Offshoring Health Risks: The Impact of the U.S. Lead Regulation on Infant Health in Mexico

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Abstract

Lead is a metal known to affect almost every organ and system in the human body. However, lead still exists in ambient air in the U.S. and continues to endanger public health and welfare. In response, the EPA substantially strengthened the National Ambient Air Quality Standard (NAAQS) for lead in 2008. The revised standard is 10 times tighter than the previous one set over 30 years ago.

In this paper, we investigate the effect of the new NAAQS for lead on (i) environmental quality in the U.S., (ii) trade patterns between the U.S. and Mexico and (iii) infant health in Mexico. A major challenge in existing studies in understanding environment-health nexus is to identify the sources of pollution in ambient air and disentangle the pollution exposure effect on health from other sources of pollution and/or from other determinants of health. We overcome these issues with two novel advantages in our approach: 1) We employ unique combination of public/non-public datasets linking trade, environment and health outcomes both in the U.S. and Mexico that provide a rare level of detail and that were not previously employed in the related fields. Importantly, our data contain exact locations of polluting plants and residential locations at a fine disaggregated level that allow us to identify critical distance over which households are exposed to pollution emitted from sources. 2) We identify exogenous variations in environmental quality under quasi-experimental research settings that enable us to address a large set of time-variant factors. These two cutting-edge features help uncover causal relationships.

We find that the new lead regulation substantially improved the ambient air quality in the U.S.; the concentrations of lead in ambient air fell in areas close to lead-emitting industrial plants than areas slightly away from these plants in the U.S. Our evidence suggests that such improvements in domestic environmental quality are driven by increased exports of lead contents to Mexico for recycle and production. We also find that exports from lead-emitting Mexican firms to the U.S. have also increased. Consequently, we find that the birth outcomes in Mexico deteriorated in proximity to battery recycling plants as compared with areas slightly away from them. Our findings are consistent with the pollution haven hypothesis suggesting that the stringent environmental policy in a developed country can induce offshoring pollution and health risks to a country with lax environmental standards.

JEL codes: F18, Q56
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I. Introduction

Whether and the extent to which low-income countries should bear responsibility for environmental protection is at the center of contentious debates at international policy discourse. Low-income countries often raise concerns that tightening environmental standards in their countries will hinder economic development, calling for stringent environmental regulations only in developed countries. An important discussion often missing in such debates is a conjecture that raising environmental standards in rich countries only may shift the production of pollution intensive products to low income countries with lax environmental standards, thereby resulting in lower environmental quality and high risks to domestic public health. This is known as pollution haven hypothesis, and it has been a central topic in the intersection of international economics and environmental economics.

A major challenge in existing studies in understanding environment-health nexus is to identify the sources of pollution in ambient air and disentangle the pollution exposure effect on health from other sources of pollution and/or from other determinants of health. This challenge is even more relevant in tracking the impact of the environment regulation of one country on health or other outcomes in other countries.[1] We overcome these issues with two novel advantages in our approach: 1) We employ unique combination of public/non-public datasets linking trade, environment and health outcomes both in the U.S. and Mexico that provide a rare level of detail and that were not previously employed in the related fields. Importantly, our data contain exact locations of polluting plants and residential locations at a fine disaggregated level that allow us to identify critical distance over which households are exposed to pollution emitted from sources. 2) We identify exogenous variations in environmental quality under quasi-experimental research settings that enable us to address a large set of time-variant factors. These two cutting-edge features help uncover causal relationships.

In this study, we test and present evidence supporting pollution haven hypothesis by exploring the effect of tightening the lead regulation in the U.S. in late 2008 as a natural experiment on (i) environmental quality in the U.S., (ii) trade flows between the U.S. and Mexico, and

[1] In his introductory article on the pollution haven hypothesis, Levinson (2008) writes that ``Empirical studies of the phenomenon have been hampered by the difficulty of measuring regulatory stringency and by the fact that stringency and pollution are determined simultaneously."

(iii) infant health in Mexico.

Our focus on a particular substance, lead, combined with the detailed data allow us to document a sharp pattern in the data which would be difficult to detect otherwise. In particular, the following features are useful. First, among manufactured products, a dominant fraction of lead today is contained in lead-acid batteries. Second, the most important source of lead production today is recycling of used lead-acid batteries. Third, while this recycling consequently is a major source of lead emission, it does not typically emit other toxic substances. These features allow us to provide clear evidence of the impact of the regulation change on trade flows and on health outcomes in Mexico.

Our findings are three-fold. First, we find that the new standards on lead in the U.S. successfully reduced lead in ambient air within 1 mile from lead-emitting industrial plants across the country substantially more compared to areas slightly away from these plants (i.e., 1-2 miles from lead-emitting industrial plants). These two areas exhibit similar pre-trends in air quality, and pollution reductions within 1 mile from lead-emitting plants occurred at the timing commensurate with the implementation of the new regulation.

Second, we show clear shifts in trade patterns of lead contents between the U.S. and Mexico in response to the new standards. On one hand, exports of lead content in the form of used acid-lead batteries for the purpose of recycling lead substantially increased since 2009 from the U.S. to Mexico. On the other hand, we find that exports from lead-emitting Mexican firms to the U.S. have also increased. These results suggest that lead-emitting production, both recycling and other lead-emitting activities shifted from the U.S. to Mexico.

Finally, we find that infant health, as measured by birthweight, length of gestation period, and other test scores, performed by birth attendants immediately after delivery, deteriorated in places within 4 miles from battery-recycling plants in Mexico as compared with areas slightly away from these plants (i.e., 4-8 miles from battery-recycling plants or other lead-emitting plants). The results are reinforced by evidence that the two areas exhibit deviation in health trends only after the implementation of the U.S. lead regulation, whose timing was completely exogenous to Mexico.

II. Literature Review

Our paper is related to several strands of literature. Our paper is an examination of the pollution haven hypothesis, which states that strengthening environmental regulations will move polluting activities to countries with less stringent environmental regulations. There are several types of the papers that analyze some part of the hypothesis.

First, there are papers that analyze the impact of environmental regulations of one country on production of plants of that country (Henderson (1996), Levinson (1996), Becker and Henderson (2002), Greenstone (2002) and Hering and Poncet (2014)). This topic is in many cases independently analyzed from the pollution haven hypothesis. Papers that aim to provide more direct evidence of the pollution haven hypothesis typically analyze foreign direct investment (FDI). Specifically, the second type of the papers analyze the impact of environmental regulations of one country on overseas activities (outgoing FDI) of the firms of that country (Eskeland and Harrison (2003), Hanna (2009) and Chung (2014)). The third type of papers have analyzed FDI in an opposite direction. Namely, they investigate whether regions or countries with tougher environmental regulations attract less incoming FDI (Javorcik and Wei (2004), Keller and Levinson (2002) and Kellenberg (2009)). Many researchers focus on FDI because multinational firms are plausibly able to shift their production across countries in response to differences in the environmental regulations. However, the shift of production may occur beyond the activities of multinational firms. In particular, Levinson and Taylor (2008) examine the relationship between abatement costs in U.S. and U.S. imports from Mexico.[2]

Focusing on the change in the U.S. lead regulation and its impact on the international trade and recycling of used batteries, we provide evidence of each of the steps written above. Furthermore, we show that the health outcomes of a country with less stringent environmental regulations do deteriorate as the result of more stringent environmental regulations by another country. Being able to document the link completing the whole channel of causation from the

[2] Other papers that analyze the link between trade and the environment within North America include Grossman and Kruger (1993), who classify channels through which the North American Free Trade Agreement (NAFTA) can affect the environment and examine them, and Cherniwchan (2015) and Gutierrez and Teshima (2014), who analyze the trade liberalization through NAFTA on plant-level environmental outcomes in US and Mexico, respectively.

strengthening the environmental regulation of one country to the deterioration of the health outcomes of another country is the unique feature of our study.

Our paper is also related to a small strand literature on trade of used or waste goods.[3] In particular, Davis and Khan (2010) find that the liberalization of used-car trade through NAFTA induced the movement from U.S. to Mexico of used-cars that are relatively dirty from the viewpoint of U.S. but clean from the Mexican one. Our paper is similar to their paper in that we analyze the movement of pollution-intensive used products from US to Mexico. There are two important differences. In our setting, the movement is driven by the strengthening of the U.S. regulation while in their case it is driven by the difference in the preferences of consumers. Second, and more importantly, we find the adverse consequences of the movement of used batteries on Mexican health outcomes.

