Journal of Public Economics 122 (2015) 68–79

Contents lists available at ScienceDirect

Journal of Public Economics

journal homepage: www.elsevier.com/locate/jpube

The effect of pollution on labor supply: Evidence from a natural experiment in Mexico City☆

Rema Hanna [a,b,c,d], Paulina Oliva [b,e,*]

[a] Harvard Kennedy School, United States
[b] NBER, United States
[c] BREAD, United States
[d] IZA, Germany
[e] University of California Santa Barbara, United States

ARTICLE INFO

Article history:
Received 29 November 2013
Received in revised form 12 October 2014
Accepted 14 October 2014
Available online 27 October 2014

Keywords:
Labor supply
Air pollution

ABSTRACT

Moderate effects of pollution on health may exert important influences on work. We exploit exogenous variation in pollution due to the closure of a large refinery in Mexico City to understand how pollution impacts labor supply. The closure led to a 19.7% decline in pollution, as measured by SO_2, in the surrounding neighborhoods. The closure led to a 1.3 h (or 3.5%) increase in work hours per week. The effects do not appear to be driven by differential labor demand shocks nor selective migration.

1. Introduction

In this paper, we estimate the relationship between pollution and labor supply in Mexico City. High levels of pollution may cause temporary illness, which in turn may cause lost work hours. Understanding the relationship between pollution and lost work hours is vital for assessing the benefits of more stringent environmental regulation, particularly for developing countries that are often hesitant to impose tougher environmental standards due to fears that they may hinder productivity and growth. Furthermore, understanding the magnitude of this effect is essential in designing optimal pollution taxes (Schwartz and Repetto, 2000; Williams, 2003).

The effect of pollution on work hours is theoretically ambiguous. On the one hand, if pollution damages the health of an individual or his or her dependents, then reductions in pollution will decrease the disutility from work and increase work hours. In other words, with better air quality, individuals may work more since they (or their children) are less likely to be sick. On the other hand, there are also many reasons why reductions in pollution would not increase work hours. First, it is possible that the effect of pollution on adult health is not large enough to interfere with work, or that individuals already practice mitigating behaviors on high pollution days (such as staying indoors) to minimize illness. Second, if individuals enjoy leisure more due to better health or they substitute away from consumption of health-related goods, they might adjust their hours of work downwards. If these effects are large enough, the overall effect of pollution on work hours may even be negative. Finally, health-related improvements in worker productivity may increase wages, which would have ambiguous effects due to competing income and substitution effects. Given these opposing theoretical predictions, the relationship between pollution and work hours is ultimately an empirical question.[1]

Our study explores the short-run relationship between pollution and work hours.[2] Estimating this effect is complicated by confounding factors: for example, a decline in business activity might affect both pollution levels and employment patterns. To circumvent this problem, we exploit the exogenous variation in pollution that resulted from the closure of a large oil refinery in the Mexico City Metropolitan Area (MCMA) in March of 1991. The closure was mandated to reduce the high levels of pollution experienced during the 1980s.

☆ We thank Jonathan Hill, Katherine Grooms, and Sebastian Bustos for their outstanding research assistance. We thank Maria Teresa Garrido, Luisa Soto and Gerardo Guillen for their cooperation for this project. We also thank Alberto Abadie, David Card, Lucas Davis, Stefano DellaVigna, Edward Glaeser, Michael Greenstone, Larry Katz, Asim Khwaja, Peter Kuhn, Shelly Lundberg, Sendhil Mullainathan, Matt Neidell, Ben Olken, Rohini Pande, Heather Royer, Reed Walker and Heidi Williams for their helpful comments, as well as the participants at the NBER Summer Institute Environmental Meetings. We also thank our editor and the three referees for their very helpful comments. Funding for this project comes from the Science Sustainability Program at the Center for International Development at Harvard, the Harvard Center for Population and Development Studies, and UCMexus.

* Corresponding author.
E-mail address: oliva@econ.ucsb.edu (P. Oliva).

[1] See the online appendix for a theoretical discussion of these issues.

[2] Pollution can also have long-run work impacts (e.g. through lung diseases), but these are not the focus of this study.

http://dx.doi.org/10.1016/j.jpubeco.2014.10.004
0047-2727/

Pollution, as measured by SO_2 fell in the vicinity of refinery: neighborhoods located within a 5 km radius of the refinery experienced, on average, a 19.7% reduction in sulfur dioxide (SO_2) relative to neighborhoods far from the refinery. Using a fixed effects strategy, we exploit these changes to understand whether pollution levels affected labor supply. Specifically, we compare the changes in labor supply for individuals who lived in neighborhoods located near the refinery (that experienced a fall in pollution) with those who lived in neighborhoods far from the refinery (that did not experience so).

We find robust evidence that the refinery closure led to an increase in work hours: neighborhoods located within a 5 km radius of the refinery experienced, on average, a 1.3 h (or a 3.5%) increase in per week hours of work relative to those that were farther away from the refinery. The closure led to large changes across the distribution of work hours: areas affected by the closure experienced a 6 percentage point increase in the probability of working over 40 h a week and about a 2.5 percentage point increase in the probability of working more than 10 h per week. To provide a sense of the magnitude of the relationship between pollution and work behavior, we can instrument our pollution measure with the refinery closure. We estimate that that a one part per hundred million increase in SO_2 (or a 20% increase) results in a decrease of 1.04 to 1.30 in work hours per week (a 2.75 to 3.5% decline).

Our design is unique in that it exploits an environmental regulation that did not have direct effects on the labor market, and as such it allows us to disentangle the effect of reduced pollution on labor market activities that operate through the health channel from the direct effect on businesses that environmental regulations typically impose. As we discuss below, the refinery employed a small share of the labor force.[3] To be certain that direct local labor market effects of the closure are not driving our results, we estimate an additional empirical model. We exploit the variation in pollution levels between different altitudes and wind patterns within areas equidistant from the refinery; this is equivalent to a triple-difference approach where you interact the post variable with the distance variable with the characteristic of the census block (e.g. wind and altitude). Equidistant areas presumably experienced similar labor market shocks related to the refinery closure. Hence, the pollution effects that we find within these areas are not susceptible to bias from a labor market mechanism. Using this triple-difference approach, we find a relationship that is similar in magnitude and significance to the core results. Therefore, we can rule out a direct effect of the closure on hours worked.

A second concern when estimating these effects is that changes in air quality may result in selective sorting. More specifically, wealthier or more educated individuals may move into the newly cleaned neighborhoods and these individuals may be more likely to be employed or work long hours. This would cause us to overestimate the effect. To reduce the probability of bias from movements, we restrict our analysis to the five years around the closure. In addition, we test for sorting using information on migration and demographic characteristics. We do not observe increased migration rates near the refinery after the closure. Finally, we also conduct robustness checks where we control for demographics and conclusions do not change. Thus, we are confident that selective migration is not leading us to overestimate the impact of pollution on hours worked.

In sum, our findings imply that the economic gains from increased work helped offset the costs of the refinery closure. Our preferred estimates imply that the closure led to a 3.5% increase in hours worked for those who lived near the refinery. Given an average annual wage of 13,700 Mexican Pesos (USD 3600), this translates to a 480 Peso (USD 126) gain per worker over the course of a year.[4] More generally, this substantial increase demonstrates the importance of accounting for work effort gains when calculating the economic benefits of environmental regulations.[5]

The paper proceeds as follows: Section 2 provides a brief discussion of related literature and the background of the refinery. Section 3 discusses the data. In Section 4, we describe our empirical strategy, while we present our findings in Section 5. Section 6 concludes.

2. Related literature and background

2.1. Related literature

The previous literature finds a fairly large association between pollution and lost work. For example, Pönka (1990) finds that SO_2 levels are associated with illness-related absenteeism; Ostro (1983) shows a statistically significant relationship between particulates and work loss; and Hausman et al. (1984) find that, controlling for city-specific effects, a standard deviation increase in particulates in the two weeks prior is associated with about a 10% increase in lost work days. However, while these two papers do control for some factors that may jointly affect pollution and work behaviors, there may remain other uncontrolled, unobservable factors that may drive the estimated relationships. More recently, studying rural households in Bangladesh, Carson et al. (2010) find that the widespread arsenic poisoning was associated with an 8% decrease in labor supply. Related to this literature, Currie et al. (2009), Ransom and Pope (1992), Gilliland et al. (2001), and Park et al. (2002) find significant effects of pollution on school absenteeism for children, which provides evidence that pollution may also have real effects on work hours if it induces higher absenteeism among workers who are responsible for child care.

In addition to affecting total hours worked, it is possible that pollution could also affect the productivity of a work hour, which in turn may affect wages and have secondary impacts on hours worked. There is increasing evidence that pollution affects productivity: Crocker and Horst (1981) and Graff and Neidell (2011) find a negative empirical relationship between air pollution and productivity for farm workers in California. Frankenberg et al. (2005) estimate that haze from fires in Indonesia caused older adults to be more likely to report having difficulty carrying a heavy load than older adults in non-haze areas.[6]

In this paper, we aim to contribute to this growing literature by estimating the causal impact of pollution on total work hours. Specifically, we exploit an environmental regulation that had a large effect on pollution, without a large accompanying direct effect on the labor market. This allows us to isolate the effect on labor supply that is driven by health.[7] Understanding this relationship is important for several reasons. First, if the effect is large, then it may be an important component in assessing the benefits of environmental regulation, as well as assessing the distributional impacts of regulation. Data limitations (e.g. lack of detailed health panels or housing data) often preclude the measurement of these benefits in developing countries; in contrast, many countries regularly collect detailed labor market data, and therefore, our paper provides an alternative method of estimating the benefits that can be replicated in other settings. Second, recent theoretical work (for example, Schwartz and Repetto, 2000; Williams, 2003) points to the importance of understanding the magnitude of the health-driven effect of air pollution on labor supply when designing optimal pollution taxes. If the effect is positive and

[3] Given upward sloping labor supply, if there had been a reduction in labor demand from both the refinery itself and businesses located in the surrounding neighborhoods after the closure, this would likely lead us to *underestimate* the effect of pollution on hours worked. While less likely, one can also imagine cases where labor supply is downward sloping, causing the estimate to be upwardly biased.

