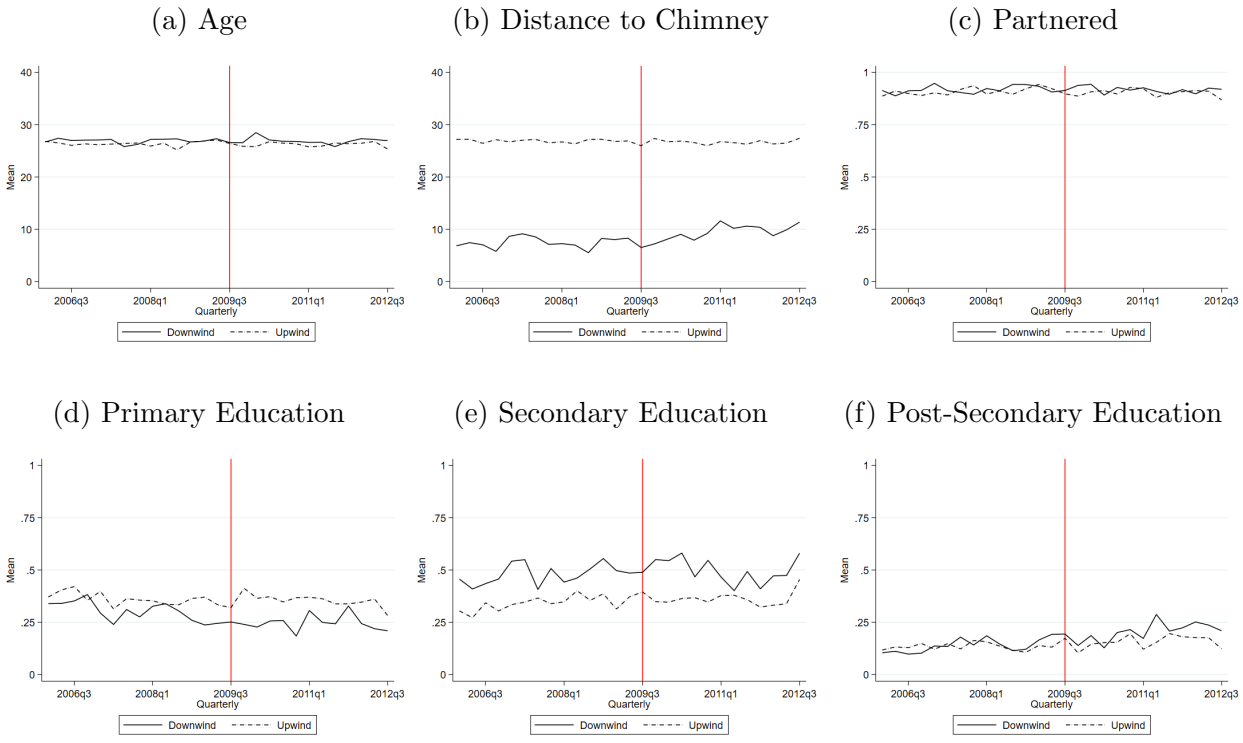
Table 2: Regression Discontinuity on Mothers' Demographics, within 50km

	(1) Age	(2) Incomplete Primary	(3) Completed Primary	(4) Completed Secondary	(5) Completed Post-Secondary	(6) Living with Partner	(7) Distance to Oroya	(8) Total Births
Panel A: Mothers' Demographics, Full Sample								
Downwind x Born 3 Months After Closure	0.111	0.006	-0.051	0.005	0.040**	0.003	2.262	-0.379
	(0.399)	(0.023)	(0.032)	(0.037)	(0.017)	(0.017)	(1.398)	(1.354)
Proportion of Mothers	26.39	0.16	0.36	0.35	0.14	0.91	26.86	19.14
Observations	14134	14134	14134	14134	14134	14134	14134	1015
Clusters	14	14	14	14	14	14	14	14
R-Squared	0.00	0.01	0.01	0.02	0.00	0.00	0.54	0.06
Panel B: Mothers' Demographics, Non-Migrants								
Downwind x Born 3 Months After Closure	0.123	0.029	-0.044	-0.020	0.034	0.002	1.646	-0.484
	(0.575)	(0.028)	(0.055)	(0.066)	(0.025)	(0.023)	(1.381)	(1.417)
Proportion of Mothers	26.22	0.16	0.35	0.35	0.13	0.90	27.36	19.37
Observations	8197	8197	8197	8197	8197	8197	8197	932
Clusters	14	14	14	14	14	14	14	14
R-Squared	0.00	0.02	0.01	0.01	0.01	0.00	0.53	0.04

* $p < .1$, ** $p < .05$, *** $p < .01$

Notes: Panel (A) regresses each outcome on the interaction variable i.e., being born downwind and three months after La Oroya closes for the all infants. Panel (B) regresses the same outcomes for the infants whose mothers reside in their own birth district. The sample includes singleton births, weighing between 100 and 6,000 grams, to mothers over the age of 13. Standard errors are calculated using district-level bootstrapping.