Our paper is a part of the emerging literature on the health consequence of trade. Pierce and Schott (2016) analyze the impact of import competition on mortality in the U.S, while Bombardini and Li (2016) analyze the impact of export market access on the environment and child mortality in China. Their and our papers analyze distinct channels and thus together are useful in understanding how trade factors can share health.

Finally, our paper contributes to the rapidly expanding literature of the consequence of lead exposure. Health economists have found that lead exposure could affect various outcomes such as academic achievement and crime. See, for example, Reyes (2007) Nilsson (2009), Aizer et al. (2015), Billings and Schnepel (2015), Grönqvist, Nilsson and Per-Olof Robling (2014). Most of the papers analyze the cases of developed countries, with an exception of Rau, Reyes and Urzúa (2013), who analyzed a case from Chile. More importantly, our paper suggests that a trade factor, namely imports of used lead-acid batteries for recycling, could be an important source of lead exposure, in particular in developing countries where the regulation is weak.

[3] Kellenberg (2012) finds that international waste trade flows are affected by the relative stringency of environmental standards of trading countries. Levionson (1999) finds that the U.S. states that increased hazardous waste disposal taxes experienced decreases in hazardous waste shipments from other states.

III. The U.S. National Ambient Air Quality Standards on Lead

Lead is a metal known to affect almost every organ and system in the human body. Children under six years old including fetuses are considered most susceptible to the effects of lead, which are often linked to retarded fetal growth, behavioral problems, learning disabilities, lower IQ, and later criminal activities.[4] The United States had historically made tremendous efforts in reducing lead in ambient air, achieving nearly 92 percent reductions in average airborne lead concentrations between 1980 and 2013 (US EPA). Much of the reduction came from the permanent phase-out of lead in gasoline for motor vehicles since the mid-1970s.

However, lead still exists in ambient air in the U.S. and continues to endanger public health and welfare. In 2010, an estimated 535,000 children aged one to five had blood lead levels high enough to damage their health, and costing over $3 billion in medical and special education costs (CDC). Increasing scientific evidence suggests that there is no safe level of lead in blood, and even a lower level than originally thought has adverse effects on health and behavior (WHO 2010, Emory et al. 1999, Canfield et al. 1999, Lanphear et al. 2005, Nigg et al. 2008). In response, the EPA substantially strengthened the national ambient air quality standards (NAAQS) for lead in 2008. The revised standard is 0.15 $\mu g/m^3$, not to be exceeded by a rolling 3-month average, which is 10 times tighter than the previous one, 1.5 $\mu g/m^3$, set over 30 years ago in 1978. This standard is identical for both the primary (health-based) and secondary (welfare-based) standards.[5]

A review of the lead standards was initiated in November 2004, leading to the release of *the Plan for Review of the National Ambient Air Quality Standards for Lead* in February 2006, and subsequently an advanced notice of proposed rulemaking on December 5, 2007. The revision on the NAAQS for lead was signed on May 1, 2008, and EPA published the final rule in Federal Register on November 12, 2008, which became effective on January 12, 2009.

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[4] See, for example, Needleman et al. (1990), Pocock et al. (1994), Burns et al. (1999), Torres-Sanchez et al. (1999), Nevin (2000), Dietrich et al. (2001), Bellinger and Needleman (2003), Braun et al. (2008), Berkowitz et al. (2006), Hu et al. (2006), Schnaas et al. (2006), Cecil et al. (2008), Wright et al. (2008), Mirghani (2010), Schwartz (1994), Reyes (2007) and Aizer et al. (2015).

[5] The standard in Mexico has been 1.5 $\mu g/m^3$ for three-month average since 1993 (NOM-043-SEMARNAT-1993). In Canada, Ontario sets the level of 0.5 $\mu g/ m^3$ for 24-hour average and 0.2 $\mu g/ m^3$ for 30-day average, while Quebec sets 0.1 $\mu g/m^3$ for one-year average.

To assess compliance with the revised NAAQS for lead, EPA expanded the lead monitoring network, requiring monitors to be placed in areas that are expected to exceed the standards, such as those near industrial facilities that emit one ton or more of lead per year.

Compliance to the new standards is evaluated over a 3-year period. EPA completed final designations of attainment/nonattainment status for every county in November, 2011, and states were required to submit State Implementation Plans for nonattainment counties to comply with the standards. All states are required to meet the standards by January 2017.

IV. Effect on Ambient Air Quality in the U.S.

Data

Lead-emitting facilities (those emit lead and/or lead compounds) are found in the Toxic Release Inventory (TRI). TRI is managed by EPA. The aim of TRI is to support informed decision-making by communities and other stakeholders by providing a resource for learning about toxic chemical releases and pollution prevention activities reported by industries and the government. Plants are required to report their emissions of specified chemicals if they employ at least ten employees at the same time operating in a certain industry and being engaged in manufacturing, processing or using a regulated substance more than a specified threshold. Though the reporting is mandatory for plants satisfying these conditions, the information registered at TRI is a self-reported measure of pollution emissions from individual facilities, and these emission estimates are known to have substantial errors.[6] To circumvent the issue, we follow Currie et al. (2015) in keeping all facilities that emit lead at least once in the relevant period, from 2003 to 2013 in our case, and in not using the information on the reported emission amount. In total, there are close to 13,000 facilities across the country that emitted lead during this period. On average, each facility that emitted any amount in the year emitted approximately 77,270 pounds of lead and lead compounds combined per year with standard deviation of 3.3 million pounds.

The data on air quality come from ground-level monitoring stations across the U.S., downloaded from the EPA website. The data provide information on average concentrations of lead in ambient air for the years between 2001 and 2013 over 569 stations across the country. We

[6] EPA relies on the monitoring stations, not on TRI, to enforce its regulation.

paired each air quality monitoring station with the closest lead-emitting facility using the geo-coded locations.

On average, each station reports values of lead concentrations 12.4 times (with standard deviation of 13.6) per month, or 139.6 times (with standard deviation of 156.2) per year. These monitors are on average 7.79 miles away from the nearest TRI facility with the standard deviation of 97.29 miles (weighted average distance from the nearest TRI facility by the number of monthly observations is 2.78 miles with the standard deviation of 37.97 miles). The monthly average lead concentrations are 0.072 $\mu g/m^3$ across the country (those within 10 miles, 2 miles, 1 mile from the nearest TRI facility are 0.074, 0.086, 0.106 $\mu g/m^3$, respectively).[7]

Graphical Evidence

If the new EPA policy had any contributions to reductions of lead productions in the U.S., we should see ambient lead concentrations near lead-emitting facilities fall subsequent to the policy implementation. Moreover, we should observe a larger impact on ambient air quality closest to the toxic facilities.

Figure 1 Panel A plots the lead pollution gradient of distance to the toxic facility locations during the pre-reform period (years 2003 through 2008). Ambient lead concentrations are the highest at monitoring stations in closest proximity to toxic plants and fall with distance from the plants until monitoring stations located about 2 miles away and beyond detect almost no lead. This evidence itself does not directly indicate that lead travels about 2 miles once emitted from industrial facilities, because lead in ambient air can also be caused by the atmospheric re-suspension of contaminated soil/road dust.

Figure 1 Panel B adds the pollution gradient during the post-reform period (years 2009 through 2013). The pollution concentrations are similar before and after the policy reform in distance over 2 miles. However, there is a clear decline in pollution concentration with proximity to toxic facilities within 1 mile, and the decline is greatest for the monitors nearest to toxic facilities. The evidence suggests that pollution has declined at monitors within 1 mile from the toxic plants, indicating that the areas within 1 mile from a toxic plant constitute the affected areas. The estimated distance is consistent with Currie et al. (2015).

[7] The annual average lead concentrations are 0.069, 0.071, 0.082, 0.103$\mu g/m^3$ across the country, within 10 miles, within 2 miles, within 1 mile, respectively.

The notion that the decline in ambient lead concentrations within 1 mile found in Figure 1 reflects a causal effect of the new EPA policy would require further evidence. In particular, the timing of decline must coincide with the implementation of the policy. An identification threat is that ambient lead concentrations have been declining over time even without the new policy, and in such a case, we would still get similar figures as in Figure 1, but the decline may simply reflect a preexisting time trend.