[4] Source for yearly earnings: National Accounting System (SCN).

[5] Note that a full benefit calculation would also include any longer-run effects of pollution on adults, as well as immediate and long-run health gains for vulnerable populations, such as children and the elderly.

[6] In addition, there is a large medical literature linking iron supplements, which improve respiratory functioning, to productivity (for example, see Davies et al. (1984); Haas and Brownlie (2001); Zhu and Haas (1998); and Woodson et al. (1978)). In turn, there is evidence from experimental studies that iron supplements can improve work output and productivity (Basta et al., 1979; Thomas et al., 2003; Li et al., 1994).

[7] Recent papers, such as Walker (2011), study the effect of environmental regulations that impose additional costs on polluting firms.

large, then it may counteract the substitution effect highlighted in the double dividend literature (Parry, 1995; Goulder and Bovenberg, 1997), bringing the optimal tax on air pollution closer to (and potentially above) the marginal damage relative to the case when this effect is ignored. Finally, more broadly, our study contributes to the literature on absenteeism and work in developing countries (e.g. Duflo et al., 2012; Banerjee and Duflo, 2006), suggesting that health concerns may contribute to the startlingly high rates of absenteeism often observed in many developing countries.

2.2. Sulfur dioxide and health

This study focuses on SO_2, a U.S. criteria pollutant and one of the main gases emitted by oil refineries. As we discuss below, we focus on SO_2 because this is the main pollutant that the Mexican Government was systematically collecting data on over this time period, as they were very concerned with SO_2 levels. While refineries do emit other pollutants, SO_2 is an important source of pollution: García Villanueva et al. (2009) document that the emissions from the Azcapotzalco Refinery, which we study in this paper, were composed primarily of sulfur dioxide, carbon monoxide, and nitrogen oxides. However, the percentage of other emissions of pollutants other than SO_2 in Mexico City constituted by refinery emissions is likely quite small as compared to other sources. For example, similar capacity refineries (Bevilacqua and Braglia, 2002) were producing about 195 t/y of PM_{10}, 379.5 t/y of CO, and 3133 t/y of NO_x. These emission amounts account for 0.4, 0.008, and 1.2% of total emissions of each respective pollutant in Mexico City (Emissions Inventory for Mexico City, 2008). In contrast, the 18,633 t/y emissions of SO_2 of a similar capacity refinery would account for 26% of total SO_2 emissions in Mexico City. In summary, the closure of the refinery likely did not result in a substantial reduction of any criteria pollutant concentrations, except for SO_2.

The existing literature has documented the effects of SO_2 on health, which may result in work absenteeism. Subjects exposed to SO_2 show decreased lung functioning and increased respiratory symptoms in most controlled human experiments, with stronger effects for higher levels of exposure.[8] While experimental trials provide evidence for potential impacts of short-term (5–10 min) exposure, individuals may not necessarily experience these adverse effects in the real world if they take precautions on high pollution days, potentially mitigating the effect of pollution on both health and work outcomes.[9] Turning to the epidemiology literature, the effects of ambient SO_2 on respiratory symptoms of adults are mixed, and therefore, it is not clear from this literature that the SO_2 reductions that we study would be large enough to affect work (EPA, 2008). However, there is at least suggestive evidence that they could be: Peel et al. (2005) and Ito et al. (2007) document an association between short run exposure to SO_2 and emergency room visits, while Schwartz et al. (1996) document an association between exposure and increases in hospital admissions due to asthma for those aged 65 and above.

Adults may also work fewer hours if their children are sick due to high levels of pollution. Children and infants are among the most susceptible to air pollution (including SO_2) as lung development continues throughout adolescence, and a developing lung is particularly at risk from exposure to toxins (Dietert et al., 2000). Countless papers in the epidemiology literature document the association between SO_2 and respiratory symptoms in children (for example, see Schwartz et al. (1994); Schildcrout et al. (2006)). In the economics literature, Lleras-Muney (2005) finds that high SO_2 concentrations led to increased hospitalization rates for children, although the effect is not significant. In addition, Jayachandran (2009) documents that smoke from Indonesian wildfires, a large source of natural SO_2, had large effects on infant mortality rates.[10]

2.3. The refinery closure

In this study, we exploit the exogenous variation in pollution that resulted from the closure of the Azcapotzalco Refinery in the MCMA on March 18, 1991 (Fig. 1). Originally opened in 1933, the refinery capacity steadily increased over time: at its peak, it occupied 174 ha and included fourteen refining facilities, three petrochemical facilities, 218 storage tanks, auxiliary service facilities, a water treatment plant, laboratories, administrative buildings, recreational facilities and a residential area for employees. It represented around 35% of Mexico's total refining capacity.

When the refinery first opened, the land use in the area was mainly agricultural. Since then, the MCMA had grown considerably, and by the late 1980s, the refinery was surrounded by residential areas. The closure was mandated to reduce the high levels of pollution experienced during the 1980s.[11] For example, the winter of 1990–1991 was considered one of "the most toxic in Mexico City history, triggering a 16% to 20% jump in the incidence of respiratory infections, nosebleeds and emphysema."[12] The Ministry of Environment estimated that, at its peak, the Azcapotzalco Refinery emitted about 85 thousand tons of air pollutants per year, or about two percent of the city's air pollution (García Villanueva et al., 2009).[13]

3. Data

3.1. Pollution data

Pollution data are notoriously absent in many developing countries. When available, the data tend to be only cross-sectional or there are often quality issues (e.g. they are not systemically collected over time, there are concerns about the quality of measurements in practice, or there are even concerns about the validity of the data Ghanem and Zhang, 2014). In this paper, we are able to take advantage of the relatively rich panel of pollution data that is available for Mexico City. Specifically, we draw the data from the Automatic Network of Atmospheric Monitoring (RAMA), which consists of 25 stations placed throughout the MCMA. Hourly sulfur dioxide (SO_2) concentrations are available for about 21 stations in the MCMA from 1986 to today. The data are considered to be of high quality and, as Davis (2008) points out, "[t]hese measures are widely used in scientific publications […]".

Ideally, we would have data on all possible pollutants that are emitted by refineries and document changes in the concentration of each pollutant as the refinery closed. However, like many papers in the literature, we lack data on all of the major pollutants. During the sample period, data for other pollutants were not systematically collected (NO_2 was measured only in 5 stations and CO was measured in 13 stations, but

8 Experimental trials have documented decreased lung function (increased respiration rates, decreased peak flow, broncho-constriction, and increased airway resistance), particularly for asthmatic subjects with SO_2 exposure (see EPA, 2008). Moreover, a series of studies have observed increased respiratory symptoms (coughing, chest tightness, throat irritation) among exercising asthmatics who are exposed to SO_2 (for example, see Linn et al. (1983, 1987)).

9 Neidell (2009) provides evidence that individuals are more likely to stay indoors on high pollution days.

10 Other key papers that document significant effects of pollution on infant mortality include Currie and Neidell (2005) and Chay and Greenstone (2003), but these studies do not explicitly consider SO_2.

11 Note that this program should have only affected pollution and not other aspects of behavior. For example, after the closure, Pemex, a state-owned company, made up the difference in gasoline production with imports and did not change the price of gasoline abruptly. Hence, we do not expect a change in driving behavior.

12 "Mexico City's Menacing Air," Time Magazine, April 1, 1991.

13 Complaints regarding refinery emissions still persist in Mexico. For example, families living near the Francisco I. Madero Refinery in the state of Tamaulipas, which is currently operating, filed a complaint in 2009 due to pungent smells, throat irritation, and skin infections caused by refinery fumes (Milenio, 2008). Moreover, when cleanup activities of the Azcapotzalco Refinery began in 2009 (to convert the land to a public space), health concerns were once again raised as the excavation reintroduced buried pollutants into the air (http://www.kaosenlared.net/noticia/mexico-vecinos-azcapotzalco-luchan-contra-danos-salud-contaminacion-ex; accessed on June 6, 2011).