Figure 4: Mothers' Demographics and Total Births, 50km



Note: Sample are mothers over the age of 13 that had singleton births, weighing between 100 and 6,000 grams. Panels (c)-(f) are binary variables, in which 1 = yes and 0 = no.

Table 3: Infant Health Outcomes, within 50km

	Birth Weight		Low Birth Weight		Gestational Length		Premature		Miscarriages & Stillbirths	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Downwind	-32.785	-44.495	0.003	0.015	0.126	0.306	-0.011	-0.034	-0.048	-0.103
	(1194.395)	(4434.290)	(0.225)	(1.401)	(1.798)	(8.929)	(1.035)	(0.113)	(0.179)	(20.021)
Downwind x Born 3 Months After Closure	-62.133***	-76.636*	0.013	0.015	-0.129	-0.110	0.014	0.009	0.033**	0.046**
	(18.785)	(39.374)	(0.013)	(0.012)	(0.107)	(0.142)	(0.017)	(0.025)	(0.016)	(0.022)
Month-Year FE	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Maternal Demographics	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Maternal Birth District FE	Y		Y		Y		Y		Y	
Control Mean	3130.807	3123.039	0.057	0.058	38.971	38.955	0.049	0.052	0.137	0.132
Population SD	445.090	443.943	0.257	0.258	1.527	1.529	0.222	0.224	0.326	0.319
Observations	13955	8195	13955	8195	13955	8195	13955	8195	13955	8195
Clusters	14	14	14	14	14	14	14	14	14	14
R-Squared	0.07	0.05	0.04	0.02	0.04	0.03	0.03	0.02	0.08	0.05

* $p < .1$, ** $p < .05$, *** $p < .01$

Notes: Low birth weight is an indicator equaling 1 if an infant weighs under 2500 grams. Prematurity is an indicator equaling 1 if an infant is born under 37 weeks. I control for distance between resident district and the chimney using a quadratic polynomial. All columns include controls for education, civil status, and whether or not the birth was delivered at a medical facility. Odd columns use the entire sample, and even columns focus on non-migrant mothers. Fixed effects for the mothers' birth district are not included in even columns as they are collinear with treatment for non-migrants. The sample includes singleton births, weighing between 100 and 6,000 grams, born to mothers over the age of 13. Standard errors are calculated using district-level bootstrapping.

Table 4: Infant Health Outcomes - Excluding La Oroya, within 50km

	Birth Weight		Low Birth Weight		Gestational Length		Premature		Miscarriages & Stillbirths	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Downwind	-55.375	-95.479	0.017	0.061	0.043	-0.126	-0.041	-0.046	-0.139	-0.173
	(7168.386)	(1155.167)	(7.487)	(0.647)	(8.186)	(5.682)	(44.954)	(0.526)	(1.706)	(3.820)
Downwind x Born 3 Months After Closure	-54.141*	-104.775**	0.010	0.025	-0.099	-0.147	0.031	0.039	0.019	0.071**
	(29.044)	(45.313)	(0.023)	(0.019)	(0.151)	(0.173)	(0.020)	(0.030)	(0.026)	(0.029)
Month-Year FE	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Maternal Demographics	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Maternal Birth District FE	Y		Y		Y		Y		Y	
Control Mean	3130.807	3123.039	0.057	0.058	38.971	38.955	0.049	0.052	0.137	0.132
Population SD	446.264	446.135	0.256	0.257	1.515	1.526	0.221	0.224	0.324	0.318
Observations	11539	6922	11539	6922	11539	6922	11539	6922	11539	6922
Clusters	13	13	13	13	13	13	13	13	13	13
R-Squared	0.07	0.06	0.04	0.03	0.04	0.03	0.03	0.02	0.08	0.06

* $p < .1$, ** $p < .05$, *** $p < .01$

Notes: Low birth weight is an indicator equaling 1 if an infant weighs under 2500 grams. Prematurity is an indicator equaling 1 if an infant is born under 37 weeks. I control for distance between resident district and the chimney using a quadratic polynomial. All columns include controls for education, civil status, and whether or not the birth was delivered at a medical facility. Odd columns use the entire sample, and even columns focus on non-migrant mothers. Fixed effects for the mothers' birth district are not included in even columns as they are collinear with treatment for non-migrants. In these regressions, infants born in the district of La Oroya are excluded. The sample includes singleton births, weighing between 100 and 6,000 grams, born to mothers over the age of 13. Standard errors are calculated using district-level bootstrapping.