Figure 2 shows the ambient lead concentration gradient over time with respect to years. The trends in ambient lead concentration levels are measured separately for monitoring stations located within 1 mile from a toxic facility (solid line) and those within 1 to 2 miles from a toxic facility (dashed line). Prior to the 2008 policy implementation, the lead concentration trend at the 1-2 mile monitoring stations was similar to the trend at the within 1 mile monitoring stations. An important implication is that these two areas present similar trends in lead in air over time without an intervention, supporting the key assumption for the econometric model described below. Interestingly, we observe a spike in ambient lead concentrations in 2008.

Importantly, the two areas illustrate distinct trends in lead concentrations after 2008; ambient lead concentration levels closest to the toxic facilities substantially fell, while lead concentration levels in the proximate 1-2 mile areas did not decline after 2008 and have been fairly constant over time. Under the assumption that these two areas would have had similar trends in ambient air quality had the EPA policy not been implemented, the differences in the amount of reductions can be interpreted as the causal effect of the new EPA regulation on lead.

<u>Regression</u>

Based on the evidence above, we run the following regression model;

$$LEAD_{jt} = \alpha + \beta Near_j \times Post_t + \mu_t + \gamma_j + \varepsilon_{jt},$$

where the outcome is the average concentration of lead in ambient air recorded at monitor *j* in time *t*. *Near* is an indicator variable taking the value of one if the monitor is located within one mile from toxic plant, and *Post* is a dummy variable for the post-reform period (years in and after 2009). We also include the time and monitor fixed effects, and all standard errors are clustered at the monitor level.

Table 1 reports the coefficients of interest, β. Column (1) suggests that average lead concentrations in areas within 1 mile from a toxic plant declined significantly more by 0.068 $\mu g/m^3$

relative to areas 1-2 miles away from a toxic plant. The point estimate is statistically significant different from zero at one percent level. Also, the point estimate is economically significant suggesting that lead concentrations near a toxic plant declined by 54% in the aftermath of the new lead regulation.[8]

As a robustness check, we expand the control group up to 5 miles from a toxic plant in Column (2). The point estimate is similar and unchanged, which is consistent with the previous figures above showing that lead does not travel beyond 2 mile. To highlight variation in the treatment effect at finer distance gradient, we use monitors within 0.5 mile from a toxic plant as the treatment area in Column (3), those within 0.5-1 mile in Column (4), while the control area remains monitors 1-2 miles away from a toxic plant. As expected, ambient air lead concentrations declined more at monitors in close proximity to a toxic plant. In Column (5), we repeat the analysis in Column (1) by aggregating the observations to an annual level (by taking an arithmetic average of lead concentrations levels for each year). The finding is the same.

V. Effect on Trade Flows

A. Effect on the U.S. Exports of Lead

Data

Annual information on lead production in the U.S. from 1996 to 2014 is drawn from Minerals Yearbook for lead published by U.S. Department of Interior.

Information on the exports of U.S. commodities are obtained from United States International Trade Commission (ITC). We obtained used lead-acid batteries and lead scrap exported from the U.S. at the monthly level between 1997 and 2014. Note that we corrected the information from ITC based on the commodity-specific statistical corrections provided by the U.S. Census Bureau, Foreign Trade Division.

Graphical Evidence

We first present the historical trends of lead production in the U.S. Figure 3 shows that U.S. primary production of lead has historically fallen over time. Domestic lead production come from

[8] Average concentration level of lead in ambient air at monitors within 1 mile from a toxic plant before 2008 is 0.125 $\mu g/m^3$.

secondary production of lead, almost all of which come from lead recovered from old scrap processed from battery lead. Storage batteries also account for approximately 90% of lead consumption. Figure 3 illustrates that secondary production was on an increasing trend before 2008. The trend, however, reversed in 2008 and afterwards.

We now present trends in the U.S. exports of lead. Figure 4 shows the total monthly amount of lead contained in U.S. exports to Mexico and Canada.[9] Lead was historically exported to Canada before 2004. Since 2004, lead exports to Mexico exceeded that to Canada. While the amount of lead exports to Mexico had been steadily increasing since then, we can see an increasing rate of lead exports to Mexico since the U.S. lead regulation was imposed, as the timing indicated by the vertical dashed line, while exports to Canada fell.

Figure 5 shows an analogous figure at annual level, disaggregating the total lead exports by the commodities between used lead-acid batteries and lead scrap. Historically, lead scrap accounted for almost all lead exports to Canada. Starting in 2004, the U.S. started exporting used lead-acid batteries to Mexico, while lead scrap exports to Mexico was almost non-existent. In the aftermath of the U.S. lead regulation, lead scrap exports to Canada dramatically fell, while exports of used lead-acid batteries sharply increased.

These findings are consistent with the fact that lead used to be recycled in the U.S., and recycled lead (lead scrap) was exported to Canada to produce lead-contained products. Due to the new lead regulation, it became costly to recycle lead in the U.S., and thus the U.S. started exporting used lead-acid batteries to Mexico for the purpose of recycling lead.

The increasing trends in lead exports after 2009 may simply reflect an increase in U.S. total lead exports not just to Mexico but to the entire world. Figure 6, however, shows that the annual share of total lead exports to Mexico sharply increased since 2009, going from approximately 45% to 80%. On the other hand, the share of lead exports to Canada fell. It is evident that Mexico became a major destination of the U.S. lead exports.

B. Effect on the Exports of Mexican Lead-emitting Plants

Data

[9] The total amount of lead contained is the sum of lead contained in used lead-acid batteries and lead scraps. We also present the raw number and weight of used lead-acid batteries exported from the U.S. to either Mexico or Canada in Appendix 1 and 2.

We link two plant/firm-level datasets to create the data on exporting activities of lead-emitting plants in Mexico. First, Registro de Emisiones y Transferencia de Contaminantes (RETC) [Registry of Emission and Transfer of Pollutants] is a registry of establishments' reports of emissions and transfers of pollutants. Plants in the specified industries emitting specified chemical substances are obliged to register to RETC every year. RETC's operation and management are administered by Secretaría de Medio Ambiente y Recursos Naturales (SEMARNAT)[Ministry of the Environment and Natural Resources].

As a part of NAFTA negotiations, Mexico made the commitment to establish a registry of public environmental information in terms of emissions and pollutant transfers, similar to TRI in the US. After a pilot program that started in 1997, the mandatory registration system was legislated in 2001, and the registry started in its full operation in 2004.

RETC publishes the information on each plant's exact location (the full address and geographic coordinates), the sector, the amount of emission of each chemical substance, and the emission channel. The information that we use for this paper is publicly available on the website of SEMARNAT.

Second, we use administrative records of the Mexican customs agency on every transaction crossing the Mexican border. Prior to carrying out an international transaction, Mexican exporters and importers must fill out a customs form on which they report the tariff classification code of the products, the value and the quantity of each product, and the destination (or source) country, among other information. We use the data from 2005 to 2011.[10] We aggregate the information at the exporter-product-destination-year level. We further aggregate all the non-US countries, therefore the destination variable is a dummy indicating whether the destination is the US or not.

We link the RETC dataset and the Mexican customs data using firm name, address and a part of tax payer ID.[11] We keep the Mexican exporters from the customs data that are linked to the RETC dataset. The Mexican exporting firms that are linked to the RETC dataset account more than 70% of all the Mexican exports each year.

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[10] The customs data changed the reporting format in June 2004, and the data before and after are not comparable. For example, the number of exporters increase by 20% and the number of exporter-product combinations increase by more than 50% from May 2004 to June 2004. We have access to the customs transaction data until April 2012.

[11] Plant ID in the RETC dataset contains the first three digit of the tax payer ID, while the customs data contains the complete tax payer ID.