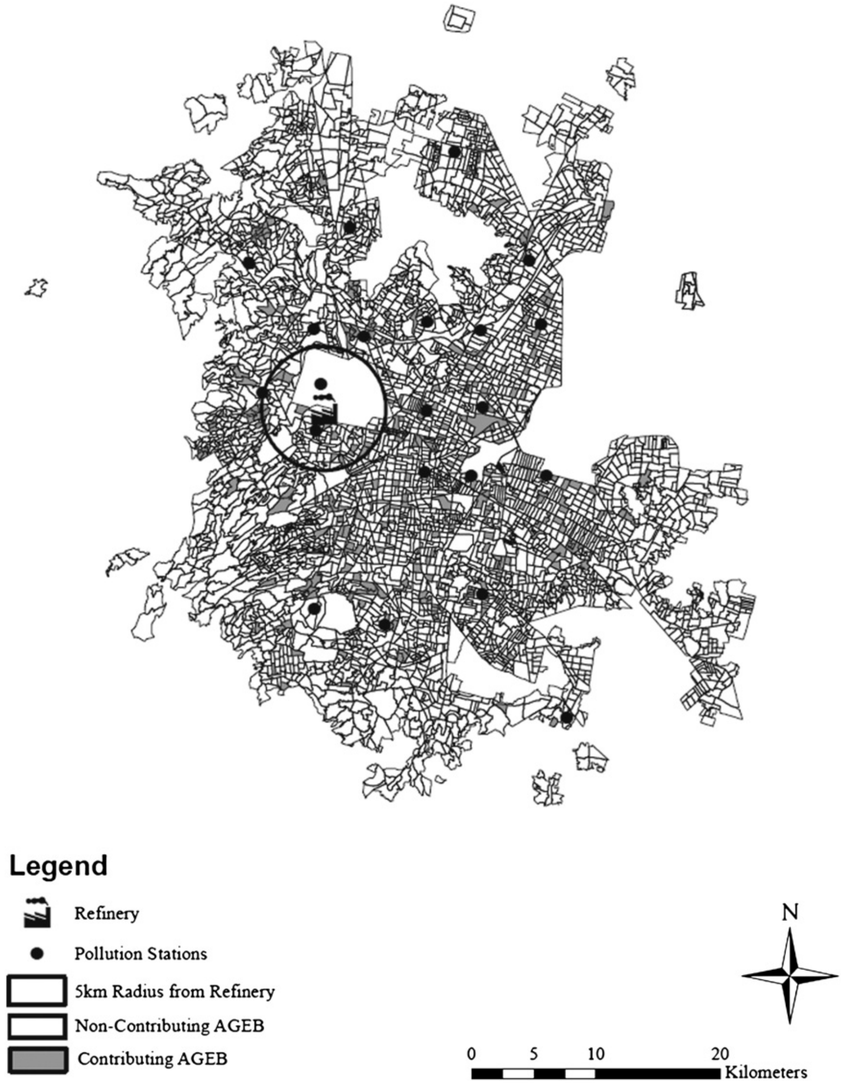

Fig. 1. Map of refinery and included census blocks. Notes: This figure shows the location of the Azcapotzalco refinery within Mexico City. The circle represents the 5 km radius surrounding the refinery. Dots denote stations. The demarcations on the map show the census enumeration blocks, or "basic geo-statistic area" (AGEB). Shaded census blocks are included in our dataset.

not in any stations near the refinery). However, as discussed above, SO_2 is one of the main pollutants generated by the refineries. Thus, we believe that SO_2 provides a good proxy for the reduction in pollution from the refinery closure.

3.2. Labor market data

We obtained labor market data from the National Employment Panel Survey of Mexico (ENEU). ENEU is a moving quarterly panel of households. The government randomly selects census blocks within the city and then randomly selects households within these selected census blocks. A household is surveyed for five consecutive quarters, after which the government randomly selects a different household within the same census block to be surveyed. When the census block is exhausted, the government randomly selects another census block to be included in the survey.

We restrict the sample to individuals in the MCMA, which includes two states (Distrito Federal and Estado de Mexico). We focus on the 1989 to 1993 surveys, the years surrounding the closure. From the data set, we generated variables for labor force participation, employment status, and hours worked.[14] Note several key facts regarding the data. First, in each quarter, individuals are randomly assigned a week in which to be interviewed, and most of the labor market questions refer to the preceding week. Therefore, we can create a dataset in which we have employment data on a randomly selected group of households for each week of the sample period. Second, the data contain information on the census block that the individual lives in. This allows us to link each individual's residence to the closest pollution measurement stations. The survey lacks data on the census block where the individual works. However, individuals presumably experience substantial morning exposure (particularly due to the presence of thermal inversions in Mexico City): prior to the closure, SO_2 peaked between 6 and 11 in the morning (Appendix Fig. 1). Third, the survey includes rich data on demographic characteristics, allowing us to test for selective migration and to explore the heterogeneity of the effect.

3.3. Wind and altitude data

Altitude data for the census block centroids come from topography maps. Data on wind direction, by station, were not collected for the period of our study. Therefore, we use the 10-year average of wind direction *for a given week* from 1997 to 2006 for 10 of the air monitoring stations used in our study. Wind patterns are very persistent over time: the correlation of wind-direction across years for a particular

[14] The survey collects data on the number of hours worked *each day* in the previous week. Unfortunately, only the weekly total is available in the public database.

week-of-the-year and location is around 0.8. Thus, the measure of wind direction should be informative of the wind patterns during the study period. Since our measures of wind vary by week within the year, a typical neighborhood may be upwind from the refinery on some weeks of the year and downwind on others.

3.4. Matching the labor and pollution data

We matched the households in the ENEU survey with pollution readings. To do so, we linked the census blocks in the ENEU to GIS maps and obtained the latitude and longitude of the center of each block. There are 481 census blocks in the ENEU. The earliest available georeferenced maps correspond to census blocks in 2000, and census block identification numbers are only concorded back to 1995. We obtained non-georeferenced maps for the 1990 census blocks from the Instituto Nacional de Estadística y Geografía (INEGI) and manually concorded the data. We were able to ascertain the locations of 389 census blocks (81%).[15] Appendix Table 2 shows that the unmatched census blocks do not appear to be significantly different than the matched ones.

Following Currie and Neidell (2005), we created census block-specific measures of pollution using the inverse of the distance to nearby stations as weights. There is a trade-off between including areas that are far from a station where pollution estimates are imprecise and including more observations in the analysis. We only included census blocks that were within 8 km of a station.[16] Therefore, 265 census blocks (55%) were included in the regression analysis. Most of the census blocks that were near a station were located within Distrito Federal, which composes the center part of the city and is also where the refinery is located (190 out of 199 census blocks in Distrito Federal were within 8 km of a station). Only 75 out of 190 matched census blocks in Estado de Mexico (the outer areas of the city) were near a station and included. Appendix Table 2 shows that the included census blocks have higher unemployment and lower hours worked than those not included.

3.5. Descriptive statistics

Table 1 provides sample statistics for the full sample (column 1) and the periods before (column 2) and after (column 3) the closure. Pollution concentrations are high (Panel A). The mean SO_2 level was 4.46 parts per hundred million (pphm), shown in column 1. Mean SO_2 in the United States during the same period was 0.82 pphm, and the 90th percentile, New York City, was 1.05. Pollution fell by about a fifth in the post-closure period from 5.02 (column 2) to 4.04 pphm (column 3).[17]

About four percent of those in the labor force were unemployed, with no change in the post-closure period (Panel B). This was larger than Mexico's overall national unemployment rate of 2.7% in 1990.[18] Individuals typically worked 38.07 h per week conditional on being in the labor force, with higher hours in the post period (38.27 as compared to 37.79 prior to the closure).

Table 1
Sample statistics.

	1989–1993	Pre-closure	Post-closure
	(1)	(2)	(3)
Panel A: Pollution concentration			
Sulfur dioxide (SO_2)	4.46	5.02	4.04
	(2.13)	(1.49)	(2.42)
	143,311	61,438	81,873
Panel B: Labor outcomes			
Hours worked	38.07	37.79	38.27
	(18.94)	(18.62)	(19.18)
	143,311	61,438	81,873
Unemployed	0.04	0.04	0.04
	(0.20)	(0.20)	(0.20)
	143,311	61,438	81,873

Notes: This table provides sample statistics for the key variables for the full sample (column 1), the pre-closure sample (column 2), and the post-closure sample (column 3). Standard deviations are provided in parentheses and the sample size below that.

4. Empirical strategy

4.1. Core strategy

We estimate the reduced form effects of the refinery closure. We first explore the effect on SO_2 to confirm whether pollution levels indeed fell when the refinery closed. Then, we measure the effect on work behaviors. Specifically, we estimate:

$$Y_{int} = \theta_0 + \alpha_{t-1} + \delta_n + \theta\left\{Post_{(t-1)} \times f(D_{in})\right\} + \lambda_n \times T_{(t-1)} + \epsilon_{in(t-1)} \quad (1)$$

where Y_{int} is either SO_2 or hours worked over the last week, $Post_{(t-1)}$ is an indicator variable for after the refinery closure, $f(D_{in})$ is a quadratic function of distance in kilometers between the census block n and the refinery, θ is a vector of coefficients corresponding to the polynomial terms in $f(D_{in})$, α_{t-1} represents week fixed effects, δ_n represents census-block fixed effects, and ν_{int} represents all unobserved determinants of labor supply. We model the effect of the closure as a quadratic function of distance since we expect pollution to dissipate further from the source. Fig. 2A graphs the relationship between the difference in pollution levels before and after the closure and distance, and it confirms that the difference in pollution increases with distance at a

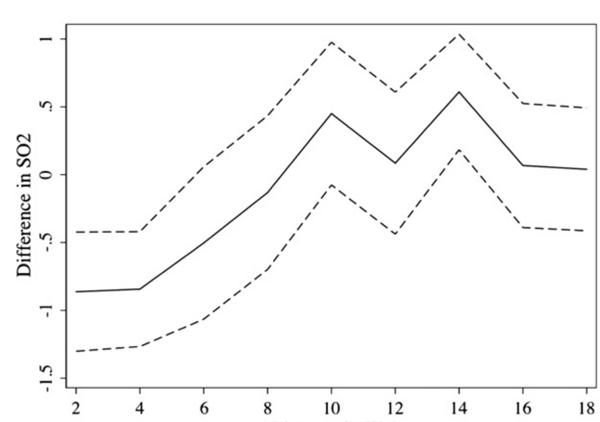

Fig. 2. The change in SO_2 (post-pre closure) by distance from the refinery. Notes: This graph plots the coefficients of a regression of SO_2 on the interaction between each 2 km distance indicator and the post-closure indicator. We control for week fixed effects, census block fixed effects, census block-specific time trends, and demographic characteristics. The dashed lines correspond to the 95% confidence intervals. The regression is fully saturated, so each coefficient should be interpreted as the change in SO_2 at each distance interval from the refinery.