Table 5: Infant Health Outcomes - Migrant Status, within 50km

	Non-Migrant					Migrant				
	(1) Low Weight	(2) Weight	(3) Premature	(4) Gestation Period	(5) Miscarriages & Stillbirths	(6) Low Weight	(7) Weight	(8) Premature	(9) Gestation Period	(10) Abortions & Stillbirths
Downwind	0.015	-44.495	-0.034	0.306	-0.103	0.010	-35.127	0.004	0.076	-0.027
	(2.026)	(1666.088)	(0.211)	(4.211)	(1.522)	(0.369)	(340.191)	(0.204)	(0.906)	(0.184)
Downwind x Born 3 Months After Closure	0.015	-76.636**	0.009	-0.110	0.046**	0.018	-52.213*	0.014	-0.133	0.020
	(0.012)	(38.518)	(0.023)	(0.136)	(0.023)	(0.023)	(28.439)	(0.017)	(0.126)	(0.031)
Month-Year FE	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Maternal Demographics	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Control Mean	0.058	3123.039	0.052	38.955	0.132	0.055	3143.873	0.045	38.998	0.145
Population SD	0.258	443.943	0.224	1.529	0.319	0.256	446.525	0.219	1.524	0.334
Observations	8195	8195	8195	8195	8195	5936	5936	5936	5936	5936
Clusters	14	14	14	14	14	14	14	14	14	14
R-Squared	0.02	0.05	0.02	0.03	0.05	0.03	0.06	0.03	0.03	0.07

* $p < .1$, ** $p < .05$, *** $p < .01$

Notes: Low birth weight is defined as an infant weighing under 2500 grams. Prematurity is an indicator equaling 1 if an infants is born under 37 weeks. I control for distance between resident district and the chimney using a quadratic polynomial. All columns include controls for education, civil status, and whether or not the birth was delivered at a medical facility. Fixed effects for the mothers' birth district are not included, as it is collinear with treatment for non-migrants. The sample includes singleton births, weighing between 100 and 6,000 grams, to mothers over the age of 13. Standard errors are calculated using district-level bootstrapping.

Table 6: Infant Health Outcomes - Primary Schooling, within 50km

	Birth Weight		Low Birth Weight		Gestational Length		Premature		Miscarriages & Stillbirths	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Panel A: Incomplete Primary Education										
Downwind	-1.743	-117.064	-0.047	0.038	0.177	0.385	-0.030	-0.028	0.002	-0.067
	(4102.620)	(3621.858)	(2.634)	(4.010)	(22.346)	(16.417)	(1.252)	(1.268)	(0.942)	(1.490)
Downwind x Born 3 Months After Closure	-42.788	-79.962	-0.060	-0.019	-0.341	0.139	0.053	0.040	-0.079	-0.003
	(64.041)	(107.234)	(0.055)	(0.042)	(0.606)	(0.302)	(0.042)	(0.040)	(0.116)	(0.122)
Month-Year FE	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Maternal Demographics	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Maternal Birth District FE	Y		Y		Y		Y		Y	
Control Mean	3095.440	3106.437	0.062	0.055	38.990	39.008	0.051	0.047	0.112	0.114
Population SD	441.028	431.215	0.264	0.257	1.524	1.466	0.227	0.214	0.318	0.305
Observations	1658	1012	1658	1012	1658	1012	1658	1012	1658	1012
Clusters	14	14	14	14	14	14	14	14	14	14
R-Squared	0.18	0.15	0.16	0.14	0.16	0.14	0.12	0.09	0.13	0.12
Panel B: Completed Primary Education										
Downwind	-26.743	23.500	-0.008	-0.005	0.268	0.566	-0.024	-0.083	-0.123	-0.091
	(710.343)	(5351.931)	(0.273)	(0.346)	(3.029)	(2.237)	(0.078)	(0.343)	(0.519)	(0.787)
Downwind x Born 3 Months After Closure	-49.063	-106.143***	0.025	0.043	-0.111	-0.262	0.010	0.039	0.037	0.063
	(36.002)	(34.693)	(0.028)	(0.038)	(0.141)	(0.191)	(0.019)	(0.031)	(0.037)	(0.068)
Month-Year FE	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Maternal Demographics	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Maternal Birth District FE	Y		Y		Y		Y		Y	
Control Mean	3122.164	3111.543	0.059	0.065	38.966	38.946	0.050	0.057	0.133	0.122
Population SD	441.555	442.513	0.260	0.269	1.461	1.489	0.220	0.229	0.319	0.311
Observations	4627	2715	4627	2715	4627	2715	4627	2715	4627	2715
Clusters	14	14	14	14	14	14	14	14	14	14
R-Squared	0.10	0.09	0.06	0.06	0.07	0.06	0.05	0.05	0.12	0.10