With the linked data, we run the following regression model;

$$LogExports_{isut} = \alpha + \beta Lead_i * US_u * Post_t + \Sigma\tau_t Lead_i * Year_t + \mu_{st} + \gamma_{ut} + \varepsilon_{isut}$$

$Exports_{isut}$ is exports of firm i in sector s for destination u (U.S. or non-U.S.) at yeat t. $Lead_i$ is a dummy indicating whether firm i owns at least one of its plants register lead as one of its emitting substances. US_u is a dummy indicating whether the destination country is the U.S. We analyze whether the exports of lead emitting plants to U.S. increased after the regulation change. This is a triple-difference strategy, where one treatment is lead emitting plants (as opposed to plants emitting other substances) and the other treatment is US. The parameter of interest is β, which can be interpreted as a causal effect of the regulation on exports. We control lead-emitting plants-year effects, sector-year effects, as well as, US-year effects, which control, respectively, differential supply trends between lead-emitting plants and non-lead-emitting-plants, differential sectorial trends, and differential demand trends between the U.S. and other countries.

Table 2 shows the results. Regardless of the definition of sector, we find that the exports to the U.S. by Mexican lead-emitting firms increased after the regulation change, relative to their exports to the other destinations, and relative to Mexican firms not emitting lead but other substances.

VI. Effect on Infant Health in Mexico

Data

Our data on infant health come from the universe of birth certificates between 2008 and 2013. The birth certificate is a preliminary identification document issued at birth, only once, by the Mexican National Health System (NHS)[12] to every newborn born alive[13] within the Mexican territory since September 2007, regardless of parents' nationality or immigration status.[14]

[12] The National Health System (NHS), established in 1984 as part of the General Health Act (*Ley General de Salud*), is the network of all listed hospitals, health facilities and care providers, including both governmental and private. The NHS' goal is to provide access to the healthcare services.

[13] The legal definition of a newborn born alive considers all human fetuses or babies that have been expelled or extracted from the mother's body, regardless of lengths of gestation and/or whether newborns are physically separated from mothers, show voluntary or involuntary muscular movements, are breathing, or their umbilical cord is beating at some point.

[14] By law, when a baby is born alive in a listed medical facility, and therefore within the NHS or at any other locations with assistance of a registered midwife or doctor, the professional who delivers the baby is obliged to issue the birth certificate within the next 24 hours after the birth. If under any given circumstances the birth

The issuing of the NHS birth certificate is a relatively new legal mandate in Mexico. The only proof of birth for all births occurred prior to September 1st, 2007 is the civil registry-issued birth certificate (*acta de nacimiento*). As a consequence, our data necessarily start from 2008. While being born on Mexican soil concedes the Mexican nationality, the civil registry requires the submission of the NHS birth certificate in order to issue its civil birth certificate (*acta de nacimiento*), which is the first valid official identification document for civil purposes. Therefore, it is mandatory for the health system personnel to issue the NHS birth certificate immediately following births.

In addition, birth certificates are used to provide statistics as to number of births and health of newborns and mothers. For these purposes, the data not only include demographic information of mothers (i.e., age, residential locality, educational, occupation, and prenatal care and pregnancy history) but also report birth outcomes such as birthweight, length of gestation period as well as Apgar and Silverman test scores.[15]

In the analysis we describe in more detail below, we use distance from the nearest authorized battery-recycling plant to define the treatment status of each residential locality; births adjacent to a battery-recycling plant are considered as the treatment group and births near but slight away from a battery-recycling plant as the control group. We compiled the list of the authorized recycling plants at various point of time from the SEMARNAT website.

For the purpose of the analysis, we use all births near lead-emitting plants including both authorized battery recycling plants and other lead-emitting plants found from RETC, the register of plants emitting various chemicals, which we use and explained in the previous section. In the latter case, we use the same distance buffer from lead-emitting plants for observations near an

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certificate was not issued within this timeframe, the certificate is issued according to the biological mother's clinical record and filled by the health care provider who delivered the baby, or by the head of the corresponding healthcare facility or her representative. If a non-listed person assists the delivery, and consequently she does not posses any issuing capacities, the NHS birth certificate will be supplied by the corresponding listed healthcare facility within the next year. Usually, this is the closest healthcare unit to the place of birth, but it may not be the case and rather depend on the mother's affiliation status to any of the current social security schemes (IMSS, ISSSTE, Pemex, *Secretaría de Salud*, or Army). The data can be obtained from the National Basic Health Information System on the website of Ministry of Health.

[15] The Apgar test is performed on a baby at 5 minutes after birth. Each letter represents five factors used to evaluate the baby's condition; Appearance (skin color), Pulse (heart rate), Grimace response (reflexes), Activity (muscle tone), and Respiration (breathing rate and effort). The Silverman test score rates upper chest retractions, lower chest retractions, xiphoid retractions, nasal flaring, and expiratory grunting immediately after birth. Note that both scores are scaled from 0 to 2 per factor, and thus from 0 to 10 in total, higher Apgar scores are better (a score of 8-10 is considered normal), while lower Silverman scores are better (normal babies have a score close to 0).

unauthorized plant. Localities near an authorized plants are considered as the treatment, while other localities, those away from a battery recycling plant and those near and away from other lead-emitting plant, are considered as the control group. The obvious advantage to use observations surrounding other lead-emitting plants is the increase in the sample size. There are only 27 authorized plants, while there are more than 3,700 plants that emitted lead at least once at any time between 2007 and 2013 (Note that this number indicates a pure total, not the number of plants that locate near any births we have in our sample-1730). Under the assumption that localities near lead-emitting plants present similar trends in infant health regardless of the authorization status, we can include observations near other lead-emitting firms as a control group. We present validity of such an assumption later.

We can explain our idea for empirical strategy using Figure 7, which shows the location of localities, a battery recycling plant, and other lead emitting plants in one city, Aguascalientes in the state of Aguascalientes. Each small colored dot shows the location of a locality. The point around which there are two circles is the location of a battery recycling plant. Red dots, marked as A in the legend of the map, are the localities within four miles of the battery recycling plants. Blue dots, marked as B in the legend of the map, are localities located between four and eight miles away from the battery recycling plants, but not located within four miles of any other lead emitting plants. Green dots, marked as C in the legend of the map, are the localities that are not located within four miles of the battery recycling plants, but within four miles of another lead emitting plant. Purple dots, marked as D in the legend of the map, are localities not located within four miles of the battery recycling plants, but located between four and eight miles away from another lead emitting plant. Orange dots, marked as E in the legend of the map, are localities in the same city that are not located within eight miles of either the battery recycling plant or any other lead emitting plants. Our empirical strategy is to use localities shown as red dots (A) as the treatment group and localities shown as green or purple dots (B +D) as the control group.

There is, however, an important issue with respect to how we define the treatment status. We eliminate localities near ("near" as we define below) a lead-emitting other plant from our control group for two reasons. First, while battery recycling is most lead-emission intensive activity, other lead emitting plants are also likely to increase their production, as is documented in the previous section on the response of Mexican exporters. Treating the localities near these other lead emitting plants as a control group would introduce a bias. Second, there is no knowledge, by its illegal nature, whether other lead-emitting plants without a particular authorization to recycle batteries truly did not dispose of lead batteries or conducted illegal disposal. Indeed, a New York Times alerts increased health risks near the specific plant due to increased lead-battery recycles, but this plant is not authorized to dispose of lead.[16] In the presence of illegal disposal, localities away from an authorized plant yet close to other-lead emitting plant should be considered as a treatment group, while the treatment status based on a mere distance from an authorized plant, as we use, assign these localities as a control group, as the distance is sufficiently long enough for lead to be transported from an authorized plant.

Summary Statistics

Graphical Evidence as the Basis of the Research Design

The empirical analysis requires knowledge on how far lead transports once emitted in order to define the distance over which households are affected by pollution emissions. The previous literature does not provide a consensus estimate, and thus this is one of the contributions of this research. In the previous section, we have shown that lead travels approximately 1 mile once emitted from industrial facilities in the U.S., using the dataset that matches a lead-emitting facility with air quality readings in its neighborhood. However, there is no rationale to believe that the estimate in Mexico would be the same, as the distance should be a function of not only the chemical substance but also intensity of industrial activity, mode of emission, pollution abatement technology, and initial emission levels. Thus, we nonparametrically estimate the distance using birth outcomes near authorized plants. If the new EPA policy in the U.S. had any adverse effect to infant health in Mexico, we should see infant health outcomes deteriorate subsequent to the policy implementation. Moreover, we should observe a larger impact on infant health closest to the toxic plants.