[15] There are two reasons why we could not fully complete the concordance. First, on the 1990 maps, we could not fully read the identification numbers for some blocks. Second, we were unable to locate the original census block on the map if it split before 1990.

[16] As we describe below, we test the sensitivity of the results to this assumption and find qualitatively similar results.

[17] Other policies may have contributed to the fall in pollution. These policies had either no effect or a city-wide effect, and therefore, should not affect our empirical strategy. For instance, the Driving Restrictions Program (Hoy No Circula program), which affected all vehicles in circulation, was introduced in 1989 (see Davis (2008)). In 1990, Pemex introduced unleaded gasoline. Low SO_2 diesel and three-way catalytic converters were both introduced in 1993, but in both cases the introductions were gradual and their effects were not localized (Secretaría de Medio Ambiente, DF).

[18] Source: Secretaría del Trabajo y Previsión Social.

decreasing rate. [19]Moreover, we also estimate models where we discretize the distance variable by classifying areas as "close" or "far" from the refinery and then interact $Post_{(t-1)}$ with the close indicator variable, $Close_{in}$.

Week fixed effects control for shocks that are common to all neighborhoods within the MCMA, while the census block fixed effects account for permanent differences in labor supply outcomes across census blocks. Thus, the identification of our main results relies on the assumption that areas close and far from the refinery have similar trends in labor supply. This may not be the case if, for example, areas on the outskirts of the city (some of which are far from the refinery) are growing at a faster rate than areas closer to the center of the city (some of which are near the refinery). Thus, we additionally include census block-specific linear year trends, $\lambda_n \times T_{(t-1)}$.

4.2. Ruling out alternative channels

The reduced form estimates provide the total effect of the refinery closure on work behavior. To be able to attribute this affect to the pollution-health channel, we need to first rule out two other possible effects. First, the closure may have altered the attractiveness of surrounding neighborhoods for individuals with strong preferences for air quality. Thus, the estimates may simply be capturing the differences in labor supply between the old and new residents of the refinery neighborhood. Our estimates are based on a sample that spans the five years around the closure to reduce the potential for differential migration (only 3.5% of households migrated during the 5 quarter period they remained in our sample). Nonetheless, below we empirically test whether migration rates, as well as demographics (e.g. gender and education), changed differentially for workers who lived close to the refinery.

Second, it is possible that the refinery closure *itself* directly impacted the labor market, independently of the health channel. By causing the layoff of the refinery employees, the closure could have mechanically lowered hours worked. Refinery workers were often provided with housing in the neighborhoods surrounding the refinery, and many of them remained living in the area after the closure (Bazán, 1999). The presence of these refinery workers in the surrounding neighborhoods could lead us to *underestimate* the relationship between pollution and labor supply that is due to health. This downward bias would be large if the refinery workers composed a large share of the labor market. However, employment at the refinery was not large relative to the overall labor market. The Azcapotzalco Refinery employed about 5000 people at the time of its closure. This represented only about 0.56% of the population in the municipalities located in a 5 km range of the refinery, and 0.03% of the entire population of Mexico City (1990 Census). About 2600 of these employees were forced into early retirement, while 1500 were temporary (non-unionized) employees that were laid off according to the Mexico's minimum mandated requirements by law: a compensation of three months worth of wages. The rest were laid off according to the union's collective contract (García Villanueva et al., 2009).[20]

Even if the refinery jobs themselves did not compose a large share of the labor market, it is still possible that the closure could have affected the labor market if businesses located near the refinery were affected by closure and labor markets were very localized (i.e. individuals work in the neighborhood in which they live). This slowdown of business activity near the refinery could have resulted in a localized labor demand shock that would have reduced equilibrium wages. If labor supply is upward sloping, this fall in wages could have led to reductions in work hours, leading to an *underestimate* of the effect of pollution on labor supply.[21] Again, the evidence suggests that this bias may be quite small: existing data suggest that the labor market within Mexico City is quite integrated across neighborhoods. Data from the MCMA travel survey of 1994 reveal that, on average, individuals commute 57 km to go to work, while the average census block in our sample is 0.36 km^2. Therefore, this demand shock was likely spread across a wide area.

Nevertheless, we conduct additional analysis to understand whether the closure had an effect on hours worked that is independent of the health channel. We exploit additional variation in refinery-related pollution that is orthogonal to the distance from the refinery to isolate the health channel from other localized effects of the refinery closure.[22]

Specifically, we conduct a triple-difference approach using data on wind direction patterns as well as altitude. The intuition is as follows: Assume that the closure had an effect on hours worked that was independent of the health gains from reduced pollution levels, and that this effect also faded away as a function of the distance from the refinery. Take the census blocks that lie between d and $d+1$ miles from the refinery. The non-health effect of the closure on work hours should have been similar for all individuals inside this mile-wide ring. Now assume that on a given week of the year the census blocks north of the refinery have east-west winds, whereas the census blocks south of the refinery have north-south winds.[23] For a small d, the refinery closure would have had a larger effect on the pollution faced by those census blocks that lie south of the refinery than on those that lie north of the refinery (for a very large d, however, the closure should have no effect on pollution within the mile-wide ring). Thus, the information on wind patterns interacts with the distance from the refinery and the timing of the closure to produce variation in pollution levels that is independent from any other localized direct effect of the closure.[24] The interaction of altitude with distance and the timing of the closure may also provide exogenous variation in pollution: pollution concentrations vary at different altitudes due to thermal inversions and pollution exposure from wind patterns.

In a regression framework, we estimate:

$$\begin{aligned} Y_{int} = {} & \theta_0 + \theta_1\left\{Post_{(t-1)} \times f(D_{in}) \times \mathbf{W}_{in(t-1)}\right\} + \theta_2\left\{Post_{(t-1)} \times f(D_{in})\right\} \\ & + \theta_3\left\{Post_{(t-1)} \times \mathbf{W}_{in(t-1)}\right\} + \theta_4\left\{f(D_{in}) \times \mathbf{W}_{in(t-1)}\right\} + \theta_5 \mathbf{W}_{in(t-1)} \\ & + \alpha_{t-1} + \delta_n + \epsilon_{in(t-1)} \end{aligned} \quad (2)$$

where $f(D_{in})$ is a quadratic function of distance and $\mathbf{W}_{in(t-1)}$ is a vector of wind direction and altitude variables. This model allows us to

[19] As shown in Appendix Table 3, we experimented with alternative methods of fitting this relationship (log, linear, quadratic and cubic models) and find that the quadratic model shown in column 3 provides the strongest first stage.

[20] Total oil workers constitute less than 0.5% of our pre-closure sample (this includes anyone who worked in oil-connected industries and not just those who worked at the refinery). Appendix Table 4 confirms that employment in the oil industry fell from 0.48% in 1989:Q1 to almost zero percent in 1993:Q4. The fall began prior to the closure, and the reduction of oil workers was concentrated near the refinery (see Appendix Fig. 2).

[21] While less likely, a negative demand shock could lead us to overestimate the effect of pollution on labor supply. For example, if labor supply is downward sloping, workers may have responded to lower equilibrium wages by increasing hours of work. However, the empirical evidence does not support this. Using data from the 1990–2000 period, Arceo Gómez and Campos Vázquez (2010) estimate that the labor supply elasticity is 0.17 for men and 0.61 for women in the Mexican labor force. Non-wage effects in local labor markets could also bias our estimates upward. If real wages are rigid, a negative labor demand shock could increase the threat of unemployment for those employed and lead to increased work effort; however, rigidity of real wages is unlikely in the context of high inflation (Fehr and Goette, 2005), and the annual inflation rate in Mexico in 1991 was 22%.

[22] Note that we also directly tested for differential changes in wages near the refinery after the closure (Appendix Table 5). We find no effect, which suggests that the labor demand shock generated by the refinery was not large. However, given that the effect on wages of the closure is theoretically ambiguous (the demand shock could have lowered equilibrium wages, but the productivity shock could have raised them), we are hesitant to view this evidence as conclusive.

[23] In practice, wind patterns throughout the year are such that areas are not consistently upwind or downwind from the refinery. See Appendix Table 6, which documents the variation in wind across the year within distance bands. The table shows considerable variation in wind direction from the refinery across all the census blocks regardless of their distance from the refinery.

[24] Schlenker and Walker (2010) use a similar method to generate variation in pollution from a given distance to an airport.

Table 2
Effect of the closure on sulfur dioxide (SO_2).

	(1)	(2)
Post × Distance		0.2534***
		(0.0700)
Post × Distance^2		−0.0091***
		(0.0030)
Post × Close	−0.9903***	
	(0.2061)	
Observations	143,311	143,311
F-test	23.08	7.33
p-value	0.000	0.003

Notes: This table provides OLS estimates of the effect of the closure on sulfur dioxide. In column 1, we provide the coefficient estimate of the interaction between the post closure indicator (*Post*) and indicator variable for less than five km of distance between the census block and the refinery (*Close*). In column 2, we provide the estimates on the interaction between *Post* and a quadratic in distance. We control for census block fixed effects, week fixed effects, and linear census block time trends. Standard errors (provided in parentheses) are clustered by municipality. Statistical significance is denoted by *** for $p < 0.01$, ** for $p < 0.05$, and * for $p < 0.10$.

Table 3
Reduced-form estimates of the effect of the refinery closure on labor force participation and unemployment (OLS).