* $p < .1$, ** $p < .05$, *** $p < .01$

Notes: Low birth weight is an indicator equaling 1 if an infant weighs under 2500 grams. Prematurity is an indicator equaling 1 if an infant is born under 37 weeks. I control for distance between resident district and the chimney using a quadratic polynomial. All columns include controls for education, civil status, and whether or not the birth was delivered at a medical facility. Odd columns use the entire sample, and even columns focus on non-migrant mothers. Fixed effects for the mothers' birth district are not included in even columns as they are collinear with treatment for non-migrants. In these regressions, infants born to mothers that either did not complete primary school or completed primary and did not further their education are included. The sample includes singleton births, weighing between 100 and 6,000 grams, born to mothers over the age of 13. Standard errors are calculated using district-level bootstrapping.

Table 7: Infant Health Outcomes - Secondary Schooling,, within 50km

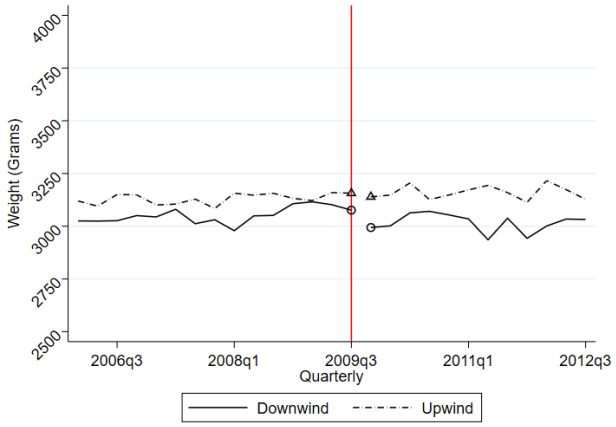
	Birth Weight		Low Birth Weight		Gestational Length		Premature		Miscarriages & Stillbirths	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Panel A: Incomplete Secondary Education										
Downwind	-3.586	-2.706	-0.014	-0.006	0.133	0.297	-0.019	-0.029	-0.052	-0.110
	(302.589)	(715.510)	(0.366)	(0.600)	(3.471)	(6.036)	(0.791)	(0.286)	(3.511)	(0.410)
Downwind x Born 3 Months After Closure	-64.534*	-77.906*	0.012	0.006	-0.177	-0.083	0.014	-0.014	-0.002	0.010
	(37.262)	(47.159)	(0.012)	(0.016)	(0.118)	(0.165)	(0.026)	(0.035)	(0.019)	(0.027)
Month-Year FE	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Maternal Demographics	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Maternal Birth District FE	Y		Y		Y		Y		Y	
Control Mean	3135.538	3125.178	0.059	0.059	38.949	38.922	0.050	0.050	0.133	0.125
Population SD	449.113	450.824	0.261	0.259	1.589	1.597	0.224	0.225	0.323	0.317
Observations	5367	3186	5367	3186	5367	3186	5367	3186	5367	3186
Clusters	14	14	14	14	14	14	14	14	14	14
R-Squared	0.09	0.07	0.06	0.04	0.07	0.05	0.06	0.05	0.11	0.08
Panel B: Completed Post-Secondary Education										
Downwind	-65.372	-225.121	0.031	0.021	-0.053	0.248	0.032	-0.038	0.019	-0.121
	(3021.046)	(3839.547)	(2.593)	(34.985)	(5.330)	(13.273)	(1.480)	(24.672)	(1.248)	(4.530)
Downwind x Born 3 Months After Closure	-72.618	-32.240	0.023	0.017	-0.108	-0.003	0.015	0.006	0.127**	0.123
	(86.674)	(120.567)	(0.059)	(0.100)	(0.325)	(0.490)	(0.035)	(0.107)	(0.064)	(0.116)
Month-Year FE	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Maternal Demographics	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Maternal Birth District FE	Y		Y		Y		Y		Y	
Control Mean	3183.220	3170.019	0.043	0.042	39.021	39.008	0.043	0.047	0.187	0.201
Population SD	441.818	435.502	0.236	0.233	1.512	1.492	0.216	0.216	0.351	0.351
Observations	2058	1279	2058	1279	2058	1279	2058	1279	2058	1279
Clusters	14	13	14	13	14	13	14	13	14	13
R-Squared	0.12	0.14	0.10	0.08	0.09	0.08	0.08	0.08	0.14	0.13