Figure 8 plots average birthweight (in Panel A) and occurrence of low birthweight (birthweight less than 2,500 gram) (in Panel B) over the distance from the nearest authorized

[16] New York Times. Lead From Old U.S. Batteries Sent to Mexico Raises Risks (Dec 8, 2011) http://www.nytimes.com/2011/12/09/science/earth/recycled-battery-lead-puts-mexicans-in-danger.html

battery-recycling plant locations.[17] The blue dotted line indicates observations before the policy reform (i.e., observations in 2008), and the red solid line indicates observations after the policy reform (i.e., observations since 2009). Interestingly, during the pre-reform period, birthweight tends to be higher and low birthweight is less likely near an authorized battery-recycling plant. Infant health in terms of birthweight falls with distance from the plant until localities located about 2 miles away and beyond detect almost no variation. This evidence itself does not directly indicate that lead does not affect infant health, because the effect is confounded by various cross-sectional variations. The comparison of infant health gradient of distance before and after the policy reform reveals that infant health is similar before and after the policy reform in distance over 2 miles. However, there is a clear decline in infant health (i.e., lower birthweight in Panel A and higher probability of low birthweight in Panel B) with proximity to battery-recycling plants within 2 miles, and the decline is greatest for the births nearest to to battery-recycling plants.

In Panels C and D, we present similar plots for the length of gestation period and occurrence of premature births (birth less than 37 weeks of gestation period), respectively. Similar to the findings in birthweight, we also find better infant health near to battery-recycling plants. On the other hand, decreases in health status in the post-reform period are captured for a longer distance, approximately 4 miles.

The findings in Figure 8 suggest that lead travels approximately 4 miles once emitted from lead-emitting industrial facilities in Mexico, and households living within 4 miles constitute the primary affected group by the policy. However, the notion that the decline in infant health within 4 miles found in Figure 1 reflects a causal effect of the new EPA policy requires further evidence. In particular, the timing of decline must coincide with the implementation of the policy. An identification threat is that infant health has been declining over time even without the new policy, and in such a case, we would still get similar figures as in Figure 1, but the decline may simply reflect a preexisting time trend.

Figure 9 shows the infant health gradient over time with respect to months of births. The trends in infant health are measured separately for births within 4 miles from a to battery-recycling plants (red solid line) and those within 4-8 miles from a to battery-recycling plant or a lead-emitting plant (blue dashed line). Prior to the 2008 policy implementation, the timing indi-

[17] Note that for observations near lead-emitting unauthorized plants that we use as a control group, we use distance from an unauthorized plant in this figure.

cated by the vertical dashed line, infant health trends at the 4-8 mile localities were similar to the trend at the within 4 miles localities, using all four indicators of infant health. If anything, infant health appears to have been improving within 4 miles, in which case, the bias goes against finding decreases in infant health.[18] An important implication is that these two areas present similar trends in infant health without an intervention, supporting the key assumption for the econometric model described below.

Importantly, the two areas illustrate distinct trends in infant health after 2009. Most notably, length of gestation period closest to the battery-recycling plants substantially fell, while that in the proximate 4-8 mile areas did not decline after 2009 and have been fairly constant over time. Similarly, occurrence of premature births within 4 miles substantially increases relative to those in 4-8 mile areas. Under the assumption that these two areas would have had similar trends in infant health had the EPA policy not been implemented, the difference in infant health can be interested as the causal effect of the new EPA regulation on infant health in Mexico.

Empirical Strategy

To empirically test the policy effect on infant health near lead-emitting sources, we employ a difference-in-differences (DID) approach to estimate the effect of policy on newborns' health. The basic idea of DID is to exploit two sources of variation in intensity of exposure to environmental hazards. The first source of variation is the spatial variation; households far from pollution sources are likely to have lower exposure to pollution than those in proximity. While having the data at the fine disaggregated level helps observe variation over spatial distance, it does not address endogenous residential sorting. For example, households in extreme proximity to pollution sources may have different attributes than those in areas away from the sources, which may explain the differences in health, generating spurious correlations between infant health and distance from pollution sources. Such evidence is relatively ubiquitous in cross-sectional studies.

The second source of variation is the temporal variation in pollution for given locations. Exploiting this source of variation helps remove effects through fixed characteristics of locations including residential sorting. Yet, an association between pollution and health changes over time is still confounded by many other time-variant variables, such as economic cycles or simply time

[18] For example, low birthweight and premature births had a decreasing trend within 4 miles relative to 4-8 miles. Such finding is even clearer if we use smaller bandwidth.

trends. For example, pollution may be falling over time due to increased public concerns and stricter regulations, while health is improving over time due to improved nutrition and advances in medical technology. Even if these phenomena are unrelated to each other, we would still observe strong negative associations between health and pollution, generating again a spurious correlation. This is a main issue with time-series analyses.

In our research design, we use policy as providing exogenous variation in pollution concentrations. The novel feature of DID is that it overcomes such shortcomings by combining both cross-sectional and time-series features, or by exploiting a panel-data setting. In particular, we run the following regression:

$$Y_{ijt} = \alpha + \beta(Near_j \times Post_t) + \lambda_j + \tau_t + X_{it}\gamma + \varepsilon_{ijt},$$

where *Y* denotes the outcome variable of interest for newborn *i* living in area *j*, born in year *t*. Newborns' health is measured by birth weight, an indicator variable for low birth weight, length of gestation period, and an indicator variable for preterm birth. *Near* is a dummy variable for areas within 4 mile of an authorized to battery-recycling plant that constitutes the treatment group. *Post* is a dummy variable for the time period after the policy was implemented (i.e., years since 2009). Inclusion of locality fixed effects, λ_j, controls for time-invariant characteristics that explain health variation across localities, the main confounding variables in cross-sectional models, whereas inclusion of year fixed effects, τ_t, helps remove all factors common for a particular year across localities, the main confounding variables in time-series models. Essentially, the difference-in-differences effect of pollution on newborn health compares the changes in newborns' health between pre- and post-reform periods, in two areas that are adjacent to each other and are both located in close proximity to a battery-recycling plants or other-lead emitting plant. We additionally include a vector of maternal characteristics in *X*.

The parameter of interest is β, which can be interpreted as a causal effect of the regulation on newborn. The changes in health in areas slightly away from pollution sources can provide counterfactual evidence on what would have happened to health in areas extremely proximate to pollution sources in the absence of the policy. The identification assumption is that the trends in newborn health would have been similar between the two types of localities had the policy not been implemented. Indeed, the graphical evidence described above provide strong support to the validity of the identification assumption that trends in infant health are similar in the absence of the policy between the areas within 4 mile from toxic plants (the treatment area) and those within 4 to 8 miles (the control area), thereby enhancing credibility of the research design.

Regresison Results

Table 3 present empirical results. In Panel A, we use localities within 4 miles from an authorized battery-recycling plant as the treatment group. Column 1 suggests that the policy effect on average birthweight is not statistically or economically significant. Column 2, in turn, suggests that the policy raised the incidence of low birthweight near authorized plants. The point estimate suggest that the incidence of low birthweight increased by 0.0022 percentage points. Similarly, Columns 3 and 4 suggest that the length of gestation period shortened, and the incidence of premature birth increased in localities near an authorized plant. In addition, Columns 5 and 6 suggest lower infant health as measured by parameters of observed health conditions performed shortly after birth.

To explore variation in the treatment effect within the treatment group, we use localities within 2 miles as the treatment group in Panel B, and localities within 2-4 miles as the treatment group in Panel C, while keeping the control group fixed and the same as Panel A. The estimated effects are consistently larger in Panel B for all the dependent variables with an exception of Silverman test score. Most notably, the policy had substantial and statistically significant effect on birthweight within 2 miles from an authorized battery-recycling plant. Panel C suggest that the policy continues to have statistically significant, yet smaller, effect on infant health as measured by all indicators except birthweight even for localities 2-4 miles away from an authorized battery-recycling plant.

VII. Conclusions

In this paper, we investigate the effect of tightened environmental standards on lead in the U.S. on domestic environmental quality, trade patterns between the U.S. and Mexico, and infant health in Mexico. Our findings highlight evidence that the new regulation resulted in improvements in air quality in the U.S. at the expense of lower infant health in Mexico due to increased exports of lead content from the U.S. to Mexico. The findings are consistent with pollution haven hypothesis.