	Labor force participation		Unemployment	
	(1)	(2)	(3)	(4)
Post × Distance		0.0033		0.0032
		(0.0031)		(0.0019)
Post × Distance^2		−0.0001		−0.0001
		(0.0001)		(0.0001)
Post × Close	−0.0127		−0.0117	
	(0.0092)		(0.0080)	
Observations	259,630	259,630	143,311	143,311
F-stat	1.895	1.319	2.147	1.773
p-value	0.182	0.287	0.156	0.192

Notes: This table explores the reduced form effect of the closure on labor force participation (columns 1 and 2) and unemployment (columns 3 and 4). In columns 1 and 3, we provide the coefficient estimate of the interaction between *Post* and an indicator variable for less than five km of distance between the census block and the refinery (*Close*). In columns 2 and 4, we provide the estimates of the interaction between Post and a quadratic in distance. All controls are the same as in Table 1. Standard errors (provided in parenthesis) are clustered by municipality. Statistical significance is denoted by *** for $p < 0.01$, ** for $p < 0.05$, and * for $p < 0.10$.

examine the variation in pollution due to wind patterns and topography within areas that are equidistant from the refinery, while holding constant all the differential changes in pollution that occur across close and far areas.

5. Results

5.1. Effect of refinery closure on pollution

We begin by estimating the effect of the refinery closure on SO_2 levels. In column 1 of Table 2, we present the estimate of the effect of the interaction of $Post_{(t-1)}$ with an indicator variable for whether the census block is located within 5 km of the refinery. While this does not exploit the full variation in the distance variable, it provides an easy interpretation of the results.[25] In column 2, we present the results of modeling the pollution differential as a squared function of distance from the refinery. We include week fixed effects, census block fixed effects, and linear census block time trends. We cluster the standard errors by the 24 municipalities within Mexico City.[26]

The refinery closure substantially reduced pollution. As shown in column 1, after the refinery closed, areas located within 5 km of the refinery experienced a 0.99 pphm decrease in SO_2 (significant at the one percent level), or 19.7% of the pre-closure mean of 5.02 pphm. We observe relatively higher SO_2 within a census block after the closure for those located farther away, but the effect of the closure fades the farther the neighborhood is from the refinery (column 2).[27]

5.2. Labor force participation and unemployment

Before we turn to our main estimates on hours worked, we first test whether the refinery closure had a differential effect on labor force participation and unemployment for those who lived close to the refinery. This is important since it helps us understand who we should include in the regressions for hours of work below. As we are estimating relatively short-run impacts, we expect little to no effect of pollution on labor force participation. Fifty-four percent of the sample is not in the labor force.[28] Many of these individuals are housewives, currently in school, or retired, and therefore their labor force participation would likely not be affected by changes in pollution.

However, conditional on being in the labor force, pollution may influence the unemployment rate for two reasons. First, if there is an effect of the refinery closure on the local labor market that is independent of health, the unemployment rate may increase near the closure. Second, while "salaried" workers would still be considered employed if they miss a week of work due to illness, "variable earning" workers who have short term contracts (i.e. by the day or by the hour) may be counted as unemployed if they do so. In this case, we would expect that the effect of the closure on unemployment would be negative. Given that about 30% of the sample is variable earning employees, this may potentially be an important effect.

In Table 3, we estimate the reduced form effect of the closure on both labor force participation (columns 1 and 2) and unemployment (columns 3 and 4). In columns 1 and 3, we examine the effect of the interaction *Post* × *Close*, while we estimate the effect of the interaction of *Post* with the quadratic function of distance in columns 2 and 4. All specifications are estimated by OLS, with standard errors clustered by municipality. In the final row, we provide the F-stat and corresponding p-value for the variables of interest. The coefficient estimate for on labor force participation is small in magnitude, in the wrong direction, and not statistically significant. This result is also consistent with the lack of changes in neighborhood composition as a result of the closure (see Section 5.4.1 for further evidence). The lack of an effect of the refinery closure on labor force participation is robust to the inclusion of demographic controls and census-block clustering of the standard errors. Given these results, from now on we concentrate only on the sample of households within the labor market.

The sign of the effects of the closure on unemployment variable (columns 3 and 4) is consistent with the closure having a positive effect on working hours of variable earning workers, but insignificant. For example, in Column 3, we find a 0.01 percentage point decrease in unemployment for those within 5 km of the refinery following the shock, but it is only significant at the 15% level. Given that we might expect an effect on unemployment for variable earning workers and empirical evidence

[25] The 5 km cutoff for distance generally maximized the variation in the first stage across our different specifications (see, for example, Appendix Table 7).

[26] Appendix Table 8 explores adding demographic controls to control for potential compositional changes in demographics. The results remain robust.

[27] To confirm that the timing of the refinery closure coincided with the local drop in pollution, we plot the difference in pollution across near and far areas over time in Appendix Fig. 1. The figure shows a drop in pollution near the refinery right after the closure date. The drop, however, seems short-lived as other pollution sources dominated both near and far from the refinery.

[28] The labor force variable was constructed following the standard definition for Mexico: Individuals were assigned to be in the labor force if they worked in the last week, owned a business, owned a business but did not work in the last week, were starting a business, were looking for paid work, were trying to carry out a job on their own, were in the process of starting a business, or were currently trying to sell something to support themselves or their family.

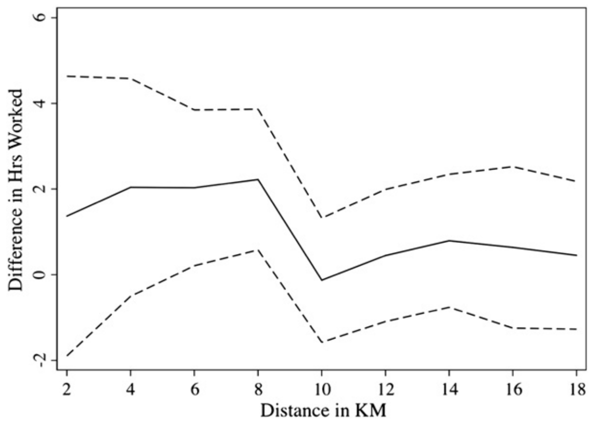

Fig. 3. The change in hours worked by distance from the refinery. Notes: This graph plots the coefficients of a regression of hours worked on the interaction between each 2 km distance indicator and the post-closure indicator. We control for week fixed effects, census block fixed effects, census block-specific time trends, and demographic characteristics. The dashed lines correspond to the 95% confidence intervals. The regression is fully saturated, so each coefficient should be interpreted as the change in hours worked at each distance interval from the refinery.

weakly suggests that the refinery may have affected this measure, we include the unemployed in the subsequent analysis of hours worked.

Table 4
Effect of closure on hours worked.

	(1)	(2)
Panel A: Reduced form		
Post × Distance		−0.2067
		(0.1220)
Post × Distance^2		(0.0057)
		(0.0053)
Post × Close	1.2891***	
	(0.4573)	
F-stat	7.945	4.763
p-value	0.00974	0.0186
Panel B: Instrumental variables		
SO_2	−1.3016***	−1.0412**
	(0.5010)	(0.5141)
Instruments	Post × Close	Post × Distance, Post × Distance^2
Observations	143,311	143,311
First stage F	23.08	7.327
p-value	7.59e-05	0.00345

Notes: This table provides the reduced form estimates (Panel A) of the refinery closure on a continuous measure of hours worked (including "0" for the unemployed), as well as the instrumental variables estimates of the effect of sulfur dioxide hours worked (Panel B). In column 1, the instrument is an interaction of the *Post* dummy with an indicator variable for census blocks within five km of the refinery. In column 2, the instruments are *Post* interacted with a quadratic in distance. See Table 1 notes for the corresponding first stage estimates. Standard errors (provided in parentheses) are clustered by municipality. Statistical significance is denoted by: *** for $p < 0.01$, ** for $p < 0.05$, and * for $p < 0.10$.

5.3. Estimated effects of pollution on work hours

We begin our analysis in this section by showing how the difference in hours worked is a function of distance from the refinery.

Fig. 3A shows the results of a regression of hours worked on the interaction of distance indicators and *Post*. The figure plots the nine coefficients (and 95% confidence intervals clustered at the census block level) that correspond to the interactions between the distance and *Post* variables.[29] Fig. 3A shows a clear gain in hours worked after the closure for those who live near the refinery. The graph shows that those within about 8 km from the refinery worked about two hours more relative to those more than 10 km away. The graph is consistent with Fig. 2A, which shows a drop in SO_2 for the neighborhoods that are 8 to 10 km from the refinery after the closure.[30]

Table 4 formalizes these results in a regression framework. Panel A provides the reduced form effect of the refinery closure on hours of work. In column 1, the variable of interest is *Post* × *Close*, while it is the interaction of *Post* with a quadratic function of distance in column 2. Standard errors are clustered by municipality.

As shown in Column 1 of Panel A, we find that neighborhoods located within a 5 km radius of the refinery experienced, on average, a 1.3 h (or a 3.5%) increase in work relative to those that were farther away from the refinery; this is significant at the 1% level. In column 2, we estimate that the closure increased hours worked for those close to the refinery and that the effect is decreasing in distance; the two interaction variables in distance are jointly significant at conventional levels, with a p-value of 0.0186. In Appendix Table 9, we show the corresponding results where we additionally include controls for demographic characteristics. The inclusion of demographic controls is potentially important if there are changes in demographic composition across neighborhoods that are not captured by our linear census-level time trends. Moreover, the inclusion of these controls may also help reduce noise in the estimates. The estimates are robust to the inclusion of controls; if anything the effects increase slightly and they are more precisely estimated.[31]

In Panel B, we employ an instrumental variables strategy to estimate the relationship between pollution and health. Specifically, we can take advantage of the plausibly exogenous variation in pollution that was generated from the refinery closure and instrument pollution with treatment status. With the caveat that we only have one pollutant (SO_2) to capture overall pollution levels, the IV estimates provides us with a general sense of the relationship between pollution levels and work outcomes.[32] In Column 1, using *Post* × *Close* as an instrument, we find that a one unit increase in SO_2 (about a 20% increase), leads to a 1.3 h decrease in work hours (about a 3.5% decline). Similarly, using the interaction of *Post* and a quadratic function of distance, we find a decrease of 1.04 h (about 2.75%). Again, all of our results are robust to including demographic controls (Panel B of Appendix Table 9).[33]

Next, we try to disentangle whether the effect comes from repeated instances of missing marginal hours within a work week or rare instances of missing full or multiple days of work. To do so, in Table 5, we explore the effect of the closure on a series of indicators that capture working more than 40 h a week (column 1), more than 30 h per week (column 2), more than 20 h per week (column 3), and more than 10 h per week

[29] Despite the sparse data above 18 km, and the fact that we lack pre-data for almost half of the census blocks above 18 km, we include these areas in the regression to help us estimate week fixed effects, but omit them from the figure.