* $p < .1$, ** $p < .05$, *** $p < .01$

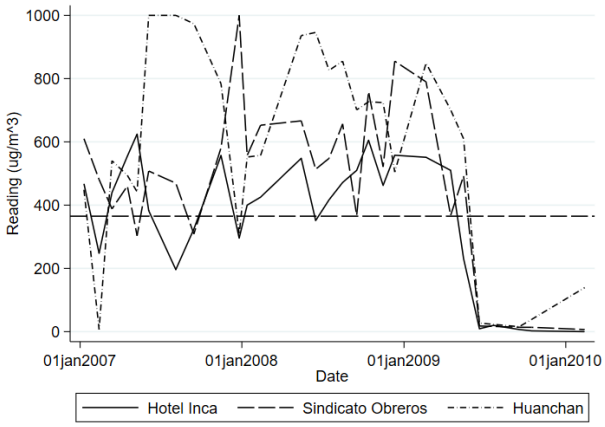
Notes: Low birth weight is an indicator equaling 1 if an infant weighs under 2500 grams. Prematurity is an indicator equaling 1 if an infant is born under 37 weeks. I control for distance between resident district and the chimney using a quadratic polynomial. All columns include controls for education, civil status, and whether or not the birth was delivered at a medical facility. Odd columns use the entire sample, and even columns focus on non-migrant mothers. Fixed effects for the mothers' birth district are not included in even columns as they are collinear with treatment for non-migrants. In these regressions, infants born to mothers that have either some secondary schooling or completed secondary schooling are included. The sample includes singleton births, weighing between 100 and 6,000 grams, born to mothers over the age of 13. Standard errors are calculated using district-level bootstrapping.