Our study raises an important policy implication that unbalanced stringency in environmental standards may spur flows of pollution intensive activities to countries with lax environmental standards. Therefore, simply tightening standards in developed countries may only end up with offshoring pollution and health risks to developing countries. It is necessary to design policies that limit the scope of such negative externalities to low-income countries.

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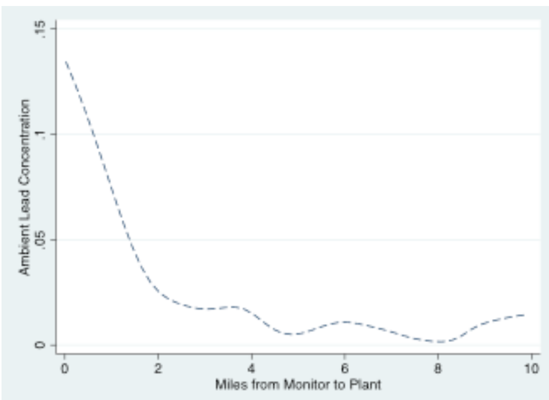
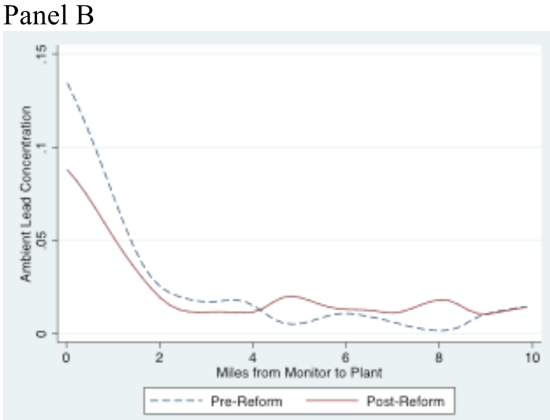
Figure 1: Average Lead Concentrations over Distance
Panel A

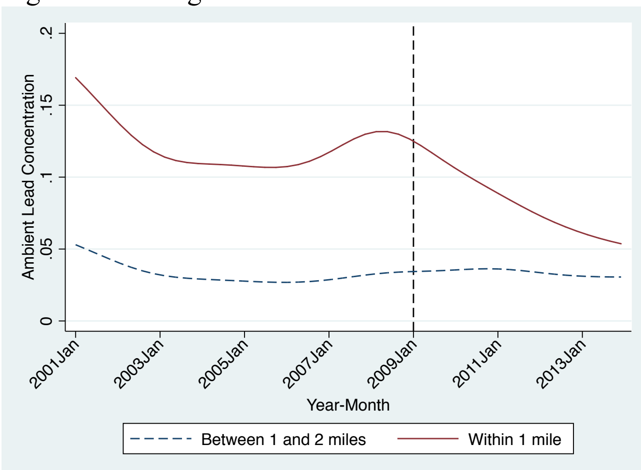


Panel B



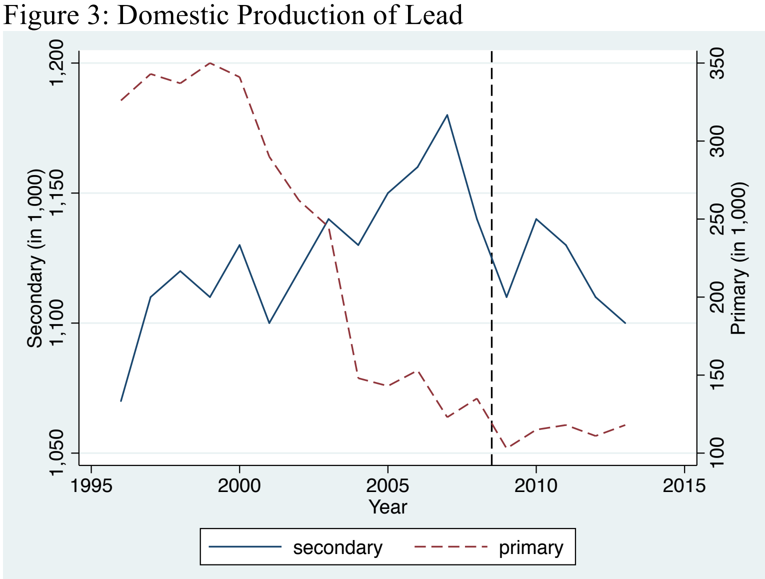
Notes: Cross-sectional variation in average lead concentrations levels in ambient air at the monitoring stations over distance from the nearest lead-emitting facility, separately for the pre-reform period (years in and before 2008) in blue dashed line, and for the post-reform period (years after 2009) in red solid line.

Figure 2: Average Lead Concentrations over Time



Notes: Time-series variation in average lead concentration levels in ambient air at the monitoring stations between 2001 and 2013, separately for the monitoring stations within 1 mile from the nearest lead-emitting facility in red solid line, and for the monitoring stations within 1 to 2 miles from the nearest lead-emitting facility in blue dashed line. The black dashed vertical line at January 2009 indicates the timing of the new EPA lead regulation implementation.

Figure 3: Domestic Production of Lead



Notes: Both units are in 1,000 metric tons.