[30] We can also show how the difference in hours worked between individuals that are close and far from the refinery looks as a function of time around the refinery closure. This exercise is somewhat more challenging due to the high variation of weekly hours worked over time. Appendix Fig. 2 shows a progressive relative increase in hours worked for those who lived near the refinery a few weeks after the refinery closure. The relative increase is temporary, mirroring the time profile observed in Appendix Fig. 2.

[31] In Appendix Table 10, we additionally probe whether there are heterogeneous effects. For conciseness, we provide the reduced form estimates using closer indicator variable as our measure of distance. These results are simply suggestive, as we cannot randomly assign demographic characteristics to individuals. We observe similar effects across those with high and low education levels. The effects appear more concentrated among men, among those with children, and among those under age 40.

[32] The IV strategy also has a secondary benefit as compared to other papers that estimate the cross-sectional relationship between pollution and health: Given that pollution is often measured with relatively few stations, classical measurement error in pollution could bias the OLS estimates towards zero. Our IV strategy addresses this problem since the measurement error in our instrument (error in distance between the subject and the refinery) is likely uncorrelated with the error in pollution.

[33] We conducted a series of robustness checks of our estimates. In Appendix Table 11, we show that the IV results are robust to choices we made in the construction of the pollution estimates, while we show that the estimates are also robust to whether or not we lag the pollution measures in Appendix Table 12. In Appendix Tables 13A and B, we show that the results are robust to alternative ways of modeling the standard errors (either accounting for potential spatial correlation using Conley's method, or adjusting for the number of observations in a difference-in-difference design using Donald-Lang's approach).

Table 5
Exploring the closure effect on indicators for varying levels of hours worked.

	More than 40 h per week	More than 30 h per week	More than 20 h per week	More than 10 h per week
	(1)	(2)	(3)	(4)
Panel A: Reduced form effect of being Close (within 5 km) in the Post period				
Post × Close	0.0620***	0.0575***	0.0338**	0.0255**
	(0.0151)	(0.0135)	(0.0128)	(0.0098)
Panel B: Reduced form effect of distance in the Post period				
Post × Distance	−0.0111***	−0.0090**	−0.0047	−0.0028
	(0.0039)	(0.0034)	(0.0029)	(0.0022)
Post × Distance^2	0.0003*	0.0002	0.0001	0.0000
	(0.0002)	(0.0001)	(0.0001)	(0.0001)
Panel C: Interaction of Close (within 5 km) and Post as the instrument for SO_2				
SO_2	−0.0626***	−0.0581***	−0.0341**	−0.0272**
	(0.0231)	(0.0219)	(0.0165)	(0.0110)
Panel D: Interaction of Post and a quadratic of distance as the instruments for SO_2				
SO_2	−0.0536**	−0.0485**	−0.0274*	−0.0197*
	(0.0234)	(0.0219)	(0.0158)	(0.0110)
Observations	143,311	143,311	143,311	143,311

Notes: This table presents the reduced form effect of the closure on indicator variables for various levels of hours worked (Panel A and B) and on the instrumental variable estimates of the effect of sulfur dioxide on these variables. The outcome of interest in columns 1, 2, 3 and 4 is an indicator variable for whether the individual worked more than 40, 30, 20 and 10 h, respectively. Controls are the same as in Table 1. Standard errors (provided in parentheses) are clustered by municipality. Statistical significance is denoted by *** for $p < 0.01$, ** for $p < 0.05$, and * for $p < 0.10$.

Table 6
Is there selective migration? (OLS).

	HH Moved	Female	Age	Married	High education	Blue collar	No HH members	No kids	Kids under 5
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
*Panel A: Post * Close as treatment of interest*									
Post * Close	−0.0084	0.0422***	−0.3007	0.0264*	−0.0115	0.016	−0.057	0.008	0.012
	(0.0049)	(0.0153)	(0.4234)	(0.0158)	(0.0116)	(0.010)	(0.093)	(0.063)	(0.022)
*Panel B: Post * Distance and Post * Distance^2 as treatments of interest*									
Post * Distance	0.0006	−0.0125***	0.1040	−0.0006	0.0019	−0.001	−0.011	0.005	−0.005
	(0.0014)	(0.0040)	(0.1103)	(0.0041)	(0.0030)	(0.003)	(0.025)	(0.014)	(0.007)
Post * Distance2	−0.0000	0.0005***	−0.0039	−0.0000	−0.0001	0.000	0.000	−0.000	0.000
	(0.0001)	(0.0002)	(0.0044)	(0.0002)	(0.0001)	(0.000)	(0.001)	(0.001)	(0.000)
N	51,929	143,311	143,311	143,302	143,292	140,577	143,311	143,311	143,311
Joint Test	0.419	6.192	0.461	1.665	0.203	0.080	0.140	0.300	0.600
P-value	0.663	0.00205	0.630	0.189	0.816	0.928	0.869	0.741	0.555

Notes: This table provides the coefficient estimates of the effect of the refinery closure for individuals close to the refinery on a dummy for migration and several key demographic characteristics. Panel A models distance as an indicator variable for 5 km or closer. Panel B uses a continuous measure of distance and distance squared. In column 1, an observation is defined at the level of the household-quarter-year, and the outcome variable is an indicator for whether the household moved in that quarter and zero otherwise. In columns 2 through 9, an observation is defined at the level of individual-quarter-year. Married is an indicator variable for being married or cohabitating. High education is defined as having had at least some university schooling. All estimates are conditioned on week, census block fixed effects, and census block, year trends. All regressions are estimated using OLS. Standard errors (provided in parentheses) are clustered at the municipality. Statistical significance is denoted by *** for $p < 0.01$, ** for $p < 0.05$, and * for $p < 0.10$.

(column 4).[34] We provide the reduced form estimates in Panel A and Panel B, as well as the IV estimates in Panel C and D. Across all specifications, the largest effects appear concentrated at the margin of working 40 h a week: for example, after the closure, those near the refinery experience a 6.3 percentage point increase in work hours. This suggests that much of the effect is driven by individuals missing a few hours (or a single day) per week rather than a few individuals missing most of the work week.

5.4. Ruling out alternative channels

The reduced form effect provides us with the full effect of the refinery closure on labor supply through all possible mechanisms. To be able to attribute the labor supply effect to pollution, we must first rule out two possible alternative mechanisms. First, we must explore whether improved pollution levels lead to differential migration. Second, we must be able to rule out a direct effect of the closure on labor market decisions.

5.4.1. Differential migration

The refinery closure may have induced differential migration into the areas that saw the sharpest reductions in pollution. For example, wealthier or more educated individuals may have chosen to move into the newly "clean" neighborhoods. We have limited the sample frame to the period immediately around the closure to limit possible migration, and in fact, our estimates are robust to further narrowing the time period around the closure to limit possible migration (see Appendix Table 14). Moreover, the fact that our estimates are robust to the inclusion of demographic controls is at least suggestive that selection is not an important source of bias in our estimates. Nonetheless, we test for selection bias in two ways.

First, we test whether migration rates changed differentially by distance after the closure. The migration rate is low: only 3.5% of households migrated during the 5 quarter period they remained in our sample. The rates are fairly constant before and after the closure for both groups (the rates are more volatile for those closer to the refinery, but this is likely due to the smaller sample size of this group). In Table 6, we formally test whether migration is correlated with the instrument. To do so, we organize the data at the level of a household-quarter. We

[34] For many jobs in Mexico at this time, a full work week consisted of 48 h.

then create an indicator variable that equals one if the household was replaced in the survey in that quarter due to migration, and zero otherwise. We then estimate the reduced form equation of the closure on migration (controlling for week and census block fixed effects). The coefficient estimate (Column 1 of Panel A of Table 6) is small in magnitude and not significantly different from zero. As an additional check, we also estimate the specifications in Table 4 restricting the sample to those families that do not move during the 5 quarter period that they remain in our sample; the results are virtually identical to those in Table 4.

Second, we test whether key demographic characteristics differentially change after the closure. We explore variables on individual demographics characteristics (e.g. gender, age, marital status), proxies for education (e.g. education, type of work), and household composition (e.g. number of household members, children). The results are presented in Columns 2 through 9 of Table 6. Out of the 24 coefficients we estimate, 3 (or 12%) are statistically significant, which is consistent with chance. Specifically, we observe more females (column 2) and a slightly higher propensity to be married (column 4). We think it is unlikely that these changes drive the results. For example, we would have to observe 4618 unemployed men (or 65% of the unemployed individuals) move away to account for our results, which would be inconsistent with the low rates of migration we observe. Moreover, all of our results are robust to directly controlling for gender and marital status.

Education level and household composition appear to be unchanging. We do not observe a change in the number of highly educated individuals (column 5), nor blue collar workers (column 6). For household composition, we might expect households with more children to move into the newly clean areas. However, the number of household members (column 7) does not change, nor does the number of children that a household has (column 8), after the closure. Finally, we do not observe a change in the number of households with at least one child under the age of 5 (column 9).