Figure 5: Birth Weights, Transfers, and Households, within 50km

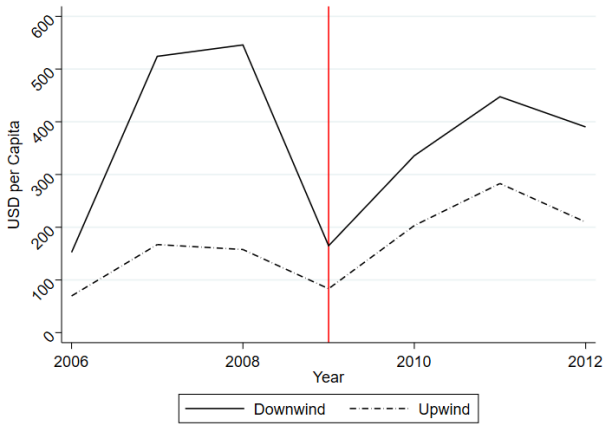
(a) Birth Weights



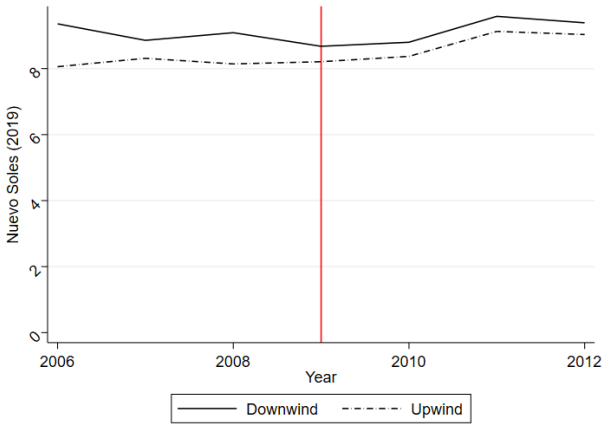
(b) Sulfur Dioxide Monitor Readings



(c) Per Capita Canon Transfers



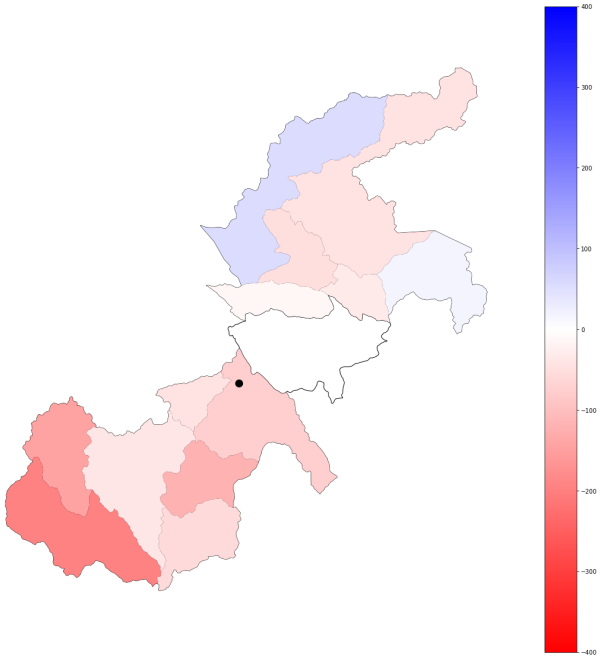
(d) Average Log Income



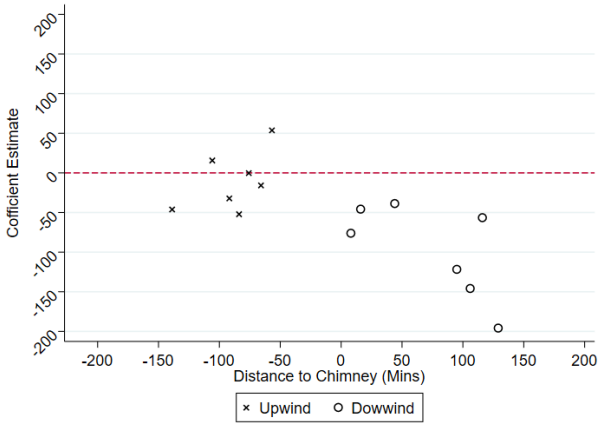
Note: In Panel (A), I take the average birth weights of singleton births weighing between 100 and 6,000 grams, born to mothers over the age of 13. In Panel (B) data on sulfur dioxide readings is extracted from official company reports to the Ministry of Health, data is publicly available through May 2010. In Panel (C) I divide the transfer received by the population estimate given in the 2007 Census. In Panel (D), expenditures are calculated as the average of the median expenditures of each district-year pair. For each household, I divide their reported expenditures by the number of household members, weighted by age categories. Children aged 1 through 4 are assigned .4, children aged 5 through 15 are assigned .5, and a 1 is assigned to everyone older.

Figure 6: Coefficient Estimates, within 50km

(a) Distance to Chimney



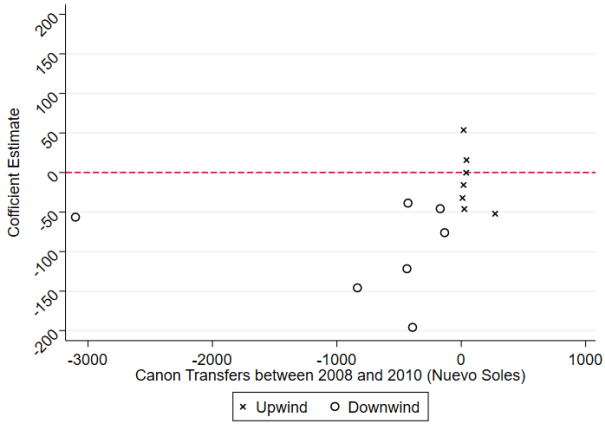
(b) Travel Time



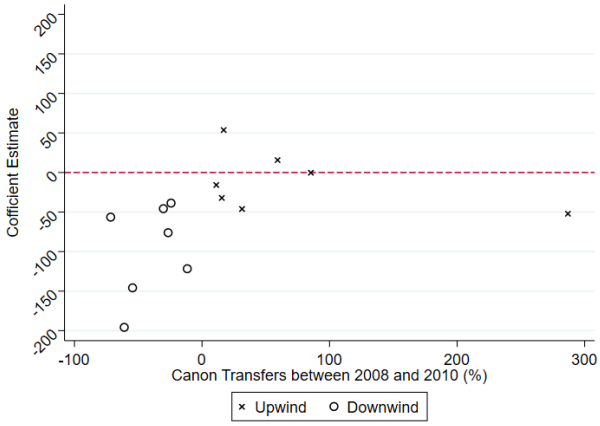
Note: Omitted district is Tarma, which lies adjacent La Oroya. Districts which did not have any births registered either before or after treatment were dropped, highlighted in grey. The percent change in per capita canon transfers are calculated using the 2008 and 2010 transfer totals divided by the district population available in the 2007 Census.

Figure 7: Correlation between Coefficient Estimates and Canon Transfers , within 50km

(a) Per Capita Difference



(b) Per Capita Percent Change



Note: Omitted district is Tarma, which lies adjacent La Oroya. Districts which did not have any births registered either before or after treatment were dropped, highlighted in grey. The percent change in per capita canon transfers are calculated using the 2008 and 2010 transfer totals divided by the district population available in the 2007 Census.