Figure 4: Total Lead Contained in the U.S. Exports

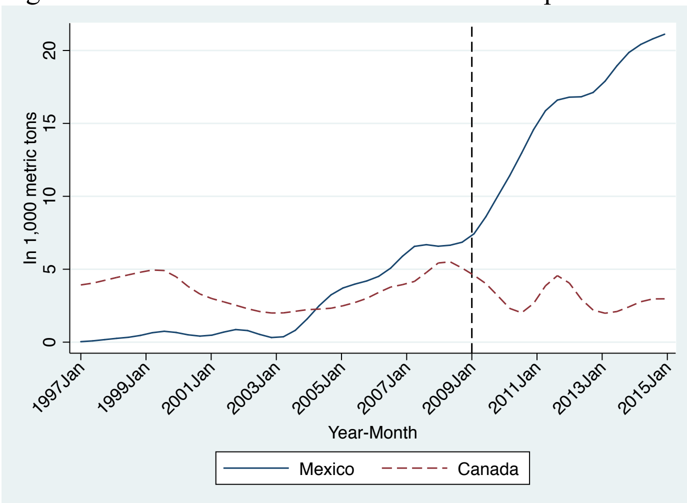


Figure 5: Contained Lead in Lead Exports from U.S. by Products

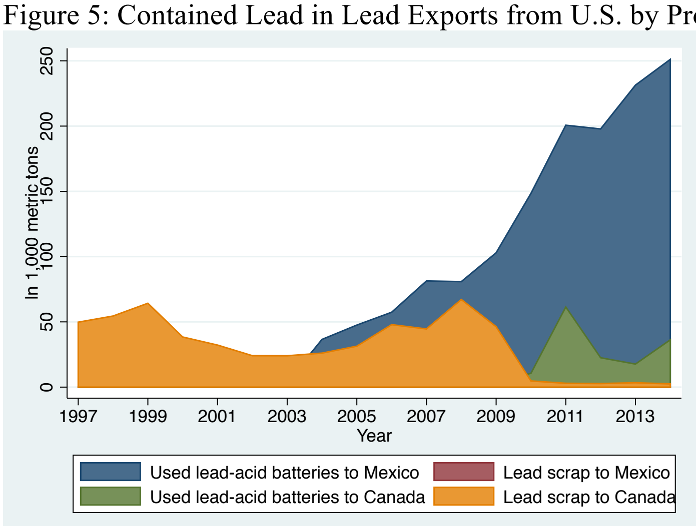
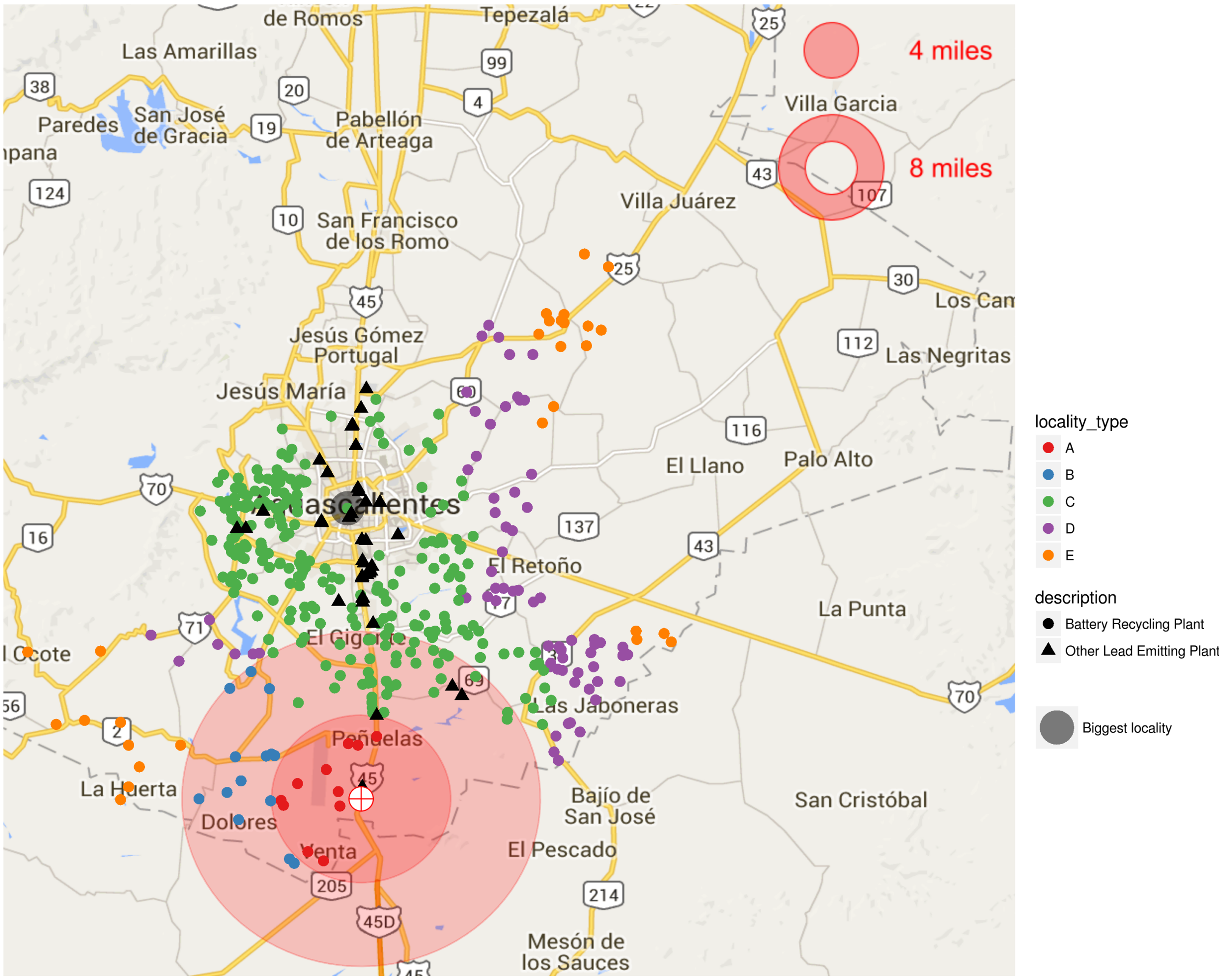


Figure 6: Share of Total Lead Exports from the U.S.

Figure 7 Construction of the treatment and control groups.



Note: Each small colored dot shows the location of each locality. The point around which there are two circles is the location of a battery recycling plant. Red dots, marked as A in the legend of the map, are located within four miles of the battery recycling plants. Blue dots, marked as B in the legend of the map, are located between four and eight miles away from the battery recycling plants, but not located within four miles of any other lead emitting plants. Green dots, marked as C in the legend of the map, are not located within four miles of the battery recycling plants, but within four miles of another lead emitting plant. Purple dots, marked as D in the legend of the map, are not located within four miles of the battery recycling plants, but between four and eight miles away from another lead emitting plant. Orange dots, marked as E in the legend of the map, are not located within eight miles of either the battery recycling plant or any other lead emitting plants, and are shown for completeness. Our empirical strategy is to use A as the treatment group and (B+D) as the control group.