5.4.2. Direct effects of refinery closure on labor market

The closure itself could have mechanically lowered hours of work in the short run due to the lay-offs of refinery workers and may also have had an effect on local business. As we discuss above in Section 4.2, the effect was likely small and would cause us to underestimate the effect that is due to pollution. Nonetheless, we exploit additional within-neighborhood variation in pollution to isolate the health channel from other localized effects of the refinery closure. Specifically, we can estimate models where we only exploit differences in the closure-driven drop in air pollution across measures of wind direction and altitude, holding constant the main effect of the closure by distance (Eq. (2)).[35] The results of this triple difference approach are shown in Tables 7A and 7B. For ease of interpretation, we show the results using the discretized measure of distance.[36]

Table 7A provides the results for the first stage and reduced form. Note that this triple difference approach is less subject to bias from diverging (or converging) time trends across areas that are close and far since our estimate is identified from variation within each concentric circle around the refinery. Nevertheless, we show the results with and without linear census block time trends. In the first stage estimation (columns 1 and 2), the coefficients of the triple interactions (Post × Close × Elevation and Post × Close × Wind Direction) have the expected sign: within the area near the refinery, an additional meter of altitude reduces the exposure to air pollution by 0.011 pphm with respect to the pre-closure level, as higher altitudes were more exposed to the emissions from the tall refinery smokestacks. It is worth noting that the lowest and highest areas in the refinery neighborhood are 68 vertical meters apart, so the maximum difference in pollution produced by altitude is of 0.75 pphm. Also within the area of the refinery, an additional degree towards the straight downwind direction from the refinery decreases by 0.0026 pphm the exposure to air pollution with respect to the pre-closure levels. Hence, the maximum difference in exposure to pollution created by wind is of 0.47 pphm.

We also show the coefficients on the double interactions for ease of interpretation. Elevation was rescaled to take the value of zero at the minimum elevation in the area. Thus, the coefficient on the Post × Close interaction can be interpreted as the effect of the closure in the neighboring areas to the refinery that were at the lowest altitude. This effect is close to zero, as low areas were less exposed to the refinery fumes and thus experienced little change in emissions with the refinery closure. The coefficient on the Close × Wind Direction interaction corresponds to the pre-closure period effect at close distance from the refinery of a degree towards a straight downwind direction from the refinery. This effect is positive, as wind from the refinery brings in

Table 7A
First stage and reduced form estimates using triple interactions.

	First stage: Dependent variable is SO_2		Reduced form: Dependent variable is hours worked	
	(1)	(2)	(3)	(4)
Post*Close*Wind Direction	−0.0026	−0.0017	0.0045	0.0332**
	(0.0024)	(0.0036)	(0.0049)	(0.0121)
Post*Close*Altitude	−10.9023***	−15.0425**	43.5280***	33.0288
	(3.7686)	(6.4684)	(10.9955)	(20.6945)
Post*Close	−0.6134***	−0.6084**	−0.9905***	−2.6081***
	(0.1473)	(0.2732)	(0.3241)	(0.5544)
Post*Altitude	0.4648	−3.1864	2.4444	−0.7521
	(1.4994)	(2.0076)	(2.6322)	(2.8698)
Post*Wind Direction	0.0001	−0.0001	0.0005	−0.0018
	(0.0024)	(0.0027)	(0.0039)	(0.0046)
Close*Wind Direction	0.0052	0.0053	−0.0035	−0.0197
	(0.0043)	(0.0054)	(0.0101)	(0.0116)
F-statistic for triple interactions	7.283	4.930	10.03	25.04
p-value for joint test	0.00482	0.0196	0.00119	6.31e-06
Census block trends	No	Yes	No	Yes
Observations	137,184	137,184	137,184	137,184

Notes: This table provides alternative first stage and reduced form estimates of the effect of the refinery closure on the sulfur dioxide and the continuous measure of hours worked. In all regressions, we control for *Wind Direction* as well as census block fixed effects and week fixed effects. In columns 2 and 4, we additionally include linear census block time trends. Standard errors (provided in parentheses) are clustered at the municipality level. Statistical significance is denoted by *** for $p < 0.01$, ** for $p < 0.05$, and * for $p < 0.10$.

Table 7B
Instrumental variable estimates using triple interactions as instruments.

	(1)	(2)
SO_2	−3.5196***	−4.7903**
	(0.7916)	(2.4252)
Census block trends	No	Yes
Observations	137,184	137,184

Notes: This table provides alternative IV estimates of the effect of air pollution on hours worked using *Post × Close × Wind Direction* and *Post × Close × Altitude* as instruments for air pollution conditional on all double interactions and *Wind Direction*. In all regressions, we control for *Wind Direction* as well as census block fixed effects and week fixed effects. In columns 2 and 4, we additionally include linear census block time trends. Standard errors (provided in parentheses) are clustered at the municipality level. Statistical significance is denoted by *** for $p < 0.01$, ** for $p < 0.05$, and * for $p < 0.10$.

[35] Note that the strategy used in these specifications requires substantial variation in altitude and wind within the groups of census blocks that are located at a similar distance to the refinery. Altitude has moderate variation close to the refinery: the mean altitude is 2256 m and the standard deviation is 15 m across census blocks within 5 km of the refinery, and 63 m across census blocks that are further than 5 km. Wind patterns have considerably greater variation across census blocks and across weeks: mean wind direction is 60° with a standard deviation of 40° in census blocks close to the refinery and 43° in census blocks further than 5 km to the refinery, where a minimum of 0° corresponds to a position directly upwind from the refinery and a maximum of 180° corresponds to a position directly downwind.

[36] The results using the continuous measure of distance are shown in Appendix Tables 15A and 15B and are qualitatively similar.

more pollution to close areas than to distant areas. Columns 3 and 4 provide the results for the reduced form.

As expected, the coefficients on the triple interactions in the reduced form have the opposite effect than in the first stage: hours of work increase with altitude relative to the pre-closure period, and increase with winds from the refinery relative to the pre-closure period. The coefficients on the double interactions are also as expected in sign and magnitude. More specifically, a worker in an area with maximum exposure to air pollution due to wind direction would have gained 0.69 h of work per week after the refinery's closure. Similarly, a worker in an area with maximum additional exposure due to altitude would have gained 2.96 h of work per week.[37]

Table 7B shows the IV results using this alternative set of instruments and controls. Despite missing wind information for five of our monitoring stations, which forces us to drop 25 of the 265 census blocks, the IV results on hours of work are consistent to the results from our core model (Table 4). The effect of SO_2 on working hours is, if anything, larger in absolute magnitude: an increase of one part per hundred million in SO_2 concentration results in about three to four less hours of work per week.[38]

We conclude from Tables 7A and 7B that our results are robust to what we believe is a fairly strict test of endogeneity, implying that the estimated effects do not appear to be driven by local labor demand shocks from the closure.

6. Conclusion

Pollution is high in the developing world and is increasing at a very fast rate. For example, China is the world's largest polluter of sulfur dioxide, with 2005 emissions estimated to be about 25 million tons. China became the world's largest emitter of greenhouse gases in 2006, while India is predicted to become the third largest emitter by 2030. Improvements in global environmental quality will not occur without the cooperation of developing countries to enforce stricter environmental regulations. However, many low income countries may be hesitant to potentially sacrifice economic growth for possible improvements in environmental quality. This study suggests that gains in worker effort may help offset some of the economic losses that may result from tougher environmental regulation. We find that a 20% increase in SO_2 results in about a 1.3 h (or 3.5%) decline in hours worked in the following week.

In sum, we find substantial impacts of the closure on hours of work. The average annual wage in Mexico City is 13,700 Mexican Pesos (USD 3600) and therefore there was a 480 Peso (or USD 126) per worker gain over the course of a year for those who lived near the refinery. Given that the closure was costly to the government, our findings suggest that some of these losses may have been balanced by substantial benefits in the form of labor income: with a population of about 890,000 in the vicinity of the refinery, this translated to a gain of about $112 million USD alone in the first year. More generally, these findings suggest that further reductions can lead to important gains: if we linearly extrapolate the estimates, a policy that reduced Mexico City's pre-closure pollution level to U.S. standards would result in a gain of 2.58 h per week, or about $247 per worker annually.

These findings contribute to the literature that documents the costs of pollution associated with short-term effects on health, as well as inform the literature on optimal pollution taxation. These results also suggest pathways for future research. First, they raise questions about the distribution of gains. If the refinery closure led to fewer sick days for fixed salary employees, and these employees enjoyed paid sick leaves, the benefits would have been accrued to the employer. However, if employees had a limited number of paid sick days or were able to cash out unused sick days, employees would have shared in the benefits of increased work ability. At the time of the closure, the work regulations in place did not specifically stipulate that employers were responsible for providing paid sick days to their employees, although some may have chosen to do so. The formally employed did enjoy an extended sick absence benefit paid through Social Security (IMSS), receiving 60% of forgone salary starting on the fourth day of an absence due to a documented illness. Thus, in the context of Mexico City, the labor regulations distributed the gains from lower air pollution between workers, employers, and the social security system. More generally, it would be interesting to explore how these labor regulations affect the propensity to miss work due to pollution-related illness, and how this in turn affects the distribution of benefits. Second, while the empirical model documents a substantial *short-run* effect of pollution changes on labor market outcomes, there may be larger long-run impacts if there are cumulative effects of pollution on health or if wages change in response to pollution. Future research should address long run outcomes on employment capabilities and changes in work productivity and wages.

Appendix A. Supplementary data

Supplementary data to this article can be found online at http://dx.doi.org/10.1016/j.jpubeco.2014.10.004.