10 Appendix

Table 8: Infant Health Outcomes - 6 Months Post, within 50km

	Birth Weight		Low Birth Weight		Gestational Length		Premature		Miscarriages & Stillbirths	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Downwind	-36.704	-48.833	0.005	0.018	0.126	0.309	-0.011	-0.033	-0.046	-0.101
	(380.691)	(1237.293)	(0.213)	(0.262)	(3.261)	(3.066)	(0.236)	(0.577)	(1.728)	(0.252)
Downwind x Born 6 Months After Closure	-56.963***	-70.951***	0.009	0.009	-0.144	-0.130	0.015	0.009	0.030*	0.043**
	(18.411)	(25.539)	(0.016)	(0.016)	(0.098)	(0.108)	(0.017)	(0.025)	(0.017)	(0.019)
Month-Year FE	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Maternal Demographics	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Maternal Birth District FE	Y		Y		Y		Y		Y	
Control Mean	3131.260	3123.515	0.058	0.058	38.969	38.955	0.049	0.052	0.136	0.130
Population SD	445.090	443.943	0.257	0.258	1.527	1.529	0.222	0.224	0.326	0.319
Observations	13955	8195	13955	8195	13955	8195	13955	8195	13955	8195
Clusters	14	14	14	14	14	14	14	14	14	14
R-Squared	0.07	0.05	0.04	0.02	0.04	0.03	0.03	0.02	0.08	0.05

* $p < .1$, ** $p < .05$, *** $p < .01$

Notes: Low birth weight is an indicator equaling 1 if an infant weighs under 2500 grams. Prematurity is an indicator equaling 1 if an infant is born under 37 weeks. I control for distance between resident district and the chimney using a quadratic polynomial. All columns include controls for education, civil status, and whether or not the birth was delivered at a medical facility. Odd columns use the entire sample, and even columns focus on non-migrant mothers. Fixed effects for the mothers' birth district are not included in even columns as they are collinear with treatment for non-migrants. In these regressions, infants who were in utero for at most three months prior to closure are treated. The sample includes singleton births, weighing between 100 and 6,000 grams, born to mothers over the age of 13. Standard errors are calculated using district-level bootstrapping.

Table 9: Infant Health Outcomes - Excluding Partially Treated, within 50km

	Birth Weight		Low Birth Weight		Gestational Length		Premature		Miscarriages & Stillbirths	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Downwind	-31.695	-48.815	0.003	0.020	0.155	0.329	-0.015	-0.031	-0.054	-0.113
	(497.891)	(28781.542)	(1013.900)	(0.355)	(3.921)	(2.878)	(0.379)	(0.284)	(0.407)	(0.310)
Downwind x In Utero After Closure	-62.329***	-80.563***	0.011	0.013	-0.117	-0.126	0.015	0.011	0.031**	0.048**
	(20.161)	(28.973)	(0.016)	(0.017)	(0.097)	(0.104)	(0.019)	(0.026)	(0.015)	(0.024)
Month-Year FE	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Maternal Demographics	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Maternal Birth District FE	Y		Y		Y		Y		Y	
Control Mean	3129.128	3121.176	0.058	0.059	38.973	38.955	0.050	0.053	0.135	0.131
Population SD	445.660	444.702	0.257	0.258	1.525	1.526	0.222	0.223	0.326	0.322
Observations	12506	7320	12506	7320	12506	7320	12506	7320	12506	7320
Clusters	14	14	14	14	14	14	14	14	14	14
R-Squared	0.07	0.06	0.04	0.02	0.04	0.03	0.03	0.02	0.08	0.06

* $p < .1$, ** $p < .05$, *** $p < .01$

Notes: Low birth weight is an indicator equaling 1 if an infant weighs under 2500 grams. Prematurity is an indicator equaling 1 if an infant is born under 37 weeks. I control for distance between resident district and the chimney using a quadratic polynomial. All columns include controls for education, civil status, and whether or not the birth was delivered at a medical facility. Odd columns use the entire sample, and even columns focus on non-migrant mothers. Fixed effects for the mothers' birth district are not included in even columns as they are collinear with treatment for non-migrants. In these regressions, infants whose time in utero overlap both pre-closure and closure are excluded. The sample includes singleton births, weighing between 100 and 6,000 grams, born to mothers over the age of 13. Standard errors are calculated using district-level bootstrapping.