Figure 8: Cross-sectional variation in infant health by period

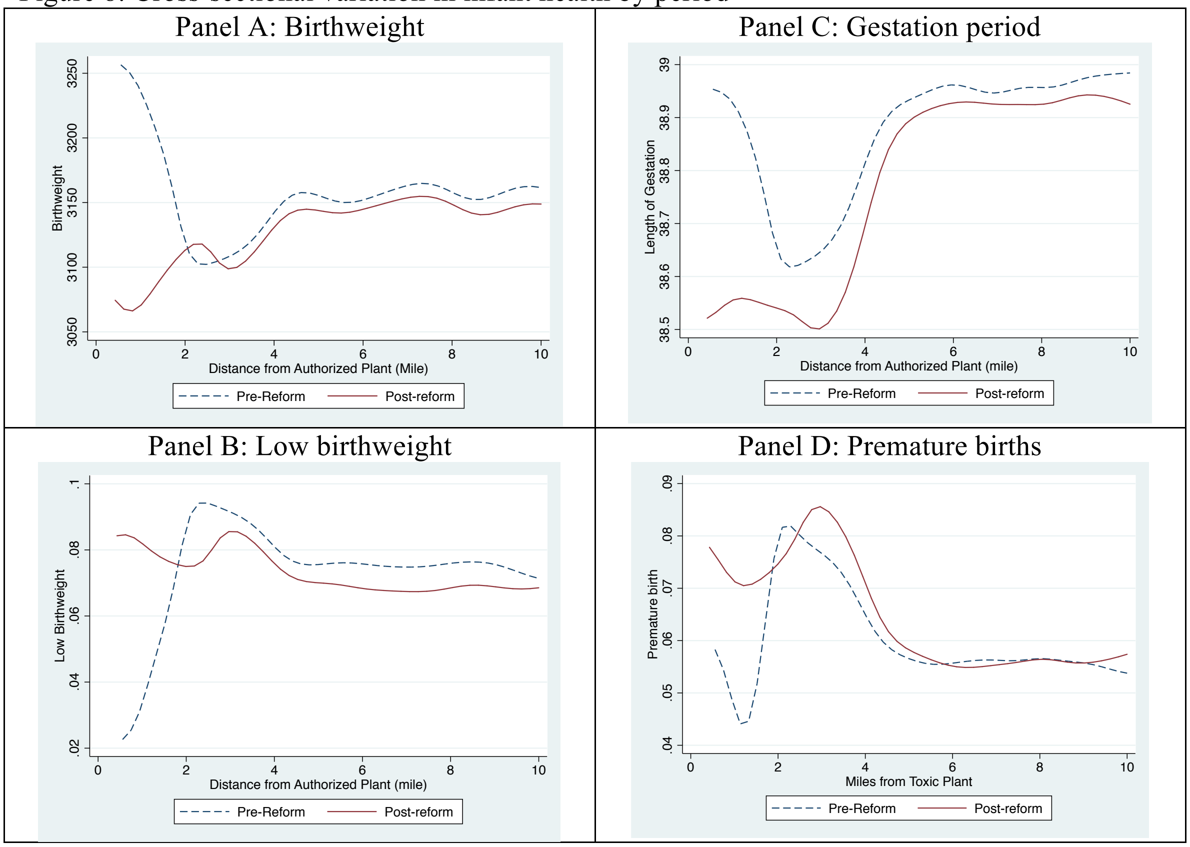


Figure 9: Time-series variation in infant health by distance

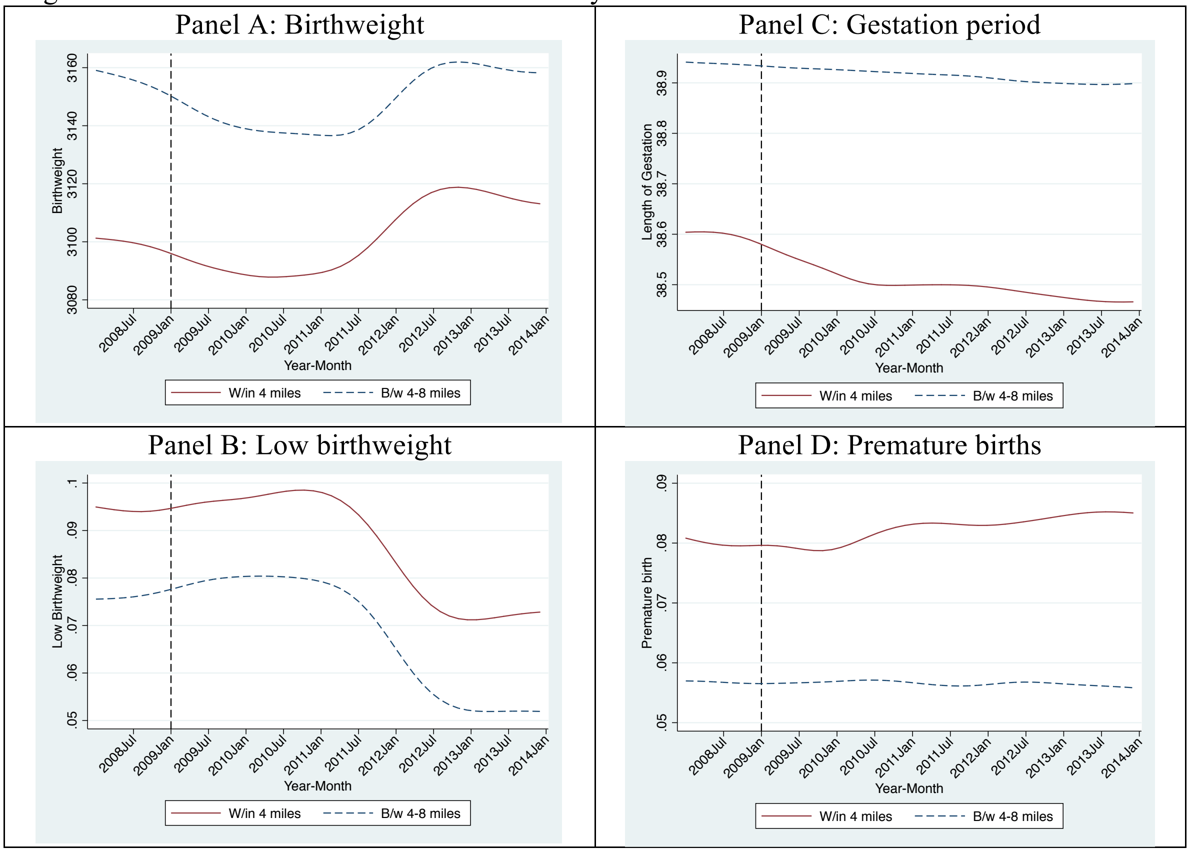


Table 1: Effect on Lead in Ambient Air

	(1)	(2)	(3)	(4)	(5)
Near×Post	-0.068***	-0.067***	-0.078***	-0.046**	-0.068***
	(0.016)	(0.016)	(0.021)	(0.020)	(0.018)
N	25,779	29,908	19,149	13,836	2,355
Near	0-1mile	0-1mile	0-0.5mile	0.5-1mile	0-1mile
Control	1-2mile	1-5mile	1-2mile	1-2mile	1-2mile

Notes: Dependent variable is the average concentrations of lead in ambient air. The observations are at the monitor-month level for years between 2001 and 2013 in Columns (1) to (4) and at the monitor-year level in Column (5). Each column uses various treatment groups (defined by the dummy variable Near) and the control groups, specified in the table. For example, 1-2 miles means monitors located more than one mile but less than or equal to 2 miles from the nearest TRI facility. All specifications include time fixed effects (i.e., year and month fixed effects in the case of monthly observations, or year fixed effects in the case of annual observations) and monitor fixed effects. The standard errors reported in the parentheses are clustered at the monitor level.

Table 2: Effect on Mexican Exports

	Log Exports Chapter-level (1)	Log Exports HS6-level (2)
	0.184**	0.307**
$Lead_i * US_u * Post_t$	(.069)	(.053)
	171, 561	536,727

Notes: The dependent variables are Log Exports at the Firm-HS-Chapter level (the first two digit of the HS code) and the Firm-HS6 digit level. Both specifications include Leat-emitting-plants-year interaction effects, Chapter (or HS6)-year interaction effects, and US-year interaction effects. All standard errors are clustered at the firm level.

Table 3: Effect on Infant Health in Mexico

Dep. var.:	Birthweight	Low birth-weight	Gestation period	Premature birth	Apgar	Silverman
	(1)	(2)	(3)	(4)	(5)	(6)
Panel A: Near = 0-4 mile						
Near×Post	-0.5710585	0.0022417	-0.11586	0.0026475	-0.037719	0.0888014
	(1.639801)	(.0009458)	(.0086817)	(.0009441)	(.0057073)	(.0069082)
p-value	0.728	0.018	0.000	0.005	0.000	0.000
N	1,548,322	1,562,923	1,594,157	1,594,157	1,579,873	1,569,600
Panel B: Near = 0-2mile						
Near×Post	-144.3363	0.0398454	-0.3222498	0.0596719	-0.1164359	0.0243492
	(36.61418)	(.0139181)	(.1040814)	(.0242455)	(.0370197)	(.0762137)
p-value	0.000	0.004	0.002	0.014	0.002	0.749
N	1,241,680	1,254,519	1,277,536	1,277,536	1,263,945	1,258,305
Panel C: Near = 2-4 mile						
Near×Post	-0.1025618	0.0021162	-0.1151628	0.002461	-0.0374659	0.0890055
	(1.638703)	(.001004)	(.0087144)	(.0009706)	(.0057145)	(.0068814)
p-value	0.95	0.035	0.000	0.011	0.000	0.000
N	1,508,903	1,523,382	1,552,867	1,552,867	1,538,588	1,528,443
	39,419	39,541	41,290	41,290	41,285	41,157

Notes: The dependent variables are indicated by the column headings; birthweight in gram, an indicator variable for low birthweight, the length of gestation period in weeks, and an indicator variable for premature births. Apgar and Silverman test scores are based on the fiver parameters (specified in the text) of observed infant health conditions performed five minutes and immediately after birth, respectively. Higher Apgar scores are better, while lower Silverman scores are better. The definition of the indicator variable "Near" changes across the panels, as indicated. The comparison group in all panels is infants born between 4 and 8 miles from a lead-emitting plant. All standard errors are clustered at the locality level.

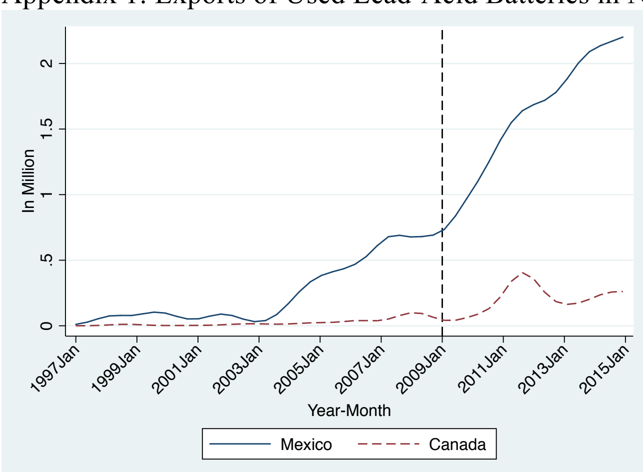
Appendix

Data Appendix

Used lead-acid batteries used in the analysis consist of three individual products: spent lead-acid storage batteries, of a kind used for starting engines (HTS = 8548102000), spend primary batteries and electrical storage batteries for recovery of lead (HST = 8548100580), and waste and scrap of primary cells, batteries, and electric storage batteries for recovery of lead (HTS = 8548102500). Lead scrap includes two commodities: lead waste and scrap obtained from lead-acid storage batteries (HST = 7802000030) and lead waste and scrap other than obtained from lead-acid storage batteries (HST = 7802000060).

To obtain the amount of lead contained in used lead-acid batteries exports, we follow the suggestions by Battery Council International (BCI) that lead accounts for 58.6 percent of the total weight of an undrained battery or 73.6 percent of a drained battery designed for a passenger car or light commercial vehicle. Most used lead-acid batteries exported to Mexico and Canada are undrained batteries, while those exported to other countries are drained batteries. We also apply the same percentage to lead contained in lead scraps.

Appendix 1: Exports of Used Lead-Acid Batteries in Number



Appendix 2: Exports of Used Lead-Acid Batteries in Metric Tons