References

Arceo Gómez, Eva, Campos Vázquez, Raymundo, 2010. Labor supply of married women in Mexico: 1990–2000. Working Paper. Centro de Estudios Economicos, COLMEX, No. XVI.
Banerjee, Abhijit, Duflo, Esther, 2006. Addressing absence. J. Econ. Perspect. 20, 117–132.
Basta, Samir S., Soekirman, Karyadi, Darwin, Scrimshaw, Nevin, 1979. Iron deficiency anemia and productivity of adult males in Indonesia. Am. J. Clin. Nutr. 32, 916–925.
Bazán, Lucía, 1999. Casa y familia. Los Recursos de los Desempleados de Pemex en la Ciudad de México. Estudios Sociológicos, Colegio de México, XVII. 50.
Bevilacqua, M., Braglia, M., 2002. Environmental efficiency analysis for ENI oil refineries. J. Clean. Prod. 10, 85–92.
Carson, Richard, Koundouri, Phoebe, Nauges, Céline, 2010. Arsenic mitigation in Bangladesh: a household labor market approach. Am. J. Agric. Econ. 92, 1–8.
Chay, Kenneth, Greenstone, Michael, 2003. The impact of air pollution on infant mortality: evidence from geographic variation in pollution shocks induced by a recession. Q. J. Econ. 118, 1121–1167.
Crocker, Thomas D., Horst Jr., Robert L., 1981. Hours of work, labor productivity, and environmental conditions: a case study. Rev. Econ. Stat. 63, 361–368.
Currie, Janet, Neidell, Matthew, 2005. Air pollution and infant health: what can we learn from California's recent experience? Q. J. Econ. 120, 1003–1030.
Currie, Janet, Hanushek, Eric, Khan, E. Megan, Neidell, Matthew, Rivken, Steven G., 2009. Does pollution increase school absences? Rev. Econ. Stat. 91, 682–694.
Davies, K.J., Donovan, C.M., Refino, C.J., Brooks, G.A., Packer, L., Dallman, P.R., 1984. Distinguishing the effects of anemia and muscle iron deficiency on exercise bioenergetics in the rat. Am. J. Physiol. Endocrinol. Metab. 246, E535–E543.
Davis, Lucas, 2008. The effect of driving restrictions on air quality in Mexico City. J. Polit. Econ. 116, 38–81.
Dietert, R.R., Etzel, R.A., Chen, D., Halonen, M., Holladay, S.D., Jarabek, A.M., Landreth, K., Peden, D.B., Pinkerton, K., Smialowicz, R.J., Zoetis, T., 2000. Workshop to identify critical window of exposure for children's health: immune and respiratory systems work group summary. Environ. Health Perspect. 108, 483–490.
Duflo, Esther, Hanna, Rema, Ryan, Stephan, 2012. Incentives work: getting teachers to come to school. Am. Econ. Rev. 102, 1241–1278.
EPA, 2008. Integrated Science Assessment for Sulfur Oxides — Health Criteria. ISA: EPA/600/R-08/047F.
Fehr, Ernst, Goette, Lorenz, 2005. Robustness and real consequences of nominal wage rigidity. J. Monet. Econ. 52, 779–804.
Frankenberg, Elizabeth, McKee, Douglas, Thomas, Duncan, 2005. Health consequences of forest fires in Indonesia. Demography 42, 109–129.
García Villanueva, Luis Antonio, Fernández Villagómez, Georgina, Iturbe Argüelles, Rosario, Ruiz Saucedo, Ulises, 2009. Caso de Estudio: Antecedentes Históricos de la Ex-refinería "18 de marzo", Ciudad de México.
Ghanem, Dalia, Zhang, Junjie, 2014. Effortless perfection: do Chinese cities manipulate air pollution data? J. Environ. Econ. Manag. 68, 203–225.
Gilliland, et al., 2001. The effects of ambient air pollution on school absenteeism due to respiratory illness. Epidemiology 12, 43–54.
Goulder, L.H., Bovenberg, L., 1997. Costs of environmentally motivated taxes in the presence of other taxes: general equilibrium analyses. Natl. Tax J. 50, 59–87.
Graff, Joshua S., Neidell, Matthew J., 2011. The impact of pollution on worker productivity. NBER Working Paper #17004.
Haas, Jere D., Brownlie IV, Thomas, 2001. Iron deficiency and reduced work capacity: a critical review of the research to determine a causal relationship. J. Nutr. 131, 676S–690S.

[37] These calculations are based on the specification without time trends. The corresponding numbers with trends are 5.12 and 2.24 respectively.

[38] Our triple-difference results are robust to using various dichotomous measures of wind direction, and to excluding altitude (see Appendix Table 19).

Hausman, Jerry, Ostro, Bart, Wise, David, 1984. Air pollution and lost work. NBER Working Paper No. 1263.
Ito, Kazuhiko, Thurston, George D., Silverman, Robert A., 2007. Characterization of PM2.5, gaseous pollutants, and meteorological interactions in the context of time-series health effects models. J. Expo. Sci. Environ. Epidemiol. 17, 45–60.
Jayachandran, Seema, 2009. Air quality and early-life mortality: evidence from Indonesia's wildfires. J. Hum. Resour. 44, 916–954.
Li, Ruowei, Chen, Xuecun, Yan, Huaicheng, Deurenberg, P., Garby, L., Hautvast, J.G., 1994. Functional consequences of iron supplementation in iron-deficient female cotton mill workers in Beijing, China. Am. J. Clin. Nutr. 59, 908–913.
Linn, W.S., Venet, T.G., Shamoo, D.A., Valencia, L.M., Anzar, U.T., Spier, C.E., Hackney, J.D., 1983. Respiratory effects of sulfur dioxide in heavily exercising asthmatics. A dose–response study. Am. Rev. Respir. Dis. 127, 278–283.
Linn, W.S., Avol, E.L., Peng, R.C., Shamoo, D.A., Hackney, J.D., 1987. Replicated dose–response study of sulfur dioxide effects in normal, atopic, and asthmatic volunteers. Am. Rev. Respir. Dis. 136, 1127–1134.
Lleras-Muney, Adriana, 2005. The relationship between education and adult mortality in the United States. Rev. Econ. Stud. 72, 189–221.
Milenio, 2008. Denuncian Emanación de Gases de Refinería Madero, (December 12).
Neidell, Matt, 2009. Information, avoidance behavior, and health: the effect of ozone on asthma hospitalizations. J. Hum. Resour. 44, 450–478.
Ostro, Bart, 1983. The effects of air pollution on work lost and morbidity. J. Environ. Econ. Manag. 10, 371–382.
Park, H., Lee, B., Ha, E.H., Lee, J.T., Kim, H., Hong, Y.C., 2002. Association of air pollution with school absenteeism due to illness. Arch. Pediatr. Adolesc. Med. 156, 1235–1239.
Parry, Ian, 1995. Pollution taxes and revenue recycling. J. Environ. Econ. Manag. 29, S64–S77.
Peel, Jennifer L., Tolbert, Paige E., Klein, Mitchel, Metzger, Kristi Busico, Flanders, W. Dana, Todd, Knox, Mulholland, James A., Ryan, P. Barry, Frumkin, Howard, 2005. Ambient air pollution and respiratory emergency department visits. Epidemiology 16, 164–174.
Pönka, A., 1990. Absenteeism and respiratory disease among children and adults in Helsinki in relation to low-level air pollution and temperature. Environ. Res. 52, 34–46.
Ransom, Michael, Pope, C. Arden, 1992. Elementary school absences and PM_{10} pollution in Utah Valley. Environ. Res. 58, 204–219.
Schildcrout, J.S., Sheppard, L., Lumley, T., Slaughter, J.C., Koenig, J.Q., Shapiro, G.G., 2006. Ambient air pollution and asthma exacerbations in children: an eight-city analysis. Am. J. Epidemiol. 164, 505–517.
Schlenker, Wolfram and Walker, Reed, 2010. Air Pollution and Contemporaneous Health: Evidence from Random Variation in Pollution Shocks from Airports. Mimeo.
Schwartz, J., Repetto, R., 2000. Nonseparable utility and the double dividend debate: reconsidering the tax-interaction effect. Environ. Resour. Econ. 15, 149–157.
Schwartz, et al., 1994. Acute effects of summer air pollution on respiratory symptom reporting in children. Am. J. Respir. Crit. Care Med. 150, 1234–1242.
Schwartz, J., Spix, C., Touloumi, G., Bacharova, L., Barumamdzadeh, T., le Tertre, A., Piekarksi, T., Ponce de Leon, A., Pönka, A., Rossi, G., Saez, M., Schouten, J.P., 1996. Methodological issues in studies of air pollution and daily counts of deaths or hospital admissions. J. Epidemiol. Community Health 50 (Suppl. 1), S3–S11.
Secretaría del Medio Ambiente, 2008. Emissions Inventory for Mexico City, 2006 (Inventario de Emisiones de la ZMVM, 2006). First edition. Gobierno del Distrito Federal.
Thomas, Duncan, et al., 2003. Iron deficiency and the well-being of older adults: early results from a randomized nutrition intervention. Paper presented at the Population Association of America Annual Meetings, Minneapolis, April 2003, and the International Studies in Health and Economic Development Network meeting, San Francisco (May).
Walker, Reed, 2011. The Transitional Costs of Policy: Evidence From the Clean Air Act and the Workforce. Mimeo.
Williams, Roberton C., 2003. Health effects and optimal environmental taxes. J. Public Econ. 87, 323–335.
Woodson, R.D., Wills, R.E., Lenfant, C., 1978. Effect of acute and established anemia on O_2 transport at rest, submaximal and maximal work. J. Appl. Physiol. 44, 36–43.
Zhu, Y. Isabel, Haas, Jere D., 1998. Altered metabolic response of iron-depleted non-anemic women during a 15-km time trial. J. Appl. Physiol. 84, 1768–1775.