Table 10: Infant Health Outcomes, between 50 and 100km

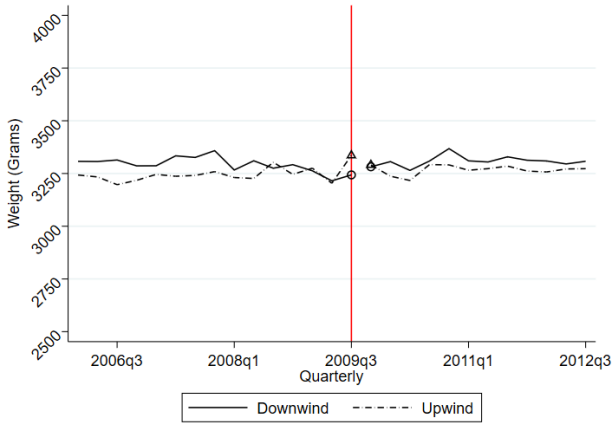
	Birth Weight		Low Birth Weight		Gestational Length		Premature		Miscarriages & Stillbirths	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Downwind	93.800	327.085	0.063	0.070	0.108	0.655	-0.024	-0.003	-0.083	0.132
	(91.033)	(273.434)	(0.043)	(0.064)	(0.721)	(0.403)	(0.045)	(0.080)	(0.080)	(0.116)
Downwind x Born 3 Months After Closure	-0.610	-15.303	0.007	-0.008	-0.109**	0.030	0.010	-0.013	-0.013	-0.067***
	(21.251)	(40.487)	(0.006)	(0.019)	(0.053)	(0.118)	(0.007)	(0.016)	(0.013)	(0.023)
Month-Year FE	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Maternal Demographics	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Maternal Birth District FE	Y		Y		Y		Y		Y	
Control Mean	3247.875	3217.689	0.045	0.048	38.975	38.913	0.048	0.051	0.196	0.159
Population SD	458.196	453.036	0.245	0.253	1.655	1.610	0.224	0.225	0.378	0.356
Observations	20004	6298	20004	6298	20004	6298	20004	6298	20004	6298
Clusters	39	30	39	30	39	30	39	30	39	30
R-Squared	0.07	0.06	0.05	0.03	0.05	0.03	0.04	0.02	0.09	0.08

* $p < .1$, ** $p < .05$, *** $p < .01$

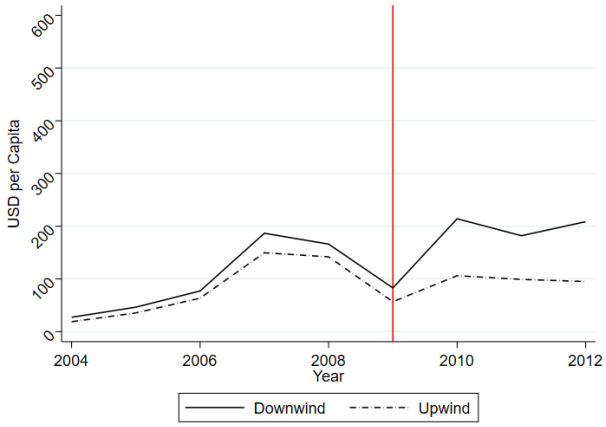
Notes: Low birth weight is an indicator equaling 1 if an infant weighs under 2500 grams. Prematurity is an indicator equaling 1 if an infant is born under 37 weeks. I control for distance between resident district and the chimney using a quadratic polynomial. All columns include controls for education, civil status, and whether or not the birth was delivered at a medical facility. Odd columns use the entire sample, and even columns focus on non-migrant mothers. Fixed effects for the mothers' birth district are not included in even columns as they are collinear with treatment for non-migrants. The sample includes singleton births, weighing between 100 and 6,000 grams, born to mothers over the age of 13. Standard errors are calculated using district-level bootstrapping.

Figure 8: Birth Weights, Transfers, and Household Expenditures between 50 and 100km

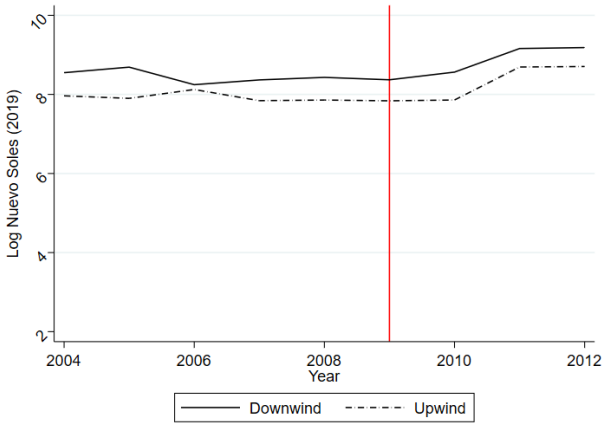
(a) Birth Weights



(b) Per Capita Canon Transfers



(c) Average Log Income



Note: In Panel (A), I take the average birth weights of singleton births weighing between 100 and 6,000 grams, born to mothers over the age of 13. In Panel (B) I divide the transfer received by the population estimate given in the 2007 Census. In Panel (C) expenditures are calculated as the average of the median expenditures of each district-year pair. For each household, I divide their reported expenditures by the number of household members, weighted by age categories. Children aged 1 through 4 are assigned .4, children aged 5 through 15 are assigned .5, and a 1 is assigned to everyone